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**GUIDELINES FOR HULL STRUCTURE  
OF VEHICLE CARRIERS**

**2010**

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## **Section 1 General Provisions**

### **1.1 Application**

1.1.1 The Guidelines apply to steel carriers having a length of 90 m or over, specifically designed and constructed for the carriage of wheeled commercial vehicles at sea.

1.1.2 Vehicle carriers are provided with ramps for the stern door and in general, ramps for one or two side shell doors.

1.1.3 Where not specified in the Guidelines, the relevant requirements of Chapters 1 and 2, PART TWO of CCS Rules for Classification of Sea-Going Steel Ships (referred to as the Rules hereinafter) are to be complied with.

### **1.2 Class notations**

1.2.1 Vehicle carriers complying with the Guidelines will be assigned the class notation Car Carrier.

### **1.3 Plans and documents**

1.3.1 The following plans and documents, in addition to those specified in Section 1, Chapter 2, PART TWO of the Rules are to be submitted to CCS for approval:

- (1) Structural arrangement and strength calculations of ramps;
- (2) Structural arrangement of stern door and side shell doors together with strength calculations of their primary structures, fastening and supporting means;
- (3) Structural arrangement and strength calculations of movable deck for vehicles;
- (4) Structural arrangement and strength calculations of sloping vehicle ramps;
- (5) Direct calculations of structural strength of cargo area;
- (6) Direct calculations of global strength of whole ship structure, if applicable.

1.3.2 The following plans and documents are to be submitted to CCS for information:

- (1) General arrangement;
- (2) Lines or offsets;

- (3) Frame lines;
- (4) Capacity plan;
- (5) Specifications for hull and equipment;
- (6) Arrangement of wheel prints for the carriage of vehicles and dates related to design loading, e.g. loads and axle loads;
- (7) Stowage arrangement of vehicles.

#### **1.4 Definitions**

1.4.1 *Length of ship  $L$*  (in m), is the distance on the summer load waterline from the forward side of the stem to the centre of the rudder stock. If the extreme length on the summer load waterline is equal to or greater than such distance,  $L$  is not to be less than 96%, and need not be greater than 97%, of this length.

1.4.2 *Minimum moulded depth  $D_F$*  (in m) is the vertical distance measured at the middle of the length  $L$  from top of keel to top of the deck beam at side on the freeboard deck.

1.4.3 *Maximum service speed*, in kn, is the greatest speed which the ship is designed to maintain at the summer draught.

#### **1.5 Arrangements and structural configuration**

1.5.1 The hull structural arrangements are to comply with the relevant requirements of Section 12, Chapter 1, PART TWO of the Rules.

1.5.2 The basic structural configuration is to be a multi-deck hull which includes a double bottom, and in some cases wing tanks up to the freeboard deck may be fitted.

1.5.3 Longitudinal framing is, in general, to be adopted at the strength deck and at the bottom.

1.5.4 Partial transverse bulkheads, or transverse web frames consisting of web frames and deck transverses, are to be fitted between the strength deck and the lowest vehicle deck. The transverse web frames are to be fitted in line with bottom plate floors, spaced not more than 4 frame spaces or 3.6 m apart, whichever is less.

## Section 2 Longitudinal Strength

### 2.1 General requirements

2.1.1 The longitudinal strength of hull girders is to comply with the requirements of Section 2, Chapter 2, PART TWO of the Rules, in addition to those of this Section.

### 2.2 Wave loads

2.2.1 The bending moments and shear forces induced by waves are to be calculated in accordance with paragraph 2.2.3, Section 2, Chapter 2, PART TWO of the Rules. If the block coefficient is less than 0.6, it is to be taken as 0.6.

2.2.2 When calculating the sagging wave bending moment  $M_w(-)$ , the distribution factor  $M$  for bending moments is to be determined according to the  $C_f$  value obtained from the following formula:

$$C_f = \frac{0.2V}{\sqrt{L}} + \frac{A_d - A_w}{Lh_f}$$

where:  $V$  — maximum service speed, in kn;

$L$  — ship length, in m;

$A_d$  — horizontal projected area, in m<sup>2</sup>, of the first tier deck above freeboard deck, forward of  $0.2L$  from the fore perpendicular;

$A_w$  — waterplane area, in m<sup>2</sup>, forward of  $0.2L$  from the fore perpendicular at the summer draught;

$h_f$  — vertical distance, in m, measured at the fore perpendicular from the summer load waterline to the first tier deck above freeboard deck at side.

(1) Where  $C_f$  is less than 0.4, the distribution factor  $M$  for bending moments is to be determined in accordance with paragraph 2.2.3.1, Section 2, Chapter 2, PART TWO of the Rules.

(2) Where  $C_f$  is equal to or greater than 0.50, the distribution factor  $M$  for bending moments within  $0.65L$  from the aft end is to be determined in accordance with paragraph 2.2.3.1, Section 2, Chapter 2, PART TWO of the Rules.

(3) Where  $C_f$  is equal to or greater than 0.50, the distribution factor  $M$  for bending moments within  $0.65L \sim 1.0L$  from the aft end is to be determined in accordance with Table 2.2.2(3). The intermediate values of  $C_f$  and  $x$  are to be obtained by linear interpolation.

**Distribution factor M for bending moments**      **Table 2.2.2(3)**

$C_f$	Distance $x$ from aft end		
	$0.65L$	$0.75L$	$1.0L$
0.4	1.0	0.714	0
$\geq 0.5$	1.0	0.8	0

### 2.3 Hull girder bending strength

2.3.1 The permissible hogging still water moment  $\overline{M}_s(+)$  and the permissible sagging still water moment  $\overline{M}_s(-)$  for hull girder sections along the ship's length are to be provided by the designer.

2.3.2 The permissible hull girder hogging and sagging still water bending moment envelopes,  $\overline{M}_s$ , are to envelop the most severe hogging and sagging still water bending moments calculated for any seagoing loading condition given in the loading manual. Loading conditions are given in paragraph 2.2.2, Section 2, Chapter 2, PART TWO of the Rules.

2.3.3 Hull girders are to comply with the requirements for the minimum midship section modulus  $W_0$  and the moment of inertia,  $I$ , of the midship section about the horizontal neutral axis, specified respectively in paragraphs 2.2.5.1 and 2.2.5.2, Section 2, Chapter 2, PART TWO of the Rules.

2.3.4 The section modulus  $W$  of each hull girder transverse section about the horizontal neutral axis at the strength deck and plate keel is not to be less than that obtained from the following formula:

$$W = \frac{|\overline{M}_s + M_w|}{[\sigma]} \times 10^3 \quad \text{cm}^3$$

where:  $\overline{M}_s$  — permissible still water bending moment, in kN · m;  
 $M_w$  — wave bending moment, in kN · m;  
 $[\sigma]$  — permissible bending stress, in N/mm<sup>2</sup>, of hull girders, determined as follows:  
[ $\sigma$ ] = 175/ $K$  within 0.4 $L$  amidships;  
[ $\sigma$ ] = 125/ $K$  within 0.1 $L$  from A.P or F.P;  
other values are to be obtained by linear interpolation,  $K$  being the material factor.

### 2.4 Hull girder shear strength

2.4.1 The permissible still water shear forces  $\overline{F}_s(+)$  and  $\overline{F}_s(-)$  for hull girder sections along the ship's length are to be provided by the designer.

2.4.2 The permissible hull girder positive and negative still water shear force envelopes,  $\overline{F}_s$ , are to be greater than the most severe positive and negative hull girder still water shear forces for any seagoing loading condition given in the loading manual. Loading conditions are given in paragraph 2.2.2, Section 2, Chapter 2, PART TWO of the Rules.

2.4.3 The permissible hull girder positive and negative still water shear force envelopes,  $\overline{F}_s$ , are to be as follows:

$$\overline{F}_s(+)\leq F_a - F_w(+)$$

$$\overline{F}_s(-)\geq -F_a - F_w(-)$$

where:  $F_w$  — wave shear force, in kN;  
 $F_a$  — hull girder shear strength capacity, in kN, calculated according to 2.4.4.

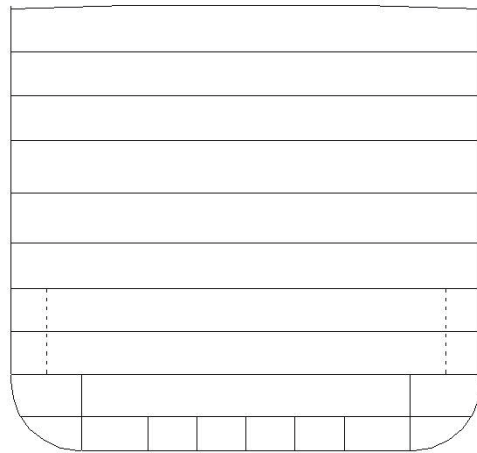
2.4.4 The hull girder shear strength capacity  $F_a$  is to be calculated as follows, taken as the minimum for all plate elements that contribute to the hull girder shear capacity

$$F_a = \frac{[\tau]t_j}{1000q_v} \quad \text{kN}$$

where:  $t_j$  — thickness, in mm, of the  $j$ th panel;  
the permissible shear stress  $[\tau] = 110/K$ , in  $\text{N/mm}^2$ ;  
 $q_v$  — shear flow for the plate, calculated as follows:

$$q_v = f_1 \left( \frac{S}{I} \right) \cdot 10^{-1} \quad \text{mm}^{-1}$$

$f_1$  — factor,  $f_1 = 0.5$  for the hull transverse section shown in Figure 2.4.4;  
 $S$  — static moment, in  $\text{cm}^3$ . Where the point considered is above the horizontal neutral axis,  $S$  is to be taken as the static moment, about the horizontal neutral axis, of all continuous longitudinal members above a horizontal line passing through the point. Where the point considered is below the horizontal neutral axis,  $S$  is to be taken as the static moment, about the horizontal neutral axis, of all continuous longitudinal members below a horizontal line passing through the point;  
 $I$  — moment of inertia, in  $\text{cm}^4$ , of the considered transverse section about the horizontal neutral axis.



**Figure 2.4.4**

2.4.5 The hull girder shear strength capacity  $F_a$  may also be determined according to the thin-wall shear flow theory, the permissible shear stress  $[\tau]$  being given in 2.4.4.

## 2.5 Hull girder buckling strength

2.5.1 For ships having a length equal to or greater than 90 m, the buckling strength of panels and longitudinal members, which are subjected to hull girder bending stresses in compression and shear stresses, is to be checked in accordance with the requirements of paragraph 2.2.7, Section 2, Chapter 2, PART TWO of the Rules.

2.5.2 The standard deduction of thickness for check of buckling strength is to comply with the requirements of Table 2.5.2.

**Standard deduction of thickness** **Table 2.5.2**

Structure	Standard deduction (mm)
(1) Panels and longitudinal members below freeboard; (2) Tank boundaries; (3) Members within tanks	As required in Table 2.2.7.4, Section 2, Chapter 2, PART TWO of the Rules
(1) Side shell above freeboard deck; (2) Exposed panels of superstructure deck used as strength deck	0.5
(1) Non-exposed panels of superstructure deck used as strength deck; (2) Vehicle deck within cargo area	0

2.5.3 The working pressure in compression,  $\sigma$ , is to be one of the values obtained from the following formulas, whichever is the greater:

$$\sigma = \frac{|\overline{M}_s + M_w|}{W_c} \times 10^3 \quad \text{N/mm}^2$$

$$\sigma = \frac{30}{K} \quad \text{N/mm}^2$$

where:  $\overline{M}_s$  — permissible still water bending moment, in kN · m;  
 $M_w$  — wave bending moment, in kN · m, determined by:  
 using  $M_w(+)$  for permissible hogging still water bending moments,  
 using  $M_w(-)$  for permissible sagging still water bending moments;  
 $W_c$  — hull girder section modulus, in cm<sup>3</sup>, at the point considered;  
 $K$  — material factor.

2.5.4 The sagging bending moment values of  $\overline{M}_s$  and  $M_w$  are to be taken for members above the neutral axis. The hogging bending moment values are to be taken for members below the neutral axis.

2.5.5 Where the still water bending moment is hogging in all loading conditions, the combined sagging bending moment  $|\overline{M}_s + M_w|$ , as considered for the calculation under paragraph 2.5.3, is to be the Rules-required sagging wave bending moment  $M_w(-)$  from which the minimum hogging still water bending moment is to be deducted, but not less than  $0.9 M_w(-)$ .

2.5.6 The working shear stress  $\tau$  is to be one of the values obtained from the following formulas, whichever is the greater:

$$\tau = \left| (\overline{F}_s(+)) + F_w(+)) \left( \frac{1000q_v}{t} \right) \right| \quad \text{N/mm}^2$$

$$\tau = \left| (\overline{F}_s(-)) + F_w(-)) \left( \frac{1000q_v}{t} \right) \right| \quad \text{N/mm}^2$$

where:  $\bar{F}_s$  — permissible still water shear force, in kN;  
 $F_w$  — wave shear force, in kN, determined by:  
 using  $F_w(+)$  for permissible positive still water shear forces,  
 using  $F_w(-)$  for permissible negative still water shear forces,  
 $t$  — plate thickness, in mm, at the point considered;  
 $q_v$  — shear flow for the plate, see 2.4.4.

## 2.6 Calculation of hull girder section characters

2.6.1 The hull girder section modulus  $W$  at any vertical distance  $Z$  above the baseline is to be calculated as follows:

$$W = \frac{I}{|Z - Z_{NA}|} \times 10^{-2} \quad \text{cm}^3$$

where:  $I$  — the moment of inertia, in  $\text{cm}^4$ , of the hull girder section about its horizontal neutral axis;  
 $Z$  — distance, in m, from the considered point to the baseline;  
 $Z_{NA}$  — distance, in m, from the horizontal neutral axis of the hull girder section to the baseline.

2.6.2 The strength deck and all continuous longitudinal members below the strength deck within  $0.4L$  amidships may be included in the calculation of the hull girder section modulus. The extension of the sheer strake above the strength deck and the continuous stringer angles may be included in the calculation.

2.6.3 The following definitions of openings are to be applied in the calculation of the hull girder section modulus:

- (1) Large openings are openings exceeding 2.5 m in length (in fore-and-aft direction) and/or 1.2 m in breadth.
- (2) Small openings are openings that are not large openings, e.g. manholes, lightening holes, etc.
- (3) Isolated openings are openings spaced not less than 1 m apart in the ship's transverse/vertical direction.

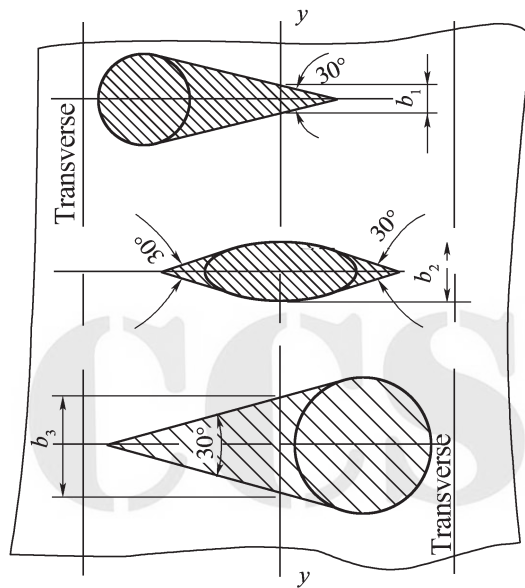
2.6.4 The following openings or their shadowed portions are to be deducted from the sectional areas used in the calculation of the hull girder section modulus:

- (1) large openings;
- (2) small openings that are not isolated.

2.6.5 Isolated small openings need not be deducted from the sectional areas used in the calculation of the hull girder section modulus, provided that the sum  $b_c$  of their breadths, or shadow area breadths (as shown in Figure 2.6.5), in one transverse section complies with the following:

$$b_c \leq 0.06 (B_1 - \Sigma b)$$

where:  $B_1$  — breadth, in m, of ship at the section considered;  
 $\Sigma b$  — sum of breadths, in m, of openings at the section considered which are to be deducted according to 2.6.4.

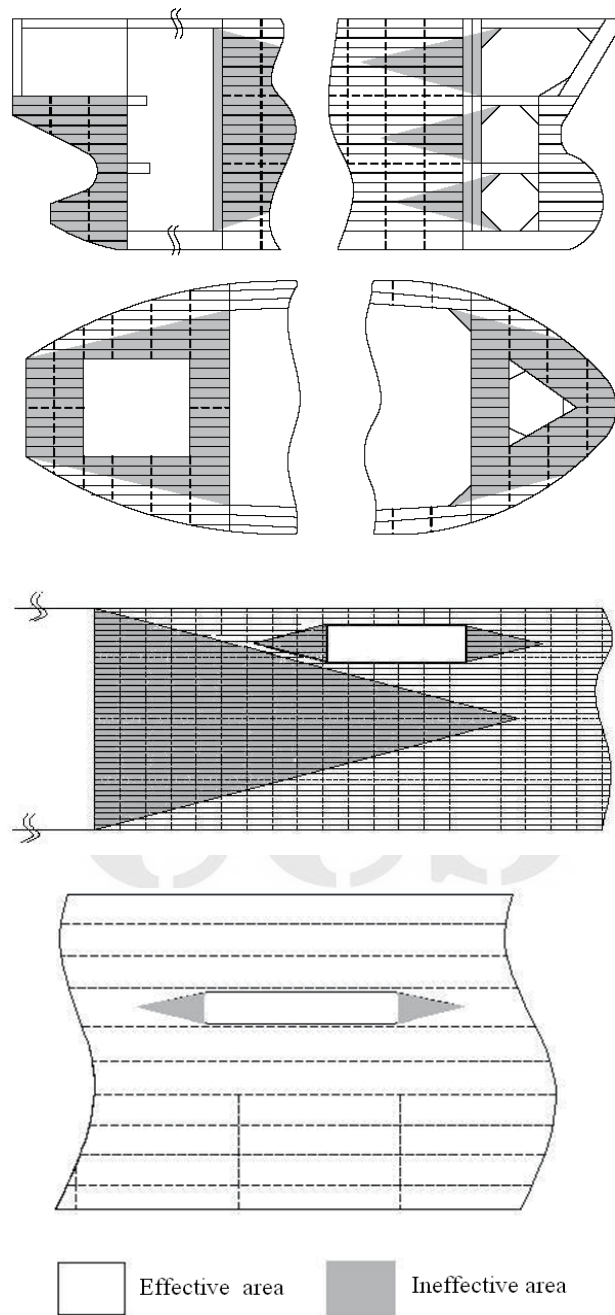


Sum of breadths of small openings at  $y$ - $y$  section is to be  $b_c = b_1 + b_2 + b_3$

**Figure 2.6.5**

2.6.6 Openings in longitudinals or longitudinal girders (such as lightening holes, freeing ports, single scallops in way of welds) need not be deducted from the sectional areas used in the calculation of the hull girder section modulus, if their depth does not exceed 25% of the web depth (with a maximum depth of 75 mm for scallops).

2.6.7 When determining the ineffective area in way of openings, noncontinuous decks, longitudinal bulkheads and side shell, the shadow area, which indicates the area that is not effective, is obtained by drawing two tangent lines with an angle of 15 degrees to the longitudinal axis of the ship.



**Figure 2.6.7**

### 2.7 Reduction factors for scantlings of local members

2.7.1 Where the maximum longitudinal bending stresses at the strength deck and plate keel are less than the permissible bending stress  $[\sigma]$ , appropriate reduction factors  $F_d$  and  $F_b$  may be taken to reduce the scantlings of local members provided the following conditions are met:

$$F_d \geq \frac{\sigma_d}{[\sigma]}$$

$$F_b \geq \frac{\sigma_b}{[\sigma]}$$

where:  $\sigma_d$  — longitudinal bending stress at strength deck, in N/mm<sup>2</sup>, calculated according to 2.5.3;  
 $\sigma_b$  — longitudinal bending stress at plate keel, in N/mm<sup>2</sup>, calculated according to 2.5.3;  
[ $\sigma$ ] — permissible hull girder bending stress, in N/mm<sup>2</sup>, see 2.3.4.

2.7.2 For shell plating and deck, reduction factors  $F_d$  and  $F_b$  are not to be less than 0.7.

2.7.3 For framing, reduction factors  $F_d$  and  $F_b$  are not to be less than 0.8.



## Section 3 Deck Structure

### 3.1 General requirements

3.1.1 This Section applies to strength decks and decks within vehicle spaces. Other decks are to comply with the relevant requirements of Chapter 2, PART TWO of the Rules.

3.1.2 The scantlings of primary members of the deck structure are to be determined by direct calculation according to the requirements of Section 7 or 8 of the Guidelines, while their structural details are to comply with the requirements of 3.6 of this Section.

### 3.2 Strength deck

3.2.1 The thickness  $t$  of the strength deck is to comply with the following requirements:

- (1) The minimum thickness of the exposed portion of the strength deck is to be 6.5 mm.
- (2) The minimum thickness of the non-exposed portion of the strength deck enclosed within a deckhouse is to be 6 mm.
- (3) The thickness  $t$  of the exposed strength deck is to be not less than that obtained from the following formulae:

$$t = (0.02L + 4.5) \sqrt{\frac{s_1 K}{s_b}} \quad \text{mm}$$

$$t = 8s \sqrt{\frac{R_{eH}}{235}} + 1 \quad \text{mm}$$

where:  $L$  — length, in m, of ship, taken not greater than 100 m in calculation;  
 $s$  — spacing, in m, of deck longitudinals;  
 $s_1$  — spacing, in m, of deck longitudinals, taken not less than  $s_b$  in calculation;  
 $s_b$  — standard spacing, in m, of deck longitudinals;  
 $K$  — material factor;  
 $R_{eH}$  — yield stress, in N/mm<sup>2</sup>, of material.

(4) The thickness of the non-exposed portion of the strength deck enclosed within a deckhouse may be reduced by 1 mm according to (3).

3.2.2 Strength deck stringer plates are to comply with the following requirements:

- (1) The breadth  $b$  of strength deck stringer plates within  $0.4L$  amidships is to be not less than:

$$b = 800 + 5L \quad \text{mm, but need not be greater than 1,800 mm}$$

where:  $L$  — ship length, in m.

(2) The breadth of strength deck stringer plates at ends of the ship is to be not less than 65% of that amidships.

(3) The thickness of strength deck stringer plates is to be not less than that of the strength deck.

3.2.3 The section modulus  $W$  of longitudinals of the strength deck is to be not less than that obtained from the following formula:

$$W = 1.13sl^2K + 0.52sLK \quad \text{cm}^3$$

where:  $L$  — length, in m, of ship, taken not greater than 200 m in calculation;  
 $s$  — spacing, in m, of longitudinals;  
 $l$  — span, in m, of the longitudinal;  
 $K$  — material factor.

3.2.4 The minimum moment of inertia,  $I$ , of strength deck longitudinals is to be calculated as follows, with the breadth of the attached plate being equal to 80% of the spacing of longitudinals:

$$I = 1.43Al^2 \frac{R_{eH}}{235} \quad \text{cm}^4$$

where:  $l$  — span, in m, of the longitudinal;  
 $A$  — sectional area, in  $\text{cm}^2$ , of the longitudinal including attached plate;  
 $R_{eH}$  — yield stress, in  $\text{N/mm}^2$ , of material.

### 3.3 Vehicle deck carrying wheeled vehicles

3.3.1 Where unexposed decks are designed for the exclusive carriage of wheeled vehicles, the deck plate thickness may be reduced by 1.5 mm according to 2.21.2.1(1), Section 21, Chapter 2, PART TWO of the Rules, but the thickness is not to be less than 5.5 mm.

3.3.2 For decks designed for the exclusive carriage of wheeled vehicles, the section modulus of deck longitudinals or deck beams is required to satisfy the most severe arrangement of print wheel loads on the stiffener in association with a permissible bending stress of  $100/K$ ,  $\text{N/mm}^2$  ( $K$  being the material factor), assuming rigid fixity of both ends.

### 3.4 Movable decks for vehicles

3.4.1 Movable decks for vehicles (referred to as movable decks hereinafter) are generally designed as pontoons comprising a web structure with top decking.

3.4.2 The supporting members of movable decks are to have sufficient strength. The strength of the fittings or members at the following supports is to be checked for the imposed loads (including the weight of the movable deck):

(1) Flexible supports: the permissible load for fittings such as chains and steel hawsers is to be taken as 1/5 of the breaking strength.

(2) Rigid supports:

$$\begin{aligned} \text{Allowable bending stress} & [\sigma] = 85/K \quad \text{N/mm}^2 \\ \text{Allowable shear stress} & [\tau] = 43/K \quad \text{N/mm}^2 \\ \text{Allowable equivalent stress} & [\sigma_e] = \sqrt{\sigma^2 + 3\tau^2} = 108/K \quad \text{N/mm}^2 \end{aligned}$$

where:  $K$  — material factor.

(3) Buckling is to be checked for the compression members.

3.4.3 The thickness of the movable deck plating is to be calculated according to 3.3.

3.4.4 The section modulus  $W$  of the stiffeners of movable decks is not to be less than that obtained from the following formula:

$$W = 1.39CPIK \quad \text{cm}^3$$

where:  $C$  — coefficient, see Table 3.4.4;  
 $P$  — maximum load, in tons, on one axle;  
 $l$  — span, in m, of stiffener;  
 $K$  — material factor.

**Coefficient  $C$**

**Table 3.4.4**

Span of stiffener/spacing of wheels	0.1	0.2	0.3	0.4	$\geq 0.5$
$C$	15.4	14.6	13.35	11.8	10.1

Note: Spacing of wheels is to be taken as the spacing between the two outermost wheels on the same axle.

3.4.5 The scantlings of girders of movable decks may be determined by direct calculation on the basis of the following criteria (loads taken as static ones):

$$\begin{aligned} \text{Allowable bending stress} & [\sigma] = 128/K \quad \text{N/mm}^2 \\ \text{Allowable shear stress} & [\tau] = 64/K \quad \text{N/mm}^2 \\ \text{Allowable equivalent stress} & [\sigma_e] = \sqrt{\sigma^2 + 3\tau^2} = 160/K \quad \text{N/mm}^2 \\ \text{Deflection} & f \leq l/400 \quad \text{mm} \end{aligned}$$

where:  $K$  — material factor;

$l$  — distance, in mm, between the supporting points of girders.

### 3.5 Vehicle ramps

3.5.1 Vehicle ramps are to comply with the relevant requirements for vehicle decks carrying commercial wheeled vehicles in paragraph 3.3.

### 3.6 Structural details of primary members of deck within vehicle spaces

3.6.1 Primary members are to be so arranged as to ensure effective continuity of structure, and abrupt changes of depth or section are to be avoided. Where members abut on both sides of a bulkhead, or on other members, arrangements are to be made to ensure that they are in alignment.

3.6.2 The web thickness  $t_w$  of primary members is to be not less than:

$$t_w = \frac{S_w}{100} \sqrt{\frac{R_{eH}}{235}} \quad \text{mm, but not less than 7 mm}$$

where:  $S_w$  — spacing of stiffeners on the web, or depth of the unstiffened web, in mm;  
 $R_{eH}$  — yield stress, in N/mm<sup>2</sup>, of material.

3.6.3 The face plate thickness of primary members is to be not less than their web thickness.

3.6.4 The web depth of primary members is generally not to be less than 2.5 times the depth of their cut-outs for the passage of secondary members. Where this value is exceeded, collar plates are to be fitted. In any case, however, the web depth of primary members is not to be less than 2 times the depth of their cut-outs for the passage of secondary members.

3.6.5 Primary members are to be supported by tripping brackets spaced not more than 3 m apart. Tripping brackets are also to be fitted to upper and lower ends of pillars and other positions where concentrated loads are expected. If the ratio of depth to thickness of the web is greater than 55, tripping brackets or stiffeners are to be fitted close to the toes of end brackets of primary members. The height of tripping brackets is to be extended to the face plate of primary members, and their breadth is not to be less than 40% of their height. Where the breadth of the face plate of primary members exceeds 180 mm on any side of the girder, the tripping bracket is to be capable of supporting the face plate. The thickness  $t_b$  (in mm) of tripping brackets is not to be less than  $(5 + 0.025L)$ , but need not be greater than that of the web of primary members, where  $L$  being length of ship. Where the free edge length  $l_b$  (in m) is greater than  $0.06 t_b$ , the tripping brackets are to have face plate or flange, and the sectional area  $A$  (in cm<sup>2</sup>) of which is generally not to be less than  $10 l_b$ .

3.6.6 Collar plates are to be fitted, at the following positions, to cut-outs on webs of primary members:

- (1) upper and lower ends of pillars;
- (2) where concentrated loads are expected;
- (3) close to the toes of end brackets;
- (4) as required in 3.6.4.

## Section 4 Side Structures

### 4.1 General requirements

4.1.1 The scantlings of primary members of side structures above the freeboard deck are to be determined by direct calculation according to the requirements of Section 7 or 8 of the Guidelines.

4.1.2 The side framing below the freeboard deck is to comply with the relevant requirements of Section 7, Chapter 2, PART TWO of the Rules, but the considered pressure head may be measured to the freeboard deck at side. In addition, the strength of primary members is to be checked by direct calculation according to the requirements of Section 7 or 8 of the Guidelines.

### 4.2 Side shell plating

4.2.1 Side shell plating is the shell plating between the bilge strake and the strength deck.

4.2.2 The breadth  $b$  of the uppermost row of side shell plating connected to the strength deck within  $0.4L$  amidships is to be not less than:

$$b = 800 + 5L \text{ mm, but need not be greater than 1,800 mm}$$

where:  $L$  — ship length, in m.

4.2.3 Where the side shell is framed transversely below the freeboard deck, the thickness  $t$  of side shell plating within  $0.4L$  amidships is to be not less than the greater of  $t_1$  and  $t_2$  obtained from the following formulae:

(1)  $t_1$  is to be calculated as follows:

$$t_1 = 0.073sE^{-1}(L+110)\sqrt{\frac{F_d}{K}} \text{ mm, above the neutral axis of hull transverse section}$$

$$t_1 = 0.072sE^{-1}(L+110)\sqrt{\frac{F_b}{K}} \text{ mm, below the neutral axis of hull transverse section}$$

where:  $s$  — spacing, in m, of frames, taken not less than the standard spacing of frames in calculation;  
 $L$  — ship length, in m, taken not greater than 200 m in calculation;

$F_d$  — reduction factor, see 2.7;

$F_b$  — reduction factor, see 2.7;

$K$  — material factor;

$$E = 1 + \frac{s^2}{S^2}, S \text{ being spacing, in m, of side stringers; } E = 1 \text{ where no side stringer is fitted.}$$

(2)  $t_2$  is to be calculated as follows:

$$t_2 = 4.2s\sqrt{(d+h_2)K} \text{ mm, } 3D_F/4 \text{ above the baseline}$$

$$t_2 = 6.3s\sqrt{(d+h_1)F_bK} \text{ mm, } D_F/4 \text{ below the baseline}$$

where:  $s$ ,  $K$  and  $F_b$  are the same as in (1);

$d$  — draught, in m;

$h_2 = 0.5C$ , taken not greater than  $0.36d$  in calculation;

$h_1 = 0.26C$ , taken not greater than  $0.2d$  in calculation;

$C$  — coefficient, see 2.2.3.1, Section 2, Chapter 2, PART TWO of the Rules.

The thickness  $t$  of side shell plating between  $D_F/4$  and  $3 D_F/4$  above the baseline is to be obtained by interpolation according to the values obtained above.

4.2.4 Where the side shell is framed longitudinally below the freeboard deck, the thickness  $t$  of side shell plating within  $0.4L$  amidships is to be not less than the greater of  $t_1$  and  $t_2$  obtained from the following formulas:

(1)  $t_1$  is to be calculated as follows:

$$t_1 = 0.06s(L+110) \sqrt{\frac{F_d}{K}} \quad \text{mm, above the neutral axis of hull transverse section}$$

$$t_1 = 0.06s(L+110) \sqrt{\frac{F_b}{K}} \quad \text{mm, below the neutral axis of hull transverse section}$$

where:  $F_d$ ,  $F_b$  and  $K$  are the same as in 4.2.3(1);

$s$  — spacing, in m, of frames, taken not less than the standard spacing of frames in calculation.

$L$  — ship length, in m, taken not greater than 190 m in calculation.

(2)  $t_2$  is to be calculated as follows:

$$t_2 = 4.2s \sqrt{(d + h_2)K} \quad \text{mm, } 3D_F/4 \text{ above the baseline}$$

$$t_2 = 5.4s \sqrt{(d + h_1)F_b K} \quad \text{mm, } D_F/4 \text{ below the baseline}$$

where:  $s$  and  $F_b$  are the same as in (1);  $K$ ,  $d$ ,  $h_1$  and  $h_2$  are the same as in 4.2.3(2).

The thickness  $t$  of side shell plating between  $D_F/4$  and  $3 D_F/4$  above the baseline is to be obtained by interpolation according to the values obtained above.

4.2.5 Where higher tensile steel is used for side shell plating below the freeboard deck, as required for local strength, the material factor  $K$  may be taken as 1 for the calculation of  $t_1$  according to 4.2.3(1) and 4.2.4(1) of this Section. However, this portion of side shell plating is to be considered as mild steel for checking the longitudinal strength.

4.2.6 The thickness  $t$  of side shell plating within  $0.4L$  amidships below the freeboard deck is also not to be less than that calculated as follows, and the thickness of side shell plating beyond  $0.4L$  amidships is to be tapered gradually to the end thickness of side shell plating:

$$t = (0.035L+6) \sqrt{K} \quad \text{mm}$$

where:  $L$  — ship length, in m;

$K$  — material factor.

4.2.7 The thickness  $t$  of side shell plating within  $0.1L$  from the ship's ends below the freeboard deck is to not to be less than that calculated as follows:

$$t = (0.035L + 6) \sqrt{\frac{sK}{s_b}} \quad \text{mm}$$

where:  $L$  — ship length, in m;  
 $s$  — spacing, in m, of frames or longitudinals, taken not less than  $s_b$  in calculation;  
 $s_b$  — standard spacing, in m, of frames or longitudinals;  
 $K$  — material factor.

4.2.8 The side shell plating from the freeboard deck to 2.3 m above the freeboard deck is to comply with the following requirements:

(1) Such side shell plating aft of  $0.1L$  from the fore perpendicular is to comply with the requirements for side plating of forecastles in Section 17, Chapter 2, PART TWO of the Rules, and such side shell plating within other areas is to comply with the requirements for side plating of bridges and poops in Section 17, Chapter 2, PART TWO of the Rules.

(2) The requirements for bending strength, shear strength and buckling strength of hull girders in 2.3, 2.4 and 2.5 of Section 2 of the Guidelines.

4.2.9 The side shell plating from 2.3 m above the freeboard deck to the strength deck is to comply with the following requirements:

(1) the requirements for boundary bulkheads of deckhouses in Section 17, Chapter 2, PART TWO of the Rules;

(2) the requirements for bending strength, shear strength and buckling strength of hull girders in 2.3, 2.4 and 2.5 of Section 2 of the Guidelines.

4.2.10 The thickness  $t$  of side shell plating below the strength deck and above the freeboard deck is, in addition to complying with the requirements of 4.2.8 and 4.2.9 of this Section, to be not less than that calculated as follows:

$$t = t_F - (Z - D_F)(0.24 + 0.0012L) \sqrt{\frac{sK}{s_b}} \quad \text{mm}$$

$$t = 0.7 \sqrt{(L + 50)K} \quad \text{mm}$$

where:  $t_F$  — thickness, in mm, of side shell plating at freeboard deck;  
 $Z$  — height, in m, of the considered point above baseline;  
 $L$  — ship length, in m;  
 $D_F$  — minimum moulded depth, in m;  
 $s$  — spacing, in m, of frames, taken not less than  $s_b$  in calculation;  
 $s_b$  — standard spacing, in m, of frames;  
 $K$  — material factor.

### 4.3 Side frames above freeboard deck

4.3.1 The section modulus  $W$  of side frames of the first-tier superstructure above the freeboard deck is to be not less than that calculated as follows:

(1) Within  $0.1L$  aft of the fore perpendicular:

$$W = 0.9\left(0.7 + \frac{4d}{D_F}\right)sdLK\sqrt{D_F} \quad \text{cm}^3$$

$$W = 0.89sLLK \quad \text{cm}^3$$

where:  $L$  — ship length, in m, need not be taken greater than 230 m in calculation;  
 $D_F$  — minimum moulded depth, in m;  
 $d$  — draught, in m;  
 $s$  — spacing, in m, of frames;  
 $l$  — span, in m, of the frame, i.e. height of 'tween deck space measured at side, taken not less than 2.3 m in calculation;  
 $K$  — material factor.

(2) Other areas:

$$W = 0.8\left(0.7 + \frac{4d}{D_F}\right)sdLK\sqrt{D_F} \quad \text{cm}^3$$

$$W = 0.54sLLK \quad \text{cm}^3$$

where: for  $L$ ,  $D_F$ ,  $d$ ,  $s$ ,  $l$  and  $K$ , see (1) above.

4.3.2 The section modulus  $W$  of side frames of the second-tier and higher superstructures above the freeboard deck is, in addition to complying with the requirements of 2.17.3.2, Section 17, Chapter 2, PART TWO of the Rules, to be not less than that calculated as follows:

$$W = 0.44sLLK \quad \text{cm}^3$$

where: for  $L$ ,  $s$ ,  $l$  and  $K$ , see 4.3.1(1).

### 4.4 Strengthening of bow side structures against slamming

4.4.1 Bow side structures are to be strengthened against slamming in accordance with Section 8, Chapter 7, PART TWO of the Rules.

## Section 5 Pillars

### 5.1 General requirements

5.1.1 This Section applies to pillars within vehicle spaces. Other pillars are to comply with Section 10, Chapter 2, PART TWO of the Rules.

5.1.2 Tubular or hollow rectangular pillars are not to be used within vehicle spaces.

### 5.2 Pillars within vehicle spaces

5.2.1 The load  $P$  supported by the pillar is to be calculated as follows:

$$P = p_d ab + P_0 \quad \text{kN}$$

where:  $a$  — mean length, in m, of deck area supported by the pillar;  
 $b$  — mean width, in m, of deck area supported by the pillar;  
 $P_0$  — load, in kN, transmitted from the pillar above;  
 $p_d$  — uniformly distributed load, in kN/m<sup>2</sup>, as designed, not less than 3.2 kN/m<sup>2</sup> for strength deck.

5.2.2 The sectional area  $A$  of pillars is not to be less than that calculated as follows:

$$A = \frac{KP}{12.26 - 5.10 \frac{l}{r\sqrt{K}}} \quad \text{cm}^2$$

where:  $P$  — load, in kN, supported by the pillar;  
 $l$  — the effective length, in m, of the pillar, taken as 0.8 times its whole length;  
 $r$  — minimum radius of inertia, in cm, of sectional area of the pillar;  
 $K$  — material factor, taken not less than 0.72.

5.2.3 In addition, pillars are to comply with the requirements of 2.10.3, Section 10, Chapter 2, PART TWO of the Rules.

5.2.4 Strengthening of structures at heads and heels of pillars

(1) The structures at the heads and heels of pillars are to be so arranged that loads are reasonably supported and transmitted. Pillars are to be attached at their heads to plates supported by efficient brackets, and insert plates are to be fitted at the heads and heels of pillars.

(2) Pillars are to be fitted on plate floors or girders, and these plate floors or girders are to be provided with vertical stiffeners. Widely spaced pillars are to be fitted at the intersection of plate floors and girders and if they are not fitted at the intersection, partial floors or girders are to be fitted below such pillars. Manholes or lightening holes are not to be cut in the floors and girders below pillars.

## **Section 6 Ramps for Stern Doors and Side Shell Doors**

### **6.1 Ramps for stern doors**

6.1.1 Ramps for stern doors are to comply with the requirements for stern doors in Section 5 and the requirements for vehicle ramps in Section 6, Chapter 9, PART TWO of the Rules.

### **6.2 Ramps for side shell doors**

6.2.1 Ramps for side shell doors are to comply with the requirements for side shell doors in Section 5 and the requirements for vehicle ramps in Section 6, Chapter 9, PART TWO of the Rules.

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## **Section 7 Direct Calculation of Structural Strength of Cargo Area**

### **7.1 General requirements**

7.1.1 The strength of primary supporting members within the cargo area is to be assessed by direct calculation in accordance with this Section.

7.1.2 The purpose of the direct calculation is to assess the strength of primary supporting members, in typical local loading conditions, within the cargo area. The primary structures are mainly as follows:

- deck structure;
- side structure;
- double bottom structure;
- bulkhead structure;
- partial bulkhead structure, if any;
- pillars.

### **7.2 Structural modeling**

7.2.1 Transverse and vertical extents of the finite element model: the breadth and moulded depth of the ship. The longitudinal extent of the model is as follows:

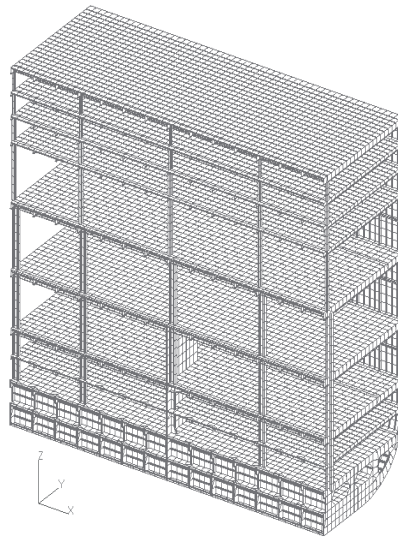
- (1) where uniformly arranged partial bulkheads are fitted within the cargo area, the model is to cover the partial bulkhead and half the spacing of partial bulkheads forward and aft of it;
- (2) where pillars, instead of partial bulkheads, are fitted within the cargo area, the model is to cover the pillar and half the spacing of pillars forward and aft of it;
- (3) where no pillar and no partial bulkhead are fitted within the cargo area, the model is to cover 3 spacings of web frames.

7.2.2 The selection of finite elements and the meshing of the model are to be in accordance with the following principles:

- (1) The mesh size is generally in accordance with the spacing of longitudinals, and webs of main supporting members (solid floors, deck transverses, girders, web frames, pillars, etc.) are simulated by plate elements and face plates by beam, rod or plate elements.
- (2) Beam elements are to be used for stiffeners subjected to lateral loads; rod elements may be used for stiffeners not subjected to lateral loads.
- (3) Plates are to be modeled by four-node plate elements, and the use of triangular elements is to be avoided as far as possible, especially in areas of high stresses and in areas around openings or in way of bracket connection and knuckle connection where there is a high stress gradient.

(4) The aspect ratio of plate elements is not to exceed 4. Where possible, the aspect ratio of plate elements in areas where there are likely to be high stresses or a high stress gradient is to be kept close to one.

Figure 7.2.2 shows an example of a finite element model of the cargo area of vehicle carriers for the port side only.



**Figure 7.2.2 Finite element model (port side only)**

7.2.3 A right-handed coordinate system is to be used for the finite element model, with

- the x-axis measured in the longitudinal direction, positive forward;
- the y-axis measured in the transverse direction, positive to port from the centreline;
- the z-axis measured in the vertical direction, positive upwards from baseline.

7.2.4 The thicknesses of structural members in the model are as-built ones.

### 7.3 Motion and acceleration

7.3.1 The rolling period and rolling angle of ship motions are to be calculated as follows:

7.3.1.1 The rolling period  $T_R$  is to be calculated as follows:

$$T_R = 2k_r / \sqrt{GM}$$

where:  $k_r$  — radius of gyration for rolling, in m, to be evaluated as follows if no specific values available:

$$k_r = 0.39B$$

where:  $B$  — breadth of the ship, in m;

$GM$ —initial metacentric height in full load departure condition, in m, to be evaluated as follows if no specific values available:

$$GM = 0.07B$$

where:  $B$  — breadth of the ship, in m.

7.3.1.2 The maximum rolling angle  $\varphi_m$  is to be calculated as follows, but need not be greater than 0.523:

$$\varphi_m = k \frac{62.5 - 1.25T_R}{B + 75} \quad \text{rad}$$

where:  $T_R$  — see 7.3.1.1;

$B$  — breadth of the ship, in m;

$k$  — coefficient, to be taken as follows:

$k = 1.2$  for ships without bilge keel;

$k = 1.0$  for ships with bilge keel;

$k = 0.8$  for ships with stabilizers.

7.3.1.3 The pitching period  $T_p$  is to be calculated as follows:

$$T_p = 1.8\sqrt{L/10}$$

where:  $L$  — length of the ship, in m.

7.3.1.4 The maximum pitching angle  $\psi_m$  is to be calculated as follows, but need not be greater than 0.14:

$$\psi_m = 0.25a_0/C_b \quad \text{rad}$$

where:  $C_b$  — block coefficient;

$a_0$  — acceleration factor, to be calculated as follows:

$$a_0 = 3SC/L + C_V V / \sqrt{L}$$

where:  $C_V = \sqrt{L}/50$ , not to be greater than 0.2;

$L$  — length of the ship, in m;

$V$  — maximum service speed, in knot;

$C$  — coefficient, to be taken as follows:

$$C = 0.0412L + 4 \quad \text{for } L < 90 \text{ m;}$$

$$C = 10.75 - \left[ \frac{(300 - L)^{1.5}}{100} \right] \quad \text{for } 90 \text{ m} \leq L \leq 300 \text{ m;}$$

$S$  — service coefficient, to be taken as follows:

$S = 1.00$  for unrestricted service;

$S = 0.95$  for service category 1;

$S = 0.90$  for service category 2;  
 $S = 0.85$  for service category 3.

7.3.2 The acceleration of ship motions is to be calculated as follows:

7.3.2.1 The sway acceleration  $a_y$  is to be calculated as follows:

$$a_y = 3a_0 \quad \text{m/s}^2$$

where:  $a_0$  — see 7.3.1.4.

7.3.2.2 The heave acceleration  $a_z$  is to be calculated as follows:

$$a_z = 7a_0 / \sqrt{C_b} \quad \text{m/s}^2$$

where: for  $a_0$  and  $C_b$ , see 7.3.1.4.

7.3.2.3 The rolling angle acceleration  $a_r$  is to be calculated as follows:

$$a_r = \varphi_m (6.28/T_R)^2 \quad \text{rad/s}^2$$

where:  $T_p$  — rolling period, to be calculated according to 7.3.1.1;  
 $\varphi_m$  — maximum rolling angle, in rad, to be calculated according to 7.3.1.2.

7.3.2.4 The pitching angle acceleration  $a_p$  is to be calculated as follows:

$$a_p = \psi_m (6.28/T_p)^2 \quad \text{rad/s}^2$$

where:  $T_R$  — pitching period, to be calculated according to 7.3.1.3;  
 $\varphi_m$  — maximum pitching angle, in rad, to be calculated according to 7.3.1.4.

7.3.2.5 The transverse composite acceleration  $a_t$  is to be calculated as follows:

$$a_t = \sqrt{a_y^2 + \left[ a_r (z - z_{rp}) + 10 \sin \varphi_m \right]^2} \quad \text{m/s}^2$$

where:  $a_y$  — sway acceleration, see 7.3.2.1;  
 $a_r$  — rolling angle acceleration, see 7.3.2.3;  
 $\varphi_m$  — maximum rolling angle, see 7.3.1.2;  
 $z$  — vertical distance from the point considered to baseline;  
 $z_{rp}$  — vertical distance from axis of gyration for rolling and that for pitching to baseline, taken as one of the values obtained from the following formulas, whichever is the lesser:

$$z_{rp1} = \frac{D}{4} + \frac{d}{2} \quad \text{m}$$

$$z_{rp2} = \frac{D}{2} \quad \text{m}$$

where:  $D$  — moulded depth, in m;  
 $d$  — draught, in m.

7.3.2.6 The vertical composite acceleration  $a_v$  is to be taken as one of the values obtained from the following formulas, whichever is the greater:

$$a_{v1} = \sqrt{a_z^2 + a_r^2 y^2} \quad \text{m/s}^2$$

$$a_{v2} = \sqrt{a_z^2 + a_p^2 (x - 0.45L)^2} \quad \text{m/s}^2$$

where:  $a_z$  — heave acceleration;  
 $a_r$  — rolling angle acceleration;  
 $a_p$  — pitching angle acceleration;  
 $x$  — vertical distance from the point considered to AP;  
 $y$  — transverse distance from the point considered to longitudinal centerline;  
 $L$  — length of ship.

#### 7.4 Conditions under consideration

7.4.1 The conditions under consideration for finite element analysis of the strength of cargo areas are given in Table 7.4.1.

**Conditions for finite element strength analysis of cargo space Table 7.4.1**

Condition	Description
1	Full load
2	Ballast
3	Rolling
4*	Transversely non-homogeneous loading
5*	Longitudinally non-homogeneous loading

\*: Where not intended for loading and unloading in multiple ports, conditions 4 and 5 may be omitted.

#### 7.4.2 Full load condition

The loads in this condition include the gravity and inertial force of the vehicle deck, those of vehicles, and static and dynamic pressures of seawater.

The vertical pressure acting on the vehicle deck is to be calculated as follows:

$$P_v = (g + 0.5a_v) (P + m_s) \quad \text{kN/m}^2$$

where:  $P$  — design load, in  $\text{t/m}^2$ , of vehicle deck;  
 $m_s$  — gravity load, in  $\text{t/m}^2$ , of vehicle deck, not less than 0.1;  
 $g$  — gravity acceleration, taken as  $9.81 \text{ m/s}^2$ ;  
 $a_v$  — vertical composite acceleration, see 7.3.2.6.

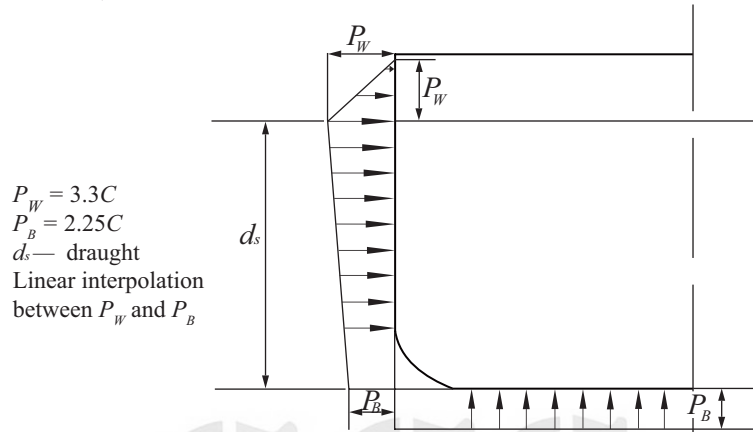
In addition, the conditions regarding axle loads are to be considered for decks intended for the carriage of large vehicles (e.g. trucks):

$$P_v = (g + 0.5a_v) Q_w \quad \text{kN}$$

where:  $Q_w$  — mass, in tons, of multiple axles simultaneously acting on one deck transverse.

The external water pressure consists of hydrostatic pressure and additional wave pressure, and the hydrostatic pressure on bottom and side depends on the draught which is the scantling draught in this condition. The distribution and values of the additional wave pressure are shown in Figure 7.4.2 where  $C$  is defined in 7.3.1.4.

The maximum value of  $a_v$  in each area is to be taken for areas under assessment.



**Figure 7.4.2 Distribution of wave crests at side and bottom of a vehicle carrier**

#### 7.4.3 Ballast condition

The loads in this condition include the structural weight of deck, and static and dynamic pressures of seawater. The structural weight of deck includes static loads only and may be applied as the gravitational field or as surface pressure, provided that the actual weight of deck is reflected.

The external water pressure consists of hydrostatic pressure and additional wave pressure, and the hydrostatic pressure depends on the draught which is the ballast draught in this condition. The additional wave pressure and its values are shown in Figure 7.4.2.

The static pressure for ballast tanks and fuel oil tanks in double bottom is to be applied according to actual load cases. Such pressure is not to be applied for empty tanks.

#### 7.4.4 Rolling condition

The loads to be analyzed for the structural strength in the rolling condition include the gravity of vehicles and hull structure, their horizontal inertial forces, and the external hydrostatic pressure. The gravity and horizontal inertial forces of vehicles and hull structure are to be calculated as follows:

$$P_v = (P + m_s) g$$

$$P_t = (P + m_s) a_t$$

where:  $a_t$  — transverse composite acceleration, see 7.3.2.5.

The external hydrostatic pressure is the still water pressure corresponding to the maximum rolling angle at the scantling draught. The maximum rolling angle is to be calculated according to 7.3.1.2.

#### 7.4.5 Transversely non-homogeneous loading

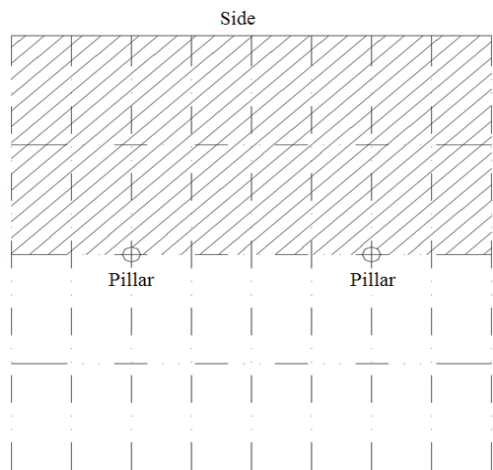
The vertical loads and seawater pressure in this condition are the same as in Condition 1, provided that the deck area on which the pressure acts is that within a span of deck transverse only. Figure 7.4.5 shows the area on which the pressure acts, and the pressure of vehicles in Condition 1 acts within the shadow area and there is no pressure of vehicles in other areas.

The external seawater pressure in this condition is the same as in Condition 2.

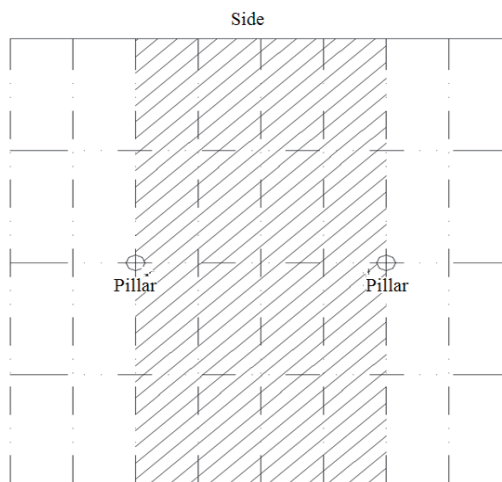
#### 7.4.6 Longitudinally non-homogeneous loading

The vertical loads and seawater pressure in this condition are the same as in Condition 1, provided that the deck area on which the pressure acts is that between two pillars only. The shadow in Figure 7.4.6 shows the area on which the pressure of vehicles acts.

The external seawater pressure in this condition is the same as in Condition 2.



**Figure 7.4.5 Area under pressure in transversely non-homogeneous loading condition**



**Figure 7.4.6 Area under pressure in longitudinally non-homogeneous loading condition**

## 7.5 Boundary conditions

7.5.1 The same boundary conditions are used for all conditions to restrain rigid displacement and to restrain unbalanced forces due to loads. Specific positions are given in Table 7.5.1 and Figure 7.5.1.

7.5.2 The displacement in  $x$  direction is restrained at one end of inner bottom so as to restrain the longitudinal displacement of the model.

7.5.3 The displacement in  $y$  direction is restrained at one side of inner bottom so as to restrain the transverse displacement of the model.

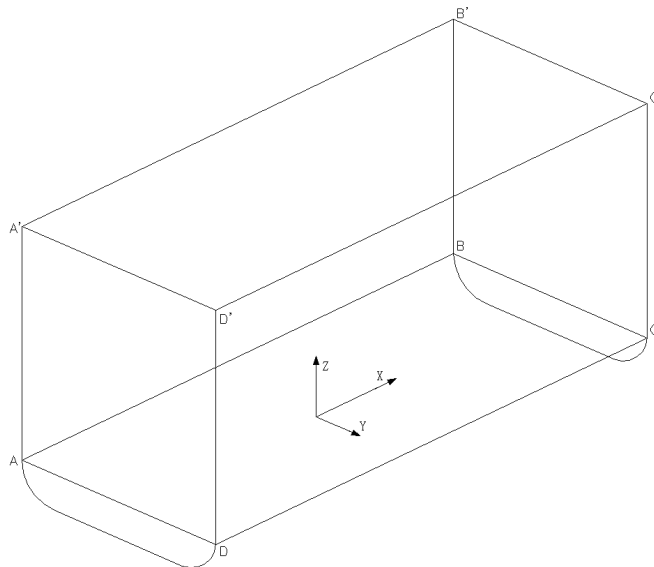
7.5.4 The displacement in  $z$  direction is restrained at both sides so as to restrain the vertical displacement of the model, thereby controlling the rotational rigid displacement of the model.

7.5.5 The rotation around the  $y$ -axis is restrained at fore and aft ends of bottom and deck girders for simulating the restraint of structural members adjacent to the model.

**Boundary conditions in various conditions**

**Table 7.5.1**

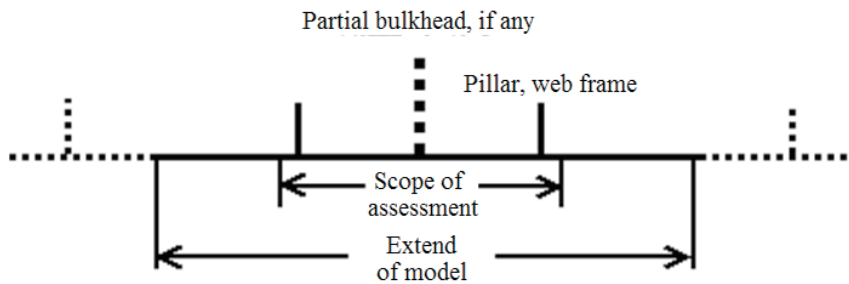
Restraint	$\delta_x = 0$	$\delta_y = 0$	$\delta_z = 0$	$\theta_y = 0$
Area affected	Line AD	Line AB	Lines AA', BB', CC', DD'	Both ends of each girder



**Figure 7.5.1 Positions for application of boundary conditions**

## 7.6 Permissible stresses

7.6.1 The scope of assessment of the results obtained from the finite element model is to be based on the middle area of the model, covering frames of partial bulkheads, web frames of pillars and ordinary web frames, see Figure 7.6.1.



**Figure 7.6.1 Assessment scope of finite element model**

7.6.2 The criteria for permissible stresses in various conditions:

Permissible shear stress:	$[\tau] = 100/K$	N/mm <sup>2</sup> ;
Permissible equivalent stress:	$[\sigma_e] = 190/K$	N/mm <sup>2</sup> ;
Permissible stress of beam and rod elements:	$[\sigma] = 190/K$	N/mm <sup>2</sup> .

### 7.7 Check of buckling strength

7.7.1 The buckling strength of the following structures within the middle area of the model is to be checked, with the buckling safety factor  $\lambda$  being not less than 1.0:

- (1) plates of transverse bulkheads and partial bulkheads;
- (2) deck transverses, web frames, solid floors;
- (3) deck girders;
- (4) bottom and inner bottom.

7.7.2 The composite of uniaxial and biaxial compressive stresses and shear stress as well as their interaction are to be incorporated in buckling calculation.

7.7.3 The general plate thickness is to be deducted by 1.0 mm of corrosion margin in calculation of plate panel buckling, with the corrosion margin of structural members within the cargo space being not less than 0.5 mm.

7.7.4 The buckling safety factor  $\lambda$  is to be derived either as indicated in Appendix 2, or by any other accepted method.

## Section 8 Direct Calculation of Global Strength of Whole Ship Structure

### 8.1 General requirements

8.1.1 This Section gives the methods for direct calculation of the global strength, aiming at check of the strength of primary structural members of vehicle carriers in head sea, beam sea and oblique sea conditions.

8.1.2 The finite element calculation of the whole ship structure is to be carried out for the following vehicle carriers:

- (1) large vehicle carriers carrying more than 5,000 vehicles or of more than 180 m in length;
- (2) vehicle carriers of a nonconventional structural design, e.g. in cases where partial bulkheads are not uniformly fitted, or where deck transverses and web frames are not arranged in one plane;
- (3) other vehicle carriers for which a whole ship structure analysis is deemed necessary by CCS.

### 8.2 Modeling of ship

8.2.1 The global model is to cover the length, breadth and moulded depth of the ship. The mesh size of the model is taken as the spacing of stiffeners, and the principles of modeling are given in 7.2. Figure 8.2.1 shows the global model of a vehicle carrier.

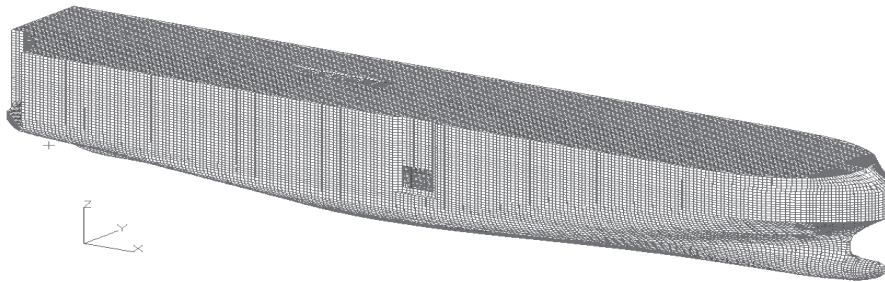


Figure 8.2.1 Global finite element model of a vehicle carrier

8.2.2 The finite element model is to be capable of simulating the actual mass, centroid and mass moment of inertia of the ship for carrying out a hydrodynamic analysis and directly applying wave loads. The model may be divided into parts and the material density of each part adjusted so as to simulate the mass of steels, outfittings and small equipment. Large equipment, ballast water and cargo are simulated by mass elements which may be arranged on appropriate structures, or connected by both virtual and actual structures.

8.2.3 The global mass model is to match the ship floating in still water. The error of total gravity and total buoyancy is to be not greater than  $\frac{1}{10000} \cdot \Delta$  where  $\Delta$  is the moulded displacement, in tons, corresponding to the draught; the error of the ordinates of centroid and centre of buoyancy is to be not greater than  $\frac{1}{4000} \cdot L$  where  $L$  is the ship's length, in m; the error of the transverse coordinate is to be not greater than  $\frac{1}{1000} \cdot B$  where  $B$  is the ship's breadth, in m.

### 8.3 Load cases

8.3.1 Each considered condition consists of still water load cases and wave load cases.

8.3.2 The following still water full load cases are selected from the Loading Manual and used as conditions for calculation:

- (1) full load case where maximum still water bending moment occurs;
- (2) full load case where maximum height of centre of gravity occurs;
- (3) other severe cases which are needed to be considered in the opinion of CCS or the designer.

8.3.3 Design wave parameters, e.g. wave direction, wave length, wave height and phase, are calculated by the probabilistic method, based respectively on the draught and mass distribution in the above still water conditions, see Appendix 1 for details.

8.3.4 Considered conditions consist of different combinations of still water load cases and wave load cases. Calculation is to be carried out for the following conditions of vehicle carriers:

<b>Conditions for calculation</b>			<b>Table 8.3.4</b>
Wave condition	Maximum vertical wave bending moment amidships	Maximum rolling angle	Maximum torque at L/4
Still water condition			
Full load condition	Condition 1	Condition 2	Condition 3

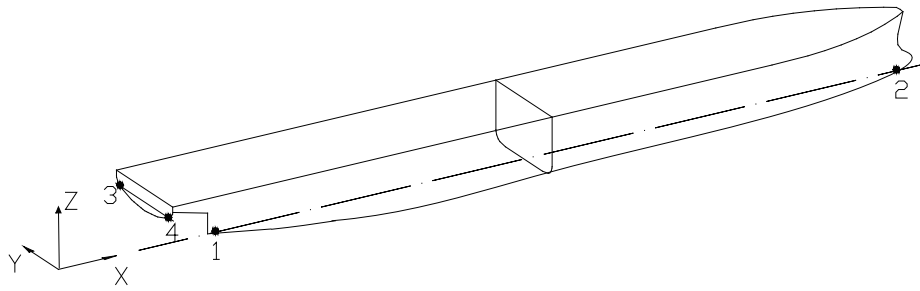
### 8.4 Loads under consideration

8.4.1 The loads under consideration include static loads and wave-induced dynamic loads. Static loads include buoyancy and gravity, applied through pressure field and gravity field. Wave-induced dynamic loads include dynamic wave pressure and appropriate inertial forces of motions, obtained by direct calculation of wave loads and motions and applied to the global finite element model.

### 8.5 Boundary conditions

8.5.1 Corresponding external loads and inertial loads are obtained by direct calculation of wave loads, and the calculation model is in a free dynamic balance. In order to prevent rigid displacement, 6 translation constraints are applied at corresponding nodes of hull, as shown in Table 8.5.1 and Figure 8.5.1

<b>Boundary constraints and their application</b>			<b>Table 8.5.1</b>
Constraint	$\delta_x = 0$	$\delta_y = 0$	$\delta_z = 0$
Application	Point 1	Points 1, 2	Points 2, 3, 4



**Figure 8.5.1 Boundary conditions**

### **8.6 Permissible stresses**

8.6.1 The stress at the mid plane in way of the centre of elements is to be used in direct calculation of the global strength of the ship, with the permissible stress being as follows:

Permissible shear stress:  $[\tau] = 100/K \text{ N/mm}^2$ ;  
 Permissible equivalent stress:  $[\sigma_e] = 190/K \text{ N/mm}^2$ .

### **8.7 Check of buckling strength**

8.7.1 As a minimum, the buckling strength of bottom, inner bottom, side shell, solid floors, bottom stringers and vehicle deck is to be checked, with the buckling safety factor  $\lambda$  being not less than 1.0.

8.7.2 The composite of uniaxial and biaxial compressive stresses and shear stress as well as their interaction are to be incorporated in buckling calculation.

8.7.3 The general plate thickness is to be deducted by 1.0 mm of corrosion margin in calculation of plate panel buckling, with the corrosion margin of structural members within the cargo space being not less than 0.5 mm.

8.7.4 The buckling safety factor  $\lambda$  is to be derived either as indicated in Appendix 2, or by any other accepted method.

## Section 9 Refined Finite Element Analysis of Local Structural Connection

### 9.1 General requirements

9.1.1 This Section contains the requirements and methods for refined finite element analysis of local structural connections, for the purpose of assessing the strength of localized areas of high stress in way of structural joints.

9.1.2 Where the local geometry of structural connections can not be adequately represented in the hull finite element model, a fine mesh analysis may be used to demonstrate satisfactory scantlings.

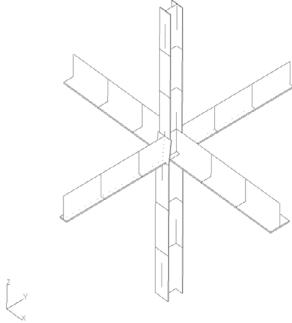
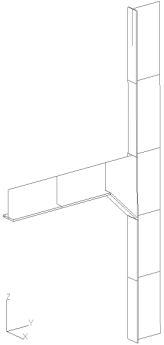
9.1.3 The refined finite element analysis of local structures is to be made for connections of various members, and the areas for which such analysis is needed are to be determined according to the requirements of 9.2.

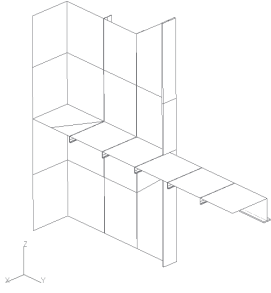
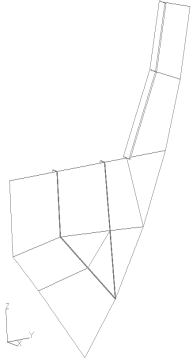
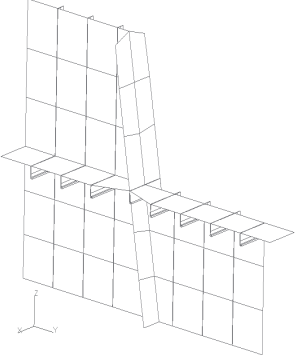
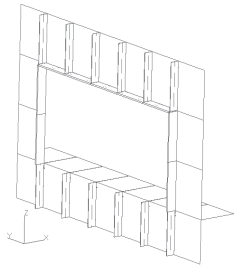
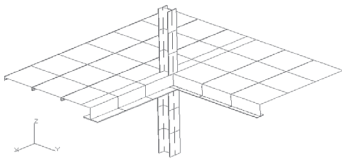
### 9.2 Refined areas

9.2.1 The areas of interest listed in Table 9.2.1 are to be refined for analysis at the locations of which the equivalent stresses, calculated as required in Sections 7 and 8 of the Guidelines, exceed 80% of the permissible stress.

Typical Refined Areas of Interest

Table 9.2.1

Structural member	Area of interest	Description
Primary member	Connection of pillar to deck transverse and deck girder	
	Connection of deck transverse to web frame	

	Connection of deck transverse to partial bulkhead	
	Connection of web frame to solid floor	
Bulkhead	Transition between partial bulkhead and transverse bulkhead	
	Opening in transverse bulkhead	
Deck	Corners of opening for ramp on vehicle deck	

9.2.2 The local structure connections other than the areas listed in Table 9.2.1 are to be refined for analysis at the locations of which the equivalent stresses, calculated as required in Sections 7 and 8 of the Guidelines, exceed 90% of the permissible stress.

### 9.3 Structural modeling

#### 9.3.1 Extent of fine mesh model

The extent of the local finite element model is to be such that the stresses at the areas of interest are not significantly affected by boundary conditions and loads. The boundary of the fine mesh model is to coincide with primary supporting members, such as girders, stringers and floors, in the hull structure.

#### 9.3.2 Required mesh size of fine mesh model

Refined areas are to be represented by shell elements, and the use of triangular elements and distorted elements is to be avoided. The aspect ratio of elements is to be kept close to 1. The mesh size in the fine mesh zones is not to be greater than 50 mm × 50 mm. The extent of the fine mesh zone is not to be less than 10 elements in all directions, and a smooth structural transition is to be maintained in the model.

#### 9.3.3 Refining method

The fine mesh model can be included in the global model for direct calculation, or separate sub-models can be used for analysis.

### 9.4 Boundary conditions and loads of fine mesh sub-models

#### 9.4.1 Boundary conditions

Where a separate local sub-model is used for the fine mesh analysis, the nodal displacements from the global model are to be imposed to the corresponding boundary nodes on the local model.

#### 9.4.2 Loads

Local loads on local refined areas are to be applied to the fine mesh model.

### 9.5 Result evaluation and acceptance criteria

9.5.1 The maximum permissible stresses are to be based on the mesh size of 50 mm × 50 mm. Where a smaller mesh size is used, an average von Mises stress calculated over an area equal to the specified mesh size may be used in check.

$$\sigma_{vm} \leq \lambda [\sigma_e]$$

where:  $\sigma_{vm}$  — equivalent von Mises stress, in N/mm<sup>2</sup>, of plate elements;  
 $\lambda$  — coefficient, taken as 1.5 for elements adjacent to weld and 1.7 for other elements;  
 $[\sigma_e]$  — permissible stress, in N/mm<sup>2</sup>, see corresponding permissible stress in 7.6 or 8.7.

## **Appendix 1 Calculation Methods for Wave-Induced Motions and Loads of Vehicle Carriers**

### **1 General requirements**

- 1.1 Ship motions and wave loads are to be calculated by the CCS006SR-96 program based on two-dimensional linear strip theory or by other three-dimensional linear programs.
- 1.2 The full load condition is in general to be taken for calculation, and other conditions may be taken as necessary.
- 1.3 Ship speed is to be taken as zero in calculation of wave loads.

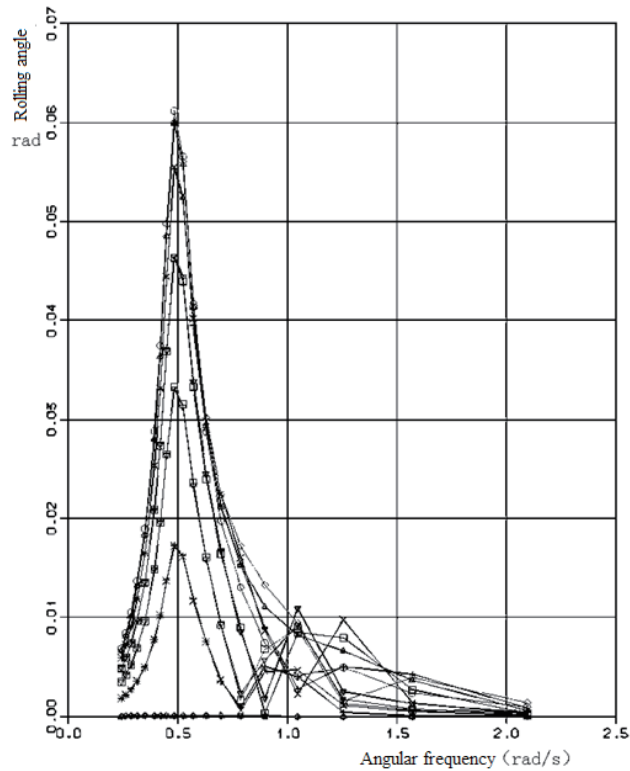
### **2 Dominant load parameters and their statistical analysis**

#### 2.1 Main dominant load parameters

- (1) For maximum hull roll motion, the wave-induced rolling angle is taken as the dominant load parameter.
- (2) For maximum vertical wave bending moment amidships, the wave-induced bending moment amidships is taken as the dominant load parameter.
- (3) In oblique sea condition, the maximum torque at  $L/4$  is taken as the dominant load parameter.

#### 2.2 To calculate the ship motions and loads under design waves for each loading condition, the input data are considered as follows:

- (1) The number of wave frequencies is to be taken not less than 20 and the range of angular wave frequencies taken as 0.1 to 1.5.
- (2) Not less than 7 wave heading angles are to be taken, including  $0^\circ$  (head sea),  $30^\circ$ ,  $60^\circ$ ,  $90^\circ$ ,  $120^\circ$ ,  $150^\circ$  and  $180^\circ$  (following sea).
- (3) The roll damping used in calculation is to be not greater than 0.07 times the critical damping.
- (4) A series of curves of frequency response functions of dominant load parameters is obtained by calculation of their amplitude responses at the unit height of the above regular waves. Figure 2.2 shows an example of the typical form of curves of frequency response functions, with each curve indicating a wave heading.



**Figure 2.2** Example of frequency response functions

### 2.3 Long-term prediction of rolling angle

(1) The wave scatter diagram recommended by IACS (IACS REC No.34) is to be used to describe the random distribution of ocean waves.

(2) The energy distribution of waves is to be set according to the P-M spectrum, and the P-M wave spectrum is to be used in the calculation of wave-induced motions and load statistics:

$$S(\omega, H_{\frac{1}{3}}, T_2, \theta) = \begin{cases} \frac{2}{\pi} 124 H_{\frac{1}{3}} T_2^{-4} \omega^{-5} \exp\left(-\frac{496}{T_2^4 \omega^4}\right) \cos^2 \theta, & |\theta| \leq \frac{\pi}{2} \\ 0, & \theta \text{ being other values} \end{cases}$$

where:  $\omega$  — angular wave frequency, in rad/s;

$H_{\frac{1}{3}}$  — significant wave height, in m;

$T_2$  — zero-crossing wave period, in s;

$\frac{2}{\pi} \cos^2 \theta$  — energy spread function;

$\theta$  — angle between complex wave and main wave heading, in rad.

(3) The exceedance probability of  $10^{-6.5}$  is taken for the long-term prediction of rolling angle and  $10^{-8}$  for others.

### 3 Determination of design wave parameters

3.1 The incidence direction of design waves is to be determined by the curves of frequency response functions of dominant load parameters, normally taken as 0 degree in head sea condition, 90 degrees in beam sea condition and 45 degrees in oblique condition.

3.2 The wave frequency  $\omega_a$  corresponding to the maximum peak value of curves of frequency response functions is to be taken as the design wave frequency.

3.3 The amplitude of design waves is to be calculated as follows:

$$a_w = \frac{L}{A}$$

where:  $a_w$  — amplitude of design waves;  
 $A$  — peak value of response functions;  
 $L$  — long-term prediction of dominant load parameters.

3.4 Phase of design waves

The phase in which the combination of the dominant load parameter response and the still water load reaches its maximum value is to be taken in calculation.

### 4 Calculation of wave-Induced motions and pressures in design wave conditions

4.1 Wave-Induced motions and pressures are to be calculated for the incidence directions, frequencies and amplitudes of design waves specified in section 3 above.

4.2 The pressure and inertial force in the phase given in 3.4 are to be used as the loads considered for the finite element analysis.

## Appendix 2 Simplified Formulas for Check of Panel Buckling Strength

### 1 Critical buckling stresses and elastic-plastic correction

1.1 The elastic critical buckling stress  $\sigma_{xcr\_e}$  of the plate panel, of which the shorter side is subjected to compression and bending, is defined as follows:

$$\sigma_{xcr\_e} = k_x C_1 \frac{\pi^2 E}{12(1-\nu^2)} \left(\frac{t}{s}\right)^2 \quad \text{N/mm}^2$$

where:  $k_x$  — buckling coefficient for shorter side subjected to compression and bending, calculated according to Table 1.1(a) of this Appendix, where  $\sigma_{x1}$  and  $\sigma_{x2}$  are defined in 2.2 of this Appendix;

$C_1$  — boundary restraint coefficient, see Table 1.1 (b) of this Appendix;

$E$  — Young's modulus,  $E = 2.06 \times 10^5$  N/mm<sup>2</sup> for steel;

$\nu$  — Poisson's ratio,  $\nu = 0.3$  for steel;

$t$  — thickness, in mm, of plate panel;

$s$  — length, in mm, of shorter side of plate panel, taken as spacing of longitudinals or stiffeners;

$x$  — defined as axial direction of longer side of plate panel.

1.2 The elastic critical buckling stress  $\sigma_{ycr\_e}$  of the plate panel, of which the longer side is subjected to compression and bending, is defined as follows:

$$\sigma_{ycr\_e} = k_y C_2 \frac{\pi^2 E}{12(1-\nu^2)} \left(\frac{t}{s}\right)^2 \quad \text{N/mm}^2$$

where:  $k_y$  — buckling coefficient for longer side subjected to compression and bending, calculated according to Table 1.1(a) of this Appendix, where  $\sigma_{y1}$  and  $\sigma_{y2}$  are defined in 2.2 of this Appendix;

where:  $l$  — length, in mm, of longer side of plate panel;

$C_2$  — boundary restraint coefficient, see Table 1.1(b) of this Appendix;

$y$  — defined as axial direction of shorter side of plate panel.

Other symbols are the same as in 1.1.

1.3 The elastic critical buckling stress  $\tau_{cr\_e}$  of the plate panel subjected to shear forces is defined as follows:

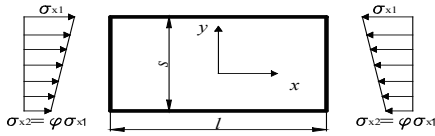
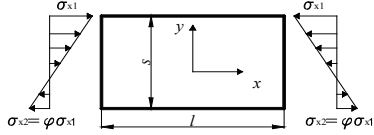
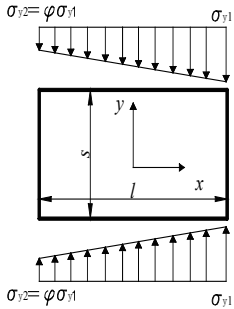
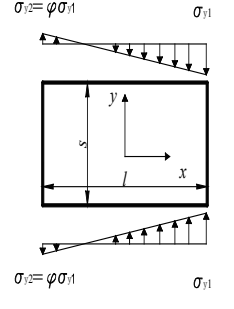
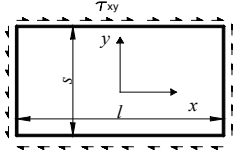
$$\tau_{cr\_e} = k_t C_1 \frac{\pi^2 E}{12(1-\nu^2)} \left(\frac{t}{s}\right)^2 \quad \text{N/mm}^2$$

where:  $k_t$  — shear buckling coefficient, calculated according to Table 3.1.1(a) of this Appendix, where  $\tau_{xy}$  is defined in 2.2 of this Appendix.

Other symbols are the same as in 1.1 and 1.2.

Buckling coefficient of plate panel

Table 1.1(a)

	Mechanical model of plate panel subject to pressure, bending and shear	Buckling coefficient
Shorter side subject to stress	 <p>where: <math>0 \leq \phi \leq 1</math></p>	$k_x = \frac{8.4}{\phi + 1.1}$
	 <p>where: <math>-1 \leq \phi &lt; 0</math></p>	$k_x = 7.6 - 6.4\phi + 10\phi^2$
Longer side subject to stress	 <p>where: <math>0 \leq \phi \leq 1</math></p>	$k_y = \left[ 1 + \left( \frac{s}{l} \right)^2 \right]^2 \frac{2.1}{\phi + 1.1}$
	 <p>where: <math>-1 \leq \phi &lt; 0</math></p>	$k_y = 1.909(1 + \phi) \left[ 1 + \left( \frac{s}{l} \right)^2 \right]^2 - k_p \phi$ $+ 10\phi(1 + \phi) \left( \frac{s}{l} \right)^2$ <p>where:</p> $k_p = \begin{cases} 24 \left( \frac{s}{l} \right)^2 & \frac{l}{s} \leq \frac{3}{2} \\ 2 + 16 \left( \frac{s}{l} \right)^2 + 8 \left( \frac{s}{l} \right)^4 & \frac{l}{s} > \frac{3}{2} \end{cases}$
Edge subject to shear stress		$k_t = 5.34 + 4 \left( \frac{s}{l} \right)^2$

**Plate panel boundary restraint coefficients  $C_1$  and  $C_2$  Table 1.1(b)**

Boundary	$C_1$	$C_2$	
		In double bottom or between double sidings	Elsewhere
Angel bar or T-stiffener	1.1	1.3	1.2
Flat bar or bulb flat	1.0	1.2	1.1

1.4 The elastic critical buckling stress of plate panels is to be corrected as follows:

$$\sigma_{\substack{ocr \\ (ocr)}} = \begin{cases} \sigma_{\substack{ocr\_e \\ (ocr\_e)}} & \text{for } \sigma_{\substack{ocr\_e \\ (ocr\_e)}} \leq \frac{R_{eH}}{2} \\ R_{eH} \left(1 - \frac{\sigma_S}{4\sigma_{\substack{ocr\_e \\ (ocr\_e)}}}\right) & \text{for } \sigma_{\substack{ocr\_e \\ (ocr\_e)}} > \frac{R_{eH}}{2} \end{cases}$$

$$\tau_{cr} = \begin{cases} \tau_{cr\_e} & \text{for } \tau_{cr\_e} \leq \frac{\tau_S}{2} \\ \tau_S \left(1 - \frac{\tau_S}{4\tau_{cr\_e}}\right) & \text{for } \tau_{cr\_e} > \frac{\tau_S}{2} \end{cases}$$

where:  $\sigma_{ocr}, \sigma_{ocr\_e}, \tau_{cr}$  — respectively as elastically-plastically corrected critical buckling compressive stress along axes  $X$  and  $Y$  under uniaxial stress and critical buckling shear stress of plate panel;

$\sigma_{ocr\_e}, \sigma_{ocr\_e}, \tau_{cr\_e}$  — respectively as elastic critical buckling compressive stress along axes  $X$  and  $Y$  under uniaxial stress and critical buckling shear stress of plate panel, see 1.1, 1.2 and 1.3 of this Appendix;

$R_{eh}$  — yield strength of material, in N/mm<sup>2</sup>;

$\tau_S$  —  $\frac{R_{eH}}{\sqrt{3}}$

## 2 Criteria for buckling strength

2.1 The buckling strength of plate panels under composite stresses is to be corrected as follows:

$$\lambda \geq [\lambda]$$

where:  $\lambda$  — ratio of the critical buckling stress under composite stress of plate panels to the actually considered compressive stress, calculated according to Table 2.1 of this Appendix;

$[\lambda]$  — plate panel buckling safety factor, see Table 2.1 of this Appendix. Where the model is fine meshed, the requirement for  $\lambda$  value may be relaxed as appropriate, subject to consent of CCS;

$\sigma_{x1}, \sigma_{y1}, \tau_{xy}$  — see 2.2;  
 $\sigma_{xcr}, \sigma_{ycr}, \tau_{cr}$  — see 1.4;  
 $l$  and  $s$  are the same as in 1.2 and 1.1.

2.2  $\sigma_{x1}$  and  $\sigma_{y1}$  in Tables of this Appendix are greater values of working stresses acting on sides of the plate panel along axes  $X$  and  $Y$ ,  $\sigma_{x2}$  and  $\sigma_{y2}$  are the lesser values of such stresses, and these values are to be taken as the average stress at the mid plane of plate panel sides (average value for two opposite nodes) in calculation;  $\tau_{xy}$  is average shear stress.  $\sigma_{x1}, \sigma_{x2}, \sigma_{y1}, \sigma_{y2}$  and  $\tau_{xy}$  are as indicated in Table 1.1 (a).

2.3 The working stresses  $\sigma_{x1}, \sigma_{y1}$  and  $\tau_{xy}$  along axes  $X$  and  $Y$ , obtained in accordance with 2.2, are considered in their absolute values in calculation. Where  $\sigma_{x1}$  and  $\sigma_{y1}$  are considered as tension stress, such stress component is to be taken as zero.

Calculation of  $\lambda$

Table 2.1

Aspect ratio of plate panel	$1 \leq \frac{l}{s} \leq \sqrt{2}$	$\sqrt{2} < \frac{l}{s} \leq 8$
Stress condition		
Biaxial compression	$\frac{1}{(1+k_1)} \frac{\sigma_{xcr}}{\sigma_{x1}}$	$\frac{1}{\sqrt{(1+k_1^2)}} \frac{\sigma_{xcr}}{\sigma_{x1}}$
Compression along $X$ -axis + edge shear		$\frac{1}{\sqrt{(1+k_2^2)}} \frac{\sigma_{xcr}}{\sigma_{x1}}$
Compression along $Y$ -axis + edge shear		$\frac{1}{\sqrt{(1+k_3^2)}} \frac{\sigma_{ycr}}{\sigma_{y1}}$
Biaxial compression + edge shear		$\frac{1}{\sqrt{(1+k_1^2+k_2^2)}} \frac{\sigma_{xcr}}{\sigma_{x1}}$

where:  $k_1 = \frac{\sigma_{y1}/\sigma_{ycr}}{\sigma_{x1}/\sigma_{xcr}}$ ,  $k_2 = \frac{\tau_{xy}/\tau_{cr}}{\sigma_{x1}/\sigma_{xcr}}$ ,  $k_3 = \frac{\tau_{xy}/\tau_{cr}}{\sigma_{y1}/\sigma_{ycr}}$ .