GUIDANCE NOTES
GD45-2023

CHINA CLASSIFICATION SOCIETY

GUIDELINES FOR HULL STRUCTURE OF CAR CARRIERS

2023

Effective from 1 January 2024

Beijing

Brief Explanation

In order to satisfy the development needs of large-size and lightweight design of car carriers, based on the review and summary of industry feedback and plan approval experience in recent years and in combination with the latest research results, the original 2010 Guidelines for Hull Structure of Vehicle Carriers has been comprehensively revised with main contents as follows:

(1) Based on the arrangement characteristics of multi-layer continuous deck, the requirements for strength deck and frame are modified;

(2) On the basis of the results of the scientific research project, the new vehicle deck requirements are converted and included;

(3) According to the characteristics of ship type structure, the requirements for the side shell plating and frame as well as the structural requirements for the bow floating area are modified;

(4) The double bottom height reduction factor is introduced and the requirements for the double bottom structure are modified;

(5) The requirements for the watertight bulkhead structure are modified according to the flooding condition characteristics of ship type;

(6) The requirements for vehicle ramp, movable vehicle deck and other ro-ro access equipment are modified according to the scientific research results;

(7) On the basis of reorganizing the application scope and checking target, the direct calculation requirements in Section 7 and Section 8 are modified and adjusted, and the rolling condition of large car carrier is included in the strength analysis of the whole ship;

(8) The original requirements for detail refinement analysis are coordinated with those for fatigue analysis;

(9) The contents of the car carrier in the original Guidelines on Fatigue Strength is included in the Guidelines, more comprehensive and clear explanation is given to the selection of fatigue analysis details, and the global finite element model and analysis method are used to evaluate the accumulative damage to the structure under left and right rolling conditions.

CONTENTS

Section 1 GENERAL PROVISIONS

1.1 Application

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

1.1.2 Where not specified in the Guidelines, the relevant requirements of Chapters 1, 2 and 9, 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 Car carriers complying with the Guidelines will be assigned the class notation Car Carrier.

1.3 Plans and documents

1.3.1 Relevant plans and documents are to be submitted according to paragraph 9.1.3, Section 1, Chapter 9, PART TWO of the Rules.

1.4 Arrangements and structural configuration

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

1.4.2 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.

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

1.4.4 Partial transverse bulkheads, or transverse web frames consisting of web frames and deck transverses, are generally to be fitted between the strength deck and the lowest vehicle deck. In general, 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.

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

1.5 Direct calculation of hull structural strength and fatigue strength assessment

1.5.1 Direct calculation of hull structural strength is to be carried out according to Sections 7 and 8 of the Guidelines and submitted to CCS.

1.5.2 Check of fatigue strength is to be carried out to hull structure details according to Section 9 of the Guidelines and submitted to CCS.

1.6 Symbol

1.6.1 Unless otherwise specified, the symbol definitions in the Guidelines are the same as those in PART TWO of the Rules.

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.

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^2, of the first tier deck above freeboard deck, forward of 0.2L from the fore perpendicular;

A_w —— waterplane area, in m^2, 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. The distribution factor M for bending moments within 0.65L ~ 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**

Distance *x* from aft end	0.65L	0.75L	1.0L
M	1.0	0.8	0

2.3 Hull girder bending strength

2.3.1 Hull girder bending strength is to comply with the requirements in paragraph 2.2.5, Section 2, Chapter 2, PART TWO of the Rules.

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 For car carriers with single side structure, the shear stress τ on the side shell plating can be calculated as follows:

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

where: $\overline{F}_s$ —— permissible still water shear force, in kN;

F_W —— wave shear force, in kN;

t—— thickness of side shell plating at the point considered, in mm;

q_v—— shear flow for the plate, calculated as follows:

$$q_v = 0.5\left(\frac{S}{I}\right)\cdot 10^{-1} \quad \text{mm}^{-1}$$

where: S —— static moment, in 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 cm^4, of the considered transverse section about the horizontal neutral axis.

2.4.4 The permissible shear stress $[\tau] = 110/K$, in N/mm^2, where K is material factor.

2.5 Hull girder buckling strength

2.5.1 For ships having a length equal to or greater than 90m, 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, σ, is to be calculated according to paragraph 2.2.5.5, Section 2, Chapter 2, PART TWO of the Rules. 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.

2.5.4 Where the still water bending moment is hogging in all loading conditions, the minimum hogging still water bending moment is to be taken for the combined sagging bending moment $\overline{M}_s$, as considered for the calculation under paragraph 2.5.3.

2.5.5 The working shear stress τ is to be calculated according to paragraph 2.4.3 of this Section.

Section 3 DECK STRUCTURE

3.1 General requirements

3.1.1 This Section applies to strength decks, vehicle decks and decks within deckhouse. 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 3.5 of this Section.

3.2 Strength deck

3.2.1 The minimum thickness of the strength deck is to be 6 mm.

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:

$$W = 3.6sl^2K + 0.015slLK \quad \text{cm}^3$$

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.

3.3 Vehicle deck

3.3.1 For unexposed vehicle decks, the deck plate thickness is not to be less than 5.5 mm.

3.3.2 For unexposed vehicle decks, the deck thickness under the action of print wheel loads is not be less than the calculated value in the following formula:

$$t = 54.8\beta_c \frac{k_2}{k_1}\sqrt{\frac{p_1 cs}{C_p R_{eH}}} + 1.0 \quad \text{mm}$$

where: β_c —— aspect ratio correction factor, to be taken as:

$$\beta_c = \begin{cases} 0.35\ln\dfrac{\ell}{s} + 0.76, & \dfrac{\ell}{s} \le 2 \\ 1, & \dfrac{\ell}{s} > 2 \end{cases};$$

k_1 —— influence factor along framing direction, to be taken as:

$$k_1=\begin{cases}-3.426(\frac{a}{s})^3+8.042(\frac{a}{s})^2-6.547(\frac{a}{s})+3.08, & \frac{a}{s}\le 1\\ -0.022(\frac{a}{s})^3+0.169(\frac{a}{s})^2-0.462(\frac{a}{s})+1.463, & 1<\frac{a}{s}<3\\ 1, & \frac{a}{s}\ge 3\end{cases};$$

k_2 —— influence factor perpendicular to framing direction, to be taken as:

$$k_2=\begin{cases}0.0272\left(\frac{b}{s}\right)^2-0.1849\frac{b}{s}+0.4165, & \frac{b}{s}\le 1\\ -0.0285\left(\frac{b}{s}\right)^3+0.1851\left(\frac{b}{s}\right)^2-0.3596\frac{b}{s}+0.4717, & 1<\frac{b}{s}\le 3\\ 0.2887, & \frac{b}{s}>3\end{cases};$$

a —— length of print wheel under consideration, see Table 3.3.2, in m;

b —— breadth of print wheel under consideration, see Table 3.3.2, in m;

c —— coefficient, to be taken as b and not more than s, in m;

s —— panel breadth, see Table 3.3.2, in m;

l —— panel length, see Table 3.3.2, in m;

e —— print wheel interval, see Table 3.3.2, in m;

p_1 —— print wheel load under consideration, see Table 3.3.2, to be taken as:

$$p_1=\lambda\frac{P_1}{ab}\times 9.81 \text{ kPa}$$

where: P_1 —— print wheel bearing, in t;

λ —— dynamic factor, to be taken as:

$\lambda=1+\frac{a_v}{g}$ for navigation condition;

$\lambda=1.10$ for port condition;

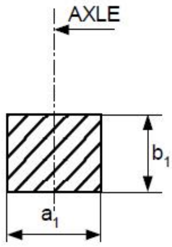
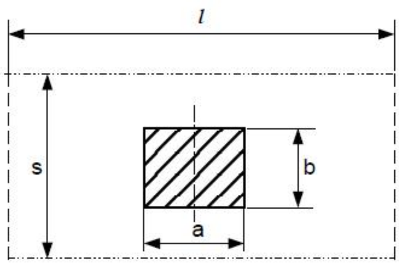
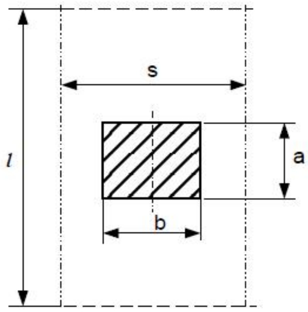
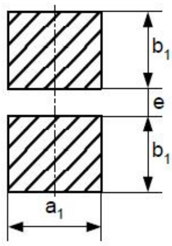
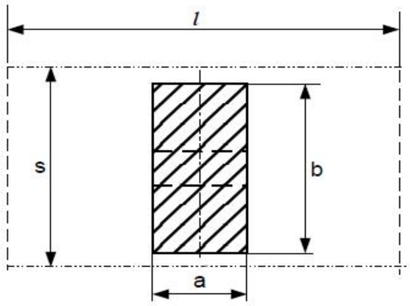
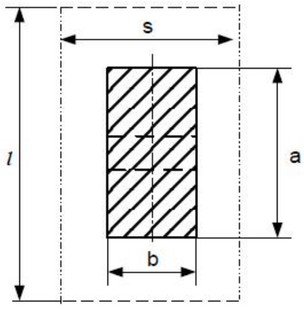
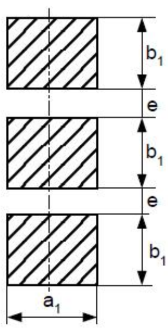
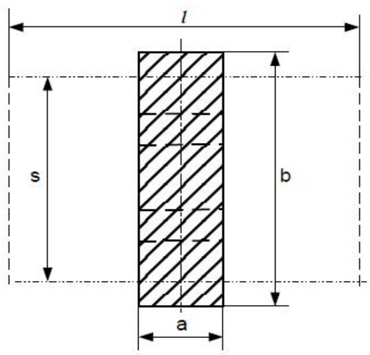
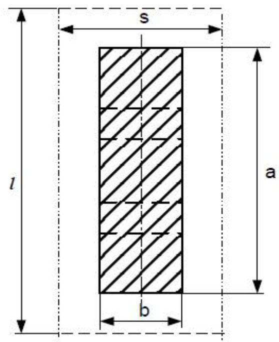
a_v —— vertical composite acceleration, see paragraph 1.5.2.2, Chapter 1, PART TWO of the Rules;

C_p —— permissible bending stress coefficient, to be taken as:

$C_p=1.0$ for navigation condition;

C_p=0.9   for port condition.

Definition of print wheel load area **Table 3.3.2**

Amount of print wheel	Size of print wheel	Load area when the axle is perpendicular to the framing	Load area when the axle is parallel to the framing
Single print wheel		 $a=a_1$, $b=b_1$	 $b=a_1$, $a=b_1$
Double print wheel	 $e<b_1$	 $a=a_1$, $b=2b_1+e$	 $b=a_1$, $a=2b_1+e$
Triple print wheel	 $e<b_1$	 $a=a_1$, $b=3b_1+2e$	 $b=a_1$, $a=3b_1+2e$

Note: In order to simplify the calculation, the load area of multiple print wheels can be equivalent to that of a single print wheel, where the equivalent load area is the original load area of multiple print wheels plus the interval between each print wheel, and is processed in the way that the center of the equivalent load area overlaps with the center of the panel.

3.3.3 For unexposed vehicle deck, the section modulus of deck framing under the action of print wheel load is not to be less than the value obtained from following formula:

$$W = \frac{1000 k_1 k_n p c d \ell}{k_2 C_s R_{eH}} \quad \text{cm}^3$$

where: k_1 —— influence factor along framing direction, to be taken as:

$$k_1 = \begin{cases} 0.07(\frac{a_1}{\ell})^2 - 0.188\frac{a_1}{\ell} + 0.185, & \frac{a_1}{\ell} \le 1 \\ 0.0103(\frac{a_1}{\ell})^3 - 0.0855(\frac{a_1}{\ell})^2 + 0.221\frac{a_1}{\ell} - 0.08, & 1 < \frac{a_1}{\ell} < 3.5 \\ 0.0833, & \frac{a_1}{\ell} \ge 3.5 \end{cases};$$

k_2 —— influence factor perpendicular to framing direction, to be taken as:

$$k_2 = \begin{cases} 0.156(\frac{b_1}{s})^2 + 0.045\frac{b_1}{s} + 1.02, & \frac{b_1}{s} \le 1 \\ -0.062(\frac{b_1}{s})^3 + 0.522(\frac{b_1}{s})^2 - 1.382\frac{b_1}{s} + 2.09, & 1 < \frac{b_1}{s} < 3.5 \\ 1, & \frac{b_1}{s} \ge 3.5 \end{cases};$$

a_1, b_1—— size of single print wheel, see Table 3.3.2;

p_2 —— print wheel load of framing under consideration, to be taken as:

$$p_2 = \lambda \frac{P_2}{a_1 b_1} \times 9.81 \quad \text{kPa}$$

where: P_2 —— single print wheel bearing, in t;

λ —— dynamic factor, to be taken as:

$\lambda = 1 + \frac{a_v}{g}$ for navigation condition;

$\lambda = 1.10$ for port condition;

a_v —— vertical composite acceleration, see paragraph 1.5.2.2, Chapter 1, PART TWO of the Rules;

c —— coefficient, to be taken as b_1 and not more than s, in m;

d —— coefficient, to be taken as a_1 and not more than ℓ, in m;

ℓ —— framing span, in m;

s —— framing spacing, in m;

k_n —— correction factor of multiple print wheels, to be taken as:

$$k_n = k_a \cdot k_b \,;$$

k_a —— correction factor of multiple print wheels along framing direction, to be taken as:

If there is one print wheel along framing direction, $k_a = 1$;

If there are two print wheels along framing direction, $k_a = \begin{cases} 1.52\left(\dfrac{e_l}{l}\right)^2 - 2.76\dfrac{e_l}{l} + 2, & 0 < \dfrac{e_l}{l} < 0.5 \\ 1, & \dfrac{e_l}{l} \geq 0.5 \end{cases}$;

If there are three print wheels along framing direction, $k_a = \begin{cases} 2\left(\dfrac{e_l}{l}\right)^2 - 5\dfrac{e_l}{l} + 3, & 0 < \dfrac{e_l}{l} < 0.5 \\ 1, & \dfrac{e_l}{l} \geq 0.5 \end{cases}$;

If there is one print wheel perpendicular to framing direction, $k_b = 1$;

If there are two print wheels perpendicular to framing direction,

$$k_b = \begin{cases} -0.71\left(\dfrac{e_s}{s}\right)^2 - 0.05\dfrac{e_s}{s} + 2, & 0 < \dfrac{e_s}{s} < 1.15 \\ 1, & \dfrac{e_s}{s} \geq 1.15 \end{cases};$$

If there are three print wheels perpendicular to framing direction,

$$k_b = \begin{cases} -0.8\left(\dfrac{e_s}{s}\right)^2 - 1.2\dfrac{e_s}{s} + 3, & 0 < \dfrac{e_s}{s} < 1 \\ 1, & \dfrac{e_s}{s} \geq 1 \end{cases};$$

e_l —— spacing of print wheels along framing direction, in m;

e_s —— spacing of print wheels perpendicular to framing, in m, as shown in Figure 3.3.3.

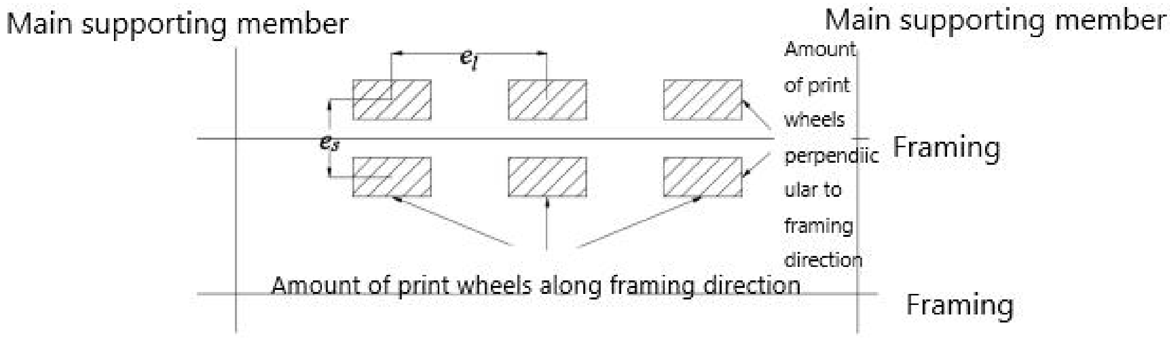


Figure 3.3.3　Schematic diagram of print wheel spacing

C_s —— permissible bending stress coefficient of framing, to be taken as:

C_s=0.95　for navigation condition;

C_s=0.85 for port condition.

3.4　Deckhouse

3.4.1　The minimum thickness of the decks in deckhouse is 5mm, of which the minimum thickness of the open part is 6mm.

3.4.2　The dimensions of the longitudinal or beam and the longitudinal girder or web beam in the deckhouse are to meet the requirements of paragraph 2.17.5, Section 17, Chapter 2, PART TWO of the Rules, where the pressure head *h* under consideration is selected as follows:

First layer: 0.9m;

Second layer: 0.6m;

Third and fourth layer: 0.45m;

Fifth layer and above: 0.25m.

3.5　Structural details of primary members of deck within vehicle spaces

3.5.1　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.

3.5.2　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 strength, in N/mm^2, of web of primary member. For high tensile steel, if the yield stress of lower strength grade can still meet the requirements of plate buckling check in direct calculation, the yield stress of lower strength grade can be taken for calculation.

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

3.5.4 The web depth of primary members is generally not to be less than 2 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 1.6 times the depth of their cut-outs for the passage of secondary members.

3.5.5 The tripping brackets for primary members are to be fitted in compliance with the requirements of paragraph 1.2.5.4, Chapter 1, PART TWO of the Rules.

3.5.6 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 paragraph 3.5.4 of this Section.

Section 4 SIDE STRUCTURES

4.1 General requirements

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

4.2 Side shell plating

4.2.1 The thickness of side shell plating below the freeboard deck is to be not less than the greater value obtained from the following formulae:

$$t_1 = 15.8s\sqrt{\frac{P_{hs}+P_{hd}}{C_p R_{eH}}} + 1.5 \quad \text{mm}$$

$$t_2 = \left(0.035L + 6\right)\sqrt{K} \quad \text{mm}$$

where: s —— panel width, in m;

P_{hs}, P_{hd} —— see paragraph 1.5.3, Section 5, Chapter 1, PART TWO of the Rules, of which structural draught is taken for draught d_l;

C_p —— to be taken as 0.76-0.9$|\sigma_b|/R_{eH}$ when the side shell is framed transversely and 0.76-0.45$|\sigma_b|/R_{eH}$ when the side shell is framed longitudinally;

σ_b —— longitudinal stress at bottom, in N/mm^2;

R_{eH} —— yield strength of shell plating, in N/mm^2;

L —— ship length, in m;

K —— material factor.

When the shell plating is used as the tank boundary, its thickness is to be increased by an additional 1mm.

4.2.2 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 0.075L from the fore perpendicular is to comply with the requirements for side plating of forecastles in paragraph 2.17.4.2(1), 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 paragraph 2.17.4.2(2), Section 17, Chapter 2, PART TWO of the Rules.

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

4.2.3 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 paragraph 2.17.3.1, Section 17, Chapter 2, PART TWO of the Rules;

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

4.2.4 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 4.2.2 and 4.2.3 of this Section, to be not less than that calculated as follows:

$$t = t_F - (Z - D_F)(0.24 + 0.006L)\sqrt{\frac{sK}{s_b}} \quad \text{mm}$$

where: t_F —— thickness, in mm, of side shell plating at freeboard deck;
Z —— height, in m, of the considered point above baseline, the considered point is to be the midpoint of the plating in the moulded depth direction, but not greater than 1.5m above plating bottom;
L —— ship length, in m;
D_F —— moulded depth measured to freeboard deck, 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

4.3.1 The section modulus of side frames below the freeboard deck is to be not less than that calculated as follows:

$$W_1 = \frac{1100(P_{hs} + P_{hd})sl^2}{7.2R_{eH}} \quad \text{cm}^3$$

$$W_2 = 0.58slLK \quad \text{cm}^3$$

where: P_{hs}, P_{hd} —— the same as 4.2.1;

s —— spacing, in m, of frames;

l —— span, in m, of the frame;

R_{eH} —— yield strength of the frame;

L —— ship length, in m;

K —— material factor.

4.3.2 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 0.075L aft of the fore perpendicular:

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

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

where: L —— ship length, in m, need not be taken greater than 230 m in calculation;
D_F —— moulded depth measured to freeboard deck, 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:

$$W = 0.55(0.7 + \frac{4d}{D_F})sdl^2K \quad \text{cm}^3$$

$$W = 0.32slLK \quad \text{cm}^3$$

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

4.3.3 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:

$$W = 11sl^2K \qquad \text{cm}^3$$

where: for 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, and in compliance with the provisions of paragraphs 4.4.2 and 4.4.3.

4.4.2 For the definition of flare angle α, see paragraph 9.4.3.1, Section 4, Chapter 9, PART TWO of the Rules.

4.4.3 For transversely framed side frames, the section modulus W and the web sectional area A are not to be less than those obtained from the following formulae:

$$W = 1.89sh_s l^2 K \qquad cm^3$$

$$A = 0.27b_{r2}lsh_s K \qquad cm^2$$

where for the definitions of each parameter, see paragraph 7.8.3.1, Section 8, Chapter 7, PART TWO of the Rules.

Section 5 DOUBLE BOTTOM, PILLARS, WATERTIGHT BULKHEAD AND DEEP TANK

5.1 General requirements

5.1.1 Unless specified in this Section, the structures of double bottom, pillars, watertight bulkhead and deep tank are to comply with Sections 6, 10, 12 and 13, Chapter 2, PART TWO of the Rules.

5.1.2 Tubular or hollow rectangular pillars are not to be used within vehicle spaces, and the lower end of the pillar may be provided only with a bracket along ship length direction.

5.2 Design load of pillars within vehicle spaces

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

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

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^2, as designed for deck.

5.3 Double bottom

5.3.1 When the height of double bottom is calculated according to paragraph 2.6.2.1, Section 6, Chapter 2, PART TWO of the Rules, h_0 is not to be less than that calculated by the following formula:

$$h_0 = 22.5B + 42d + 300 \quad \text{mm}$$

5.3.2 When the thickness of double bottom plate floor and longitudinal girder plate is calculated according to Section 6, Chapter 2, PART TWO of the Rules, reduction may be carried out according to actual height of double bottom, reduction factor $f_{db}=h_0/h_a$, but to be taken not less than 0.9, where h_0 see paragraph 5.3.1 of this Section, and h_a is actual height of double bottom.

5.3.3 The section modulus of outer bottom longitudinal is not to be less than that obtained from the following formula:

$$W = \frac{92\left(P_{hs} + P_{hd}\right)sl^2}{0.9R_{eH} - \left|\sigma_b\right|} \quad \text{cm}^3$$

where: P_{hs}, P_{hd} —— the same as 4.2.1;
s —— spacing, in m, of frames;
l —— span, in m, of the frame;
R_{eH} —— yield strength, in N/mm^2, of the frame;
σ_b —— longitudinal stress at bottom.

5.4 Watertight bulkhead and deep tank

5.4.1 The thickness of plate forming watertight boundary of tank is not to be less than that obtained from the following formula:

$$t = 15.8s\sqrt{\frac{10\Delta z}{1.15R_{eH} - C_{PF}\left|\sigma_b\right|}} + 1.5 \quad \text{mm}$$

where: s —— panel width, in m;

$\triangle z$ —— minimum vertical distance from lower edge of the panel to the deepest damaged tank equilibrium waterline, in m;

R_{eH} —— yield strength of plate, in N/mm^2;

C_{PF} —— for longitudinally framed longitudinal member, $C_{PF} = 0.25\left|D_F - z\right| / D_F$; for transversely framed longitudinal member, $C_{PF} = 0.5\left|D_F - z\right| / D_F$; for transverse member, $C_{PF} = 0$;

z —— vertical distance from lower edge of panel to baseline, in m;

For the definitions of D_F and σ_b, see Section 4.

5.4.2 The section modulus of frame forming watertight boundary of tank is not to be less than that obtained from the following formula:

$$W = \frac{920\Delta zsl^2}{1.15R_{eH} - C_{PS}\left|\sigma_b\right|} \quad \text{mm}$$

where: $\triangle z$ —— minimum vertical distance from midpoint of frame span to the deepest damaged tank equilibrium waterline, in m;

s —— spacing, in m, of frames;

l —— span, in m, of the frame;

R_{eH} —— yield strength, in N/mm^2, of the frame;

C_{PS} —— for longitudinally framed longitudinal member, $C_{PS} = 0.5\left|D_F - z\right| / D_F$, for transversely framed longitudinal member and transverse member, $C_{PS} = 0$;

z —— vertical distance from midpoint of frame span to baseline, in m;

For the definitions of D_F and σ_b, see Section 4.

5.4.3 For a tank without overflow pipe, the height of air pipe is not to be lower than that of the equilibrium waterline of the damaged tank, and the dimensions of the plates and frames forming the watertight boundary of the tank are to be checked in accordance with paragraphs 5.4.1 and 5.4.2 respectively, where $\triangle z$ is the vertical distance from the air pipe top to the point under consideration.

Section 6 RO-RO ACCESS EQUIPMENT

6.1 Stern doors and side shell doors

6.1.1 Stern doors and side shell doors are to comply with the requirements in Section 5, Chapter 9, PART TWO of the Rules.

6.2 Vehicle ramps

6.2.1 Plates and frames of vehicle ramps are to comply with the requirements of paragraph 3.3, Section 3.

6.2.2 Primary supporting members of vehicle ramps are to be subject to strength check according to following requirements:

(1) The ramps are lowered;

(2) 1.1 times the design load acts on the ramp at the most unfavorable position, taking into account the ramp weight;

(3) Permissible equivalent stress $[\sigma_e] = 180 / K$ N/mm^2

where: K —— material factor.

6.2.3 The buckling strength of the primary supporting members under pressure is to be checked.

6.2.4 The hinges at the connection of the vehicle ramps and the hull structure are to comply with the requirements of paragraph 9.6.3, Chapter 9, PART TWO of the Rules.

6.3 Movable car decks

6.3.1 Plates and frames of movable car decks are to comply with the requirements of paragraph 3.3, Section 3.

6.3.2 During seagoing, the load used to evaluate primary supporting members of movable car decks is to be taken as:

$$p = (m_s + p_d)(g + a_v) \quad \text{kN/m}^2$$

where: m_s —— deck mass, in t/m^2;

p_d —— uniformly distributed load, in kN/m^2, as designed for deck;

g —— gravity acceleration, taken as 9.81 m/s^2;

a_v —— vertical composite acceleration, see paragraph 1.5.2.2, Chapter 1, PART TWO of the Rules;

6.3.3 The criteria for evaluating primary supporting members of movable car decks is taken as:

Permissible equivalent stress $[\sigma_e] = 220 / K$ kN/m^2

where: K —— material factor.

6.3.4 The buckling strength of the primary supporting members under pressure is to be checked.

6.4 Movable vehicle ramps

6.4.1 Movable vehicle ramps are to comply with the requirements of paragraph 6.2 of this Section.

6.4.2 If movable vehicle ramps are used as car decks during seagoing, the requirements of paragraph 6.3 of this Section are to be complied with.

Section 7 DIRECT CALCULATION OF STRUCTURAL STRENGTH OF CARGO AREA

7.1 General requirements

7.1.1 The requirements for direct calculation of structural strength of cargo area of car carrier is given in this Section.

7.1.2 Cargo hold direct calculation is to be used to assess the strength of primary supporting members, in typical 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;
- pillars.

7.1.3 The hull structural strength assessment under racking condition is carried out by adopting the global finite element model in paragraph 8.2, but when one of the following conditions is met, the cargo hold model in this Section can be used for assessment:

(1) There are only 2 layers of decks for vehicles above the freeboard deck, and racking constraining structures are evenly distributed along ship length;

(2) Ship length is less than 120 m, and the anti-rolling members are evenly distributed along ship length.

7.1.4 Loading conditions used in racking strength assessment are to be included in the approved loading manual.

7.2 Structural modeling of cargo hold

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 cargo hold model is generally to take the central typical cargo hold area. If the hull structure of the vehicle cabin in other areas is obviously different from the midship area, these areas are also to be subject to modelling analysis.

7.2.3 The ramp arrangement is to be considered when determining the scope of model. According to the ramp arrangement, the longitudinal range of the model can be expanded, or the whole ship model can be adopted.

7.2.4 The finite element model is based on the as-built size of the ship, and the selection of finite elements and the meshing of the model are to meet the requirements of paragraphs 1.5.6.3 and 1.5.6.4, Section 5, Chapter 1, PART TWO of the Rules.

7.3 Motion and acceleration

7.3.1 Ship motion and acceleration are to be calculated according to paragraph 1.5.2, Section 5, Chapter 1, PART TWO of the Rules.

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	Draught	External load	Internal load
1	Full load condition	T_{SC}	Still water + wave pressure	Uniformly distributed load designed for vehicle deck
2	Ballast condition	T_{BL}	Still water + wave pressure	Static tank pressure
3	Local heavy load condition	T_{SC}	Still water + wave pressure	Vehicle deck print wheel load
4 (1)	Transversely non-homogeneous loading	T_{SC}	Still water + wave pressure	Uniformly distributed load designed for vehicle deck
5 (1)	Longitudinally non-homogeneous loading	T_{SC}	Still water + wave pressure	Uniformly distributed load designed for vehicle deck
6	Flooding condition	T_{DM}	Hydrostatic pressure	Flooding pressure
7 (2)	Racking condition	T_{SC}	Hydrostatic pressure (heeling)	Uniformly distributed load designed for vehicle deck

(1) Conditions 4 and 5 may be omitted when the design expressly prohibits non-homogeneous loading.

(2) Condition 7 may be omitted when the direct calculation for the whole ship is carried out, see paragraph 7.1.3.

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

(1) The uniformly distributed vertical pressure acting on the vehicle deck is to be calculated as follows:

$$p_V = (g + a_V)(p_d + m_S) \quad \text{kN/m}^2$$

where: p_d —— uniformly distributed load, in kN/m^2, designed for deck;

m_s —— gravity load, in t/m^2, of vehicle deck, not to be less than 0.1 t/m^2;

g —— gravity acceleration, taken as 9.81 m/s^2;

a_v —— vertical composite acceleration, see paragraph 1.5.2, Section 5, Chapter 1, PART TWO of the Rules.

(2) 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 full load 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 paragraph 2.2.3.1, Section 2, PART TWO of the Rules.

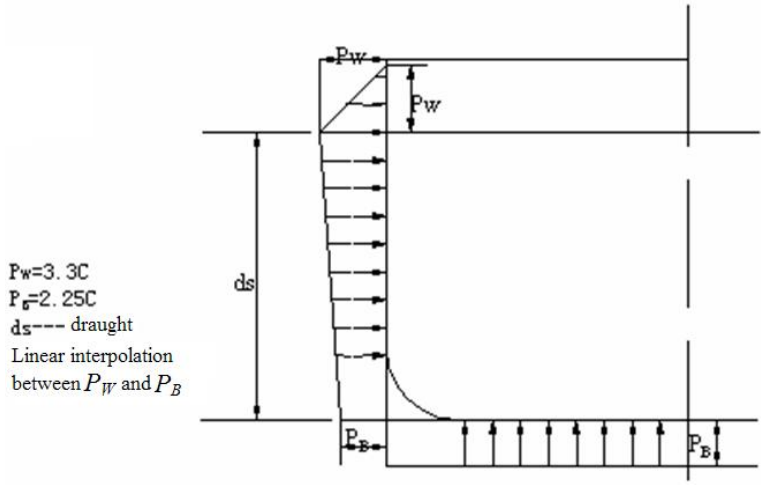


Figure 7.4.2 Distribution of wave crests at side and bottom

7.4.3 The loads in ballast condition include the structural weight of deck, and static and dynamic pressures of seawater.

(1) The structural weight of deck includes static loads only and may be applied as the gravitational field or as surface pressure.

(2) 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 distribution and values of additional wave pressure are shown in Figure 7.4.2.

(3) The static pressure for ballast tanks and fuel oil tanks in double bottom is to be applied according to actual load cases.

7.4.4 For local heavy load conditions, unfavorable loading of heavy vehicles to web beams is to be considered. The load of the vehicle deck includes two parts, i.e. the deck weight and the print wheel load. The deck weight is calculated according to following formula and applied to the model in the form of pressure:

$$p_V = (g + a_V)m_S \quad \text{kN/ m}^2$$

The print wheel load is calculated according to following formula and applied to the model in the form of node force:

$$F_V = (g + a_V)P_p \quad \text{kN}$$

where: P_p —— print wheel bearing, in t.

7.4.5 The calculation formula for deck loads and external seawater pressure in transversely non-homogeneous loading condition is the same as that in full load condition, provided that the uniformly distributed area designed for deck on which the pressure acts is that within a span of deck transverse only, and the draught is structural draught. Figure 7.4.5 shows the area with a row of pillars on which the pressure acts, and the pressure of vehicles in full load condition acts within the shadow area and there is no pressure of vehicles in other areas. When there are two rows of pillars in vehicle tank, the load areas between the pillars and between the pillar and the side are to be considered respectively.

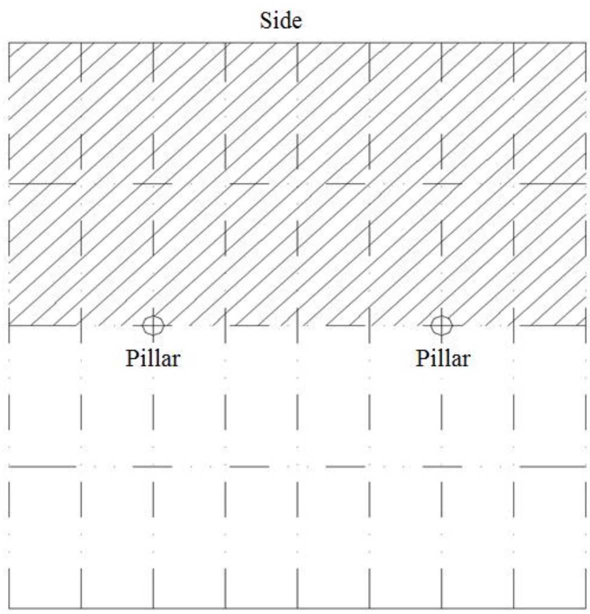


Figure 7.4.5   Area under pressure in transversely non-homogeneous loading condition

7.4.6   The calculation formula for deck loads and external seawater pressure in longitudinally non-homogeneous loading condition is the same as that in full load condition, provided that the uniformly distributed area designed for deck on which the pressure acts is the deck area between front and rear adjacent pillars, and the draught is structural draught. The shadow in Figure 7.4.6 shows the area on which the pressure of vehicles acts.

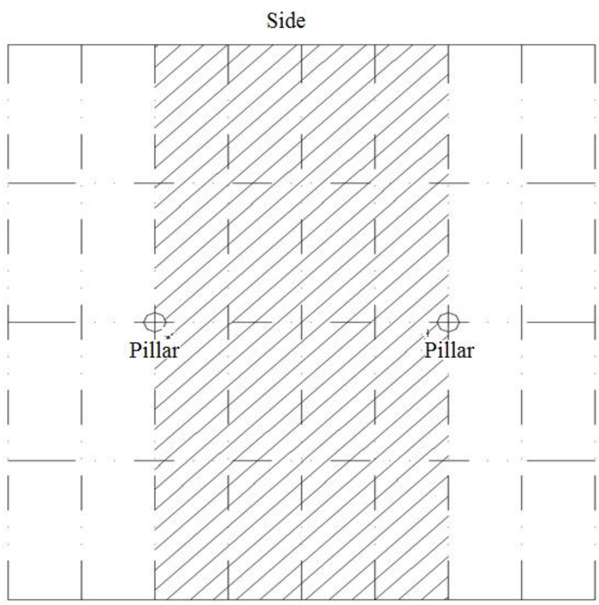


Figure 7.4.6   Area under pressure in longitudinally non-homogeneous loading condition

7.4.7   The flooding condition is used to assess the structural strength of the watertight perimeter (watertight deck). There is to be no vehicle or cargo loads on the assessed watertight deck. The hydrostatic pressure is calculated according to the deepest damaged tank equilibrium waterline.
7.4.8   The racking condition is used to assess the hull structural strength during racking. When the

cargo hold model in this Section is used for strength analysis under racking conditions, the load is shown in paragraph 8.4.3.

7.5 Boundary conditions

7.5.1 For conditions 1 to 6, following boundary conditions are to be used (see Figure 7.5.1 and Table 7.5.1):

(1) Each node on two intersection lines between freeboard deck and outer plate is constrained by the displacement in *Z* direction;

(2) Two nodes at the fore and aft ends of the intersection line between freeboard deck and port outer plate are constrained by the displacement in *Y* direction;

(3) Two nodes at the aft end of the intersection line between freeboard deck and outer plate are constrained by the displacement in *X* direction;

(4) The rotation around the *Y*-axis is restrained at nodes at the fore and aft ends of bottom and deck girders.

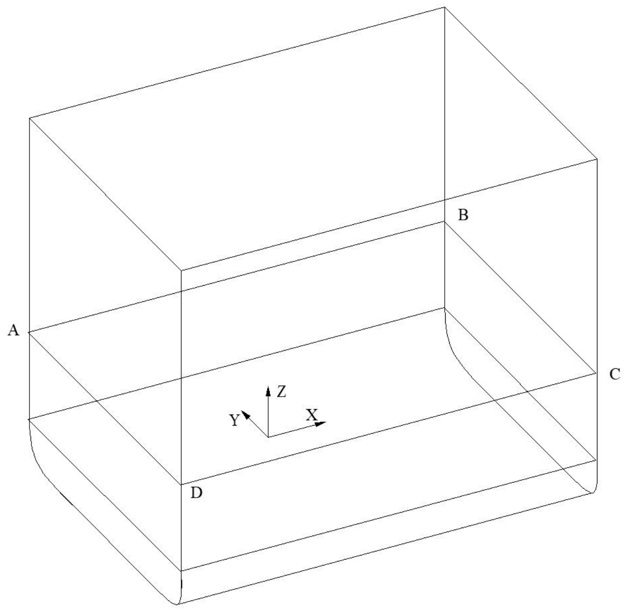


Figure 7.5.1 Positions for application of boundary conditions in conditions 1 to 6

Boundary conditions in conditions 1 to 6 **Table 7.5.1**

Restraint	$\delta_x = 0$	$\delta_y = 0$	$\delta_z = 0$	$\theta_y = 0$
Area affected	Points A and D	Points A and B	Lines AB and CD	Both ends of each girder

7.5.2 For condition 7, following boundary conditions are to be used (see Figure 7.5.2 and Table 7.5.2):

(1) Each node at the aft end of inner bottom plate is constrained by the displacement in *X* direction;

(2) Each node at side line of one side of inner bottom is constrained by the displacement in *Y* direction;

(3) Each node at the fore and aft ends of the side shell plating is constrained by the displacement in *Z* direction;

(4) The rotation around the *Y*-axis is restrained at nodes at the fore and aft ends of bottom and deck girders.

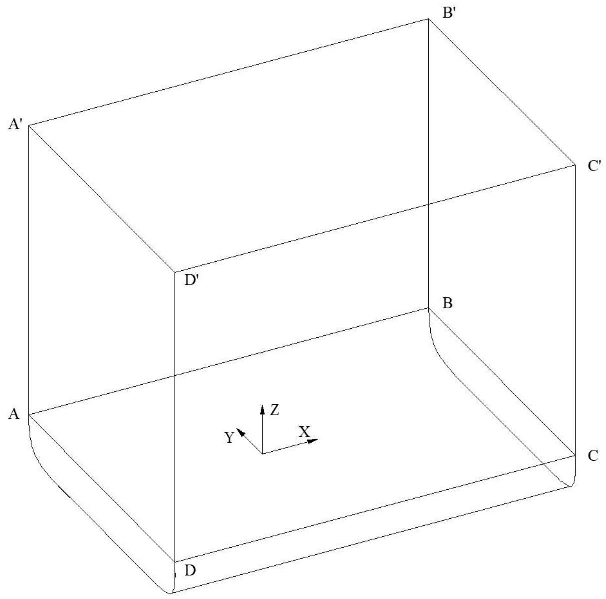


Figure 7.5.2 Positions for application of boundary conditions in condition 7

Boundary conditions in condition 7 **Table 7.5.2**

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

7.6 Yield stress assessment

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

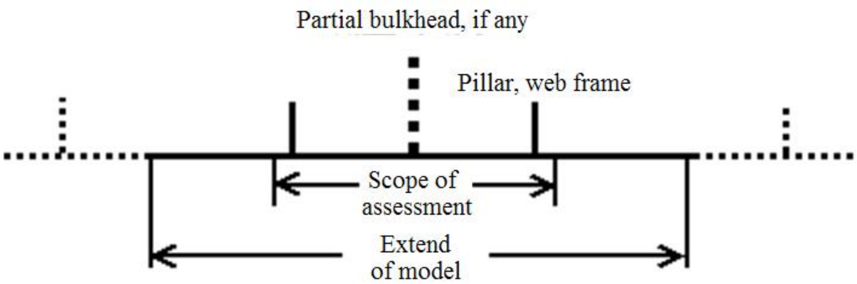


Figure 7.6.1 Assessment scope of finite element model

7.6.2 In the assessment, the von Mises equivalent stress at the mid plane in way of the center of the element is taken as the stress of plate element, and the absolute value of the axial stress is taken as the stress of beam element.

For deck girder, permissible stress $[\sigma_e] = 220 / K$

For other structure, permissible stress $[\sigma_e] = 235 / K$

where: K —— material factor.

7.7 Check of buckling strength

7.7.1 For hull structural panel, check of buckling strength is to be carried out based on stress result of direct calculation and according to the requirements of Section 4, Chapter 8, PART NINE of the Rules. The standard deduction of thickness is determined according to paragraph 2.5.2, Section 2 of the Guidelines. The permissible buckling utilization factor is taken as 0.95.

7.7.2 Other methods of buckling strength calculation can also be used if approved by CCS.

Section 8 DIRECT CALCULATION OF GLOBAL STRENGTH OF WHOLE SHIP STRUCTURE

8.1 General requirements

8.1.1 This Section gives requirements for hull structure strength assessment with global finite element model under racking condition.

8.2 Modeling of whole ship structure

8.2.1 When rolling, the members that resist the lateral loads include the transverse web frame, the partial bulkhead and the bulkhead at bow and stern. The global finite element model is to cover ship length, ship breadth and hull structure from baseline to top deck, and accurately describe all hull structures that resist the lateral loads. The requirements for mesh size and element of the finite element model are shown in 7.2.4.

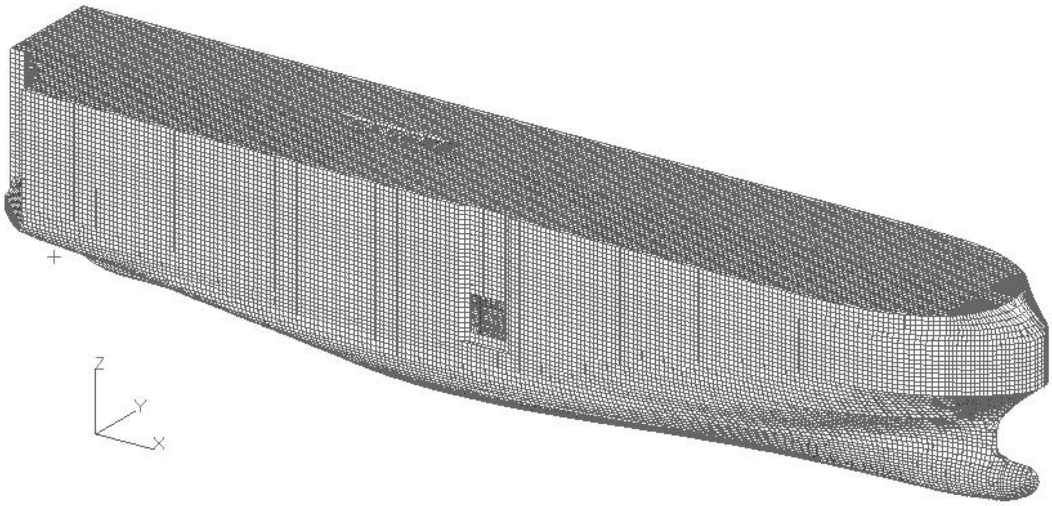


Figure 8.2.1 Global finite element model of a car carrier

8.3 Loading

8.3.1 The loading condition with the maximum racking moment is to be selected for racking load calculation. The racking moment is calculated according to the following formula:

$$M_x = \sum_{i=1}^{n} \left(m_{ci} + m_{si} \right) a_{yi} z_i \quad \text{kN·m}$$

where: n —— number of decks above freeboard deck;

m_{ci} —— mass of vehicles loaded on ith deck above freeboard deck, in t;

m_{si} —— mass of ith deck above freeboard deck, in t;

a_{yi} —— transverse acceleration at ith deck above freeboard deck, to be calculated according

to paragraph 1.5.2.2(6), Section 5, Chapter 1, PART TWO of the Rules;

z_i —— height from i[th] deck above freeboard deck to freeboard deck, in m.

8.3.2 Since loading at higher altitudes contributes more to the racking moment, the worst possible loading conditions may be determined by loading downwards from the topmost vehicle deck in accordance with its design capacity until only stability requirements can be met.
8.3.3 When the moving deck is not loaded, its mass is to be counted in the deck weight of the place where it is staying (such as the deck above it).

8.4 Conditions and loads
8.4.1 Racking conditions include left and right rolling conditions.

8.4.2 The wave load can be calculated by hydrodynamic analysis as follows:
(1) According to the selected loading, the mass distribution of the global finite element model is adjusted (by adjusting the mass characteristics of the model or defining loading in the software tool) as the mass distribution of the hydrodynamic analysis;
(2) The transverse acceleration at the height of midship top deck is selected as the load parameter, and the hydrodynamic analysis is carried out for each wave direction and frequency, and the rolling damping is set at 5%;
(3) The wave direction, frequency and phase of the design wave are determined by choosing the one with the largest amplitude of the transfer function of the transverse acceleration under the beam sea condition;
(4) The transverse acceleration at the height of midship top deck is calculated according to paragraph 1.5.2.2 (6), Section 5, Chapter 1, PART TWO of the Rules, and the amplitude of the design wave is obtained by combining the transfer function;
(5) The wave load under racking condition is obtained according to the design waves determined by (3) and (4), and the strength analysis load is obtained in combination with the static water load.
8.4.3 When there is no hydrodynamic analysis, the load is calculated according to the normative formula. The load includes the weight of the vehicle and hull structure, transverse inertia force of the vehicle and hull structure, and the outboard water pressure, as shown in Figure 8.4.3.
(1) The transverse uniformly distributed load of each vehicle deck is calculated according to following formula:

$$p_t = (p_c + m_s)a_t \quad \text{kN/m}^2$$

where: p_c —— vehicle deck loading, in t/m^2, determined according to the loading given in paragraph 8.3;

m_s —— see paragraph 7.4.2, Section 7;

a_t —— transverse composite acceleration, in m/s^2, calculated according to deck height, see paragraph 1.5.2.2(6), Section 5, Chapter 1, PART TWO of the Rules.

(2) The weight of vehicle and hull structure is applied according to loading;
(3) Outboard water pressure is the hydrostatic pressure corresponding to the maximum rolling angle under full load draught. The maximum rolling angle is calculated according to the provisions of paragraph 1.5.2, Section 5, Chapter 1, PART TWO of the Rules.

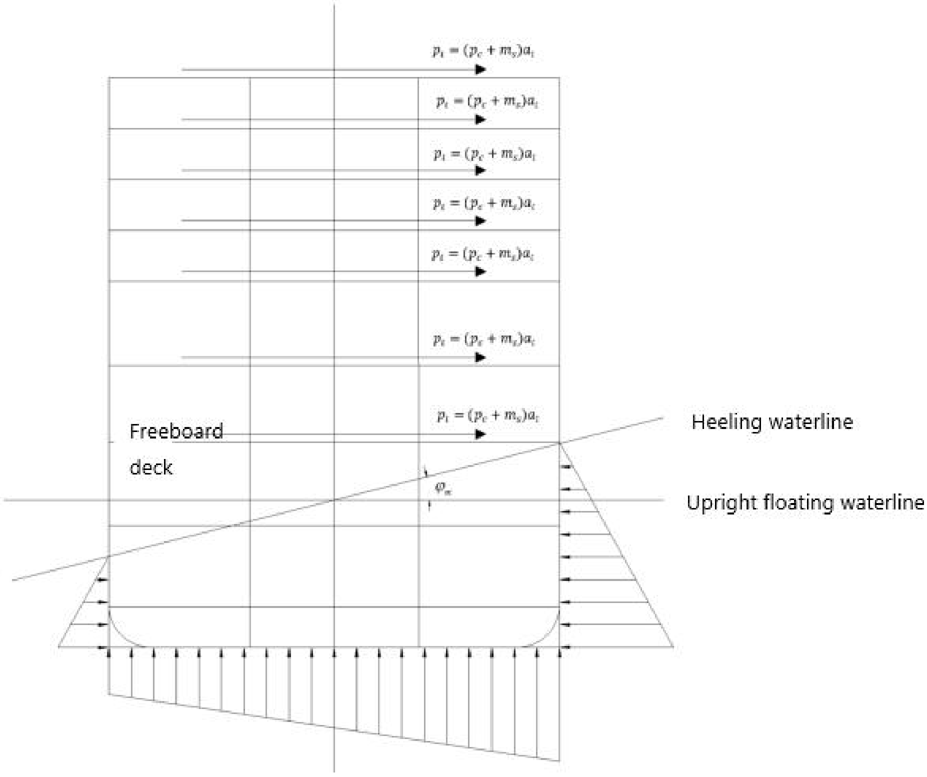


Figure 8.4.3 Normative load under racking condition

8.5 Model balance and boundary conditions

8.5.1 When the normative load in 8.4.3 is used for analysis, the following steps are taken in sequence to bring the model to an equilibrium state:

(1) Adjusting the draught to balance the vertical forces in the model;

(2) Adjusting the heeling angle and recalculating the outboard water pressure distribution, see 8.4.3(3), to balance the horizontal forces in the model;

(3) Checking the balance condition of the vertical force, and the vertical unbalanced force is not to be greater than 1% of the displacement. If it is not satisfied, the draught is to be further adjusted;

(4) Checking the balance condition of the transverse force, and the transverse unbalanced force is not to be greater than 1% of the displacement. If it is not satisfied, the heeling angle is to be further adjusted;

(5) Checking the longitudinal position of the buoyancy center and the gravity center, and the error between them is not to exceed 1% of the ship length. If it is not satisfied, the trimming angle is to be adjusted;.

(6) The unbalanced moment around X-axis in the model is eliminated by applying moment. A balance moment can be generated by applying a Z-node force opposite to the port and starboard on each node of the intersection line between the freeboard deck and the outer plate.

8.5.2 The displacement boundary conditions for direct calculation of the whole ship are shown in Table 8.5.2 and Figure 8.5.2.

Boundary constraints and their application **Table 8.5.2**

Constraint	$\delta_x = 0$	$\delta_y = 0$	$\delta_z = 0$
Application	Point 1	Points 1, 2	Points 2, 3, 4

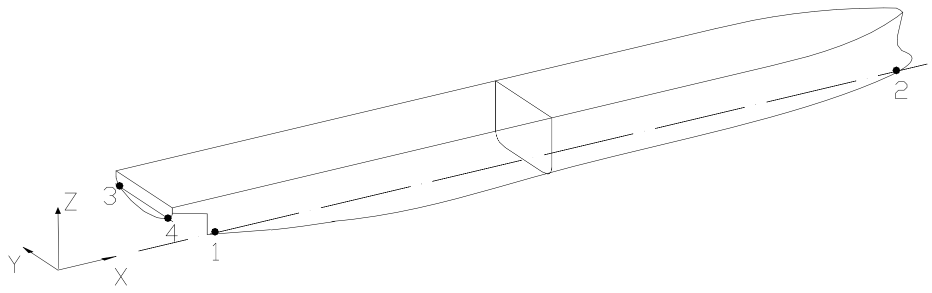


Figure 8.5.2 Boundary conditions for global analysis

8.6 Permissible stresses

8.6.1 The scope of structure assessment is to be based on the racking constraining structures throughout the ship, covering frames of partial bulkheads, web frames of pillars and ordinary web frames.

8.6.2 In the yield strength assessment, the von Mises equivalent stress at the mid plane in way of the center of the element is taken as the stress of plate element, and the absolute value of the axial stress is taken as the stress of beam element. The permissible stress $[\sigma_e] = 220 / K$

where: K —— material factor.

8.7 Check of buckling strength

8.7.1 For the requirements for buckling strength, see paragraph 7.7 of the Guidelines.

Section 9 FATIGUE STRENGTH

9.1 General requirements

9.1.1 This Section is applicable to the fatigue strength assessment for structural details of car carriers.

9.1.2 Fatigue assessment is based upon linear cumulative damage model, and the simplified stress analysis method of equivalent design wave and the global finite element stress analysis method are to be used for fatigue strength assessment.

9.1.3 As an alternative, finite element fatigue assessment can also be carried out in accordance with CCS Guidelines for the Fatigue Strength Assessment of Hull Structure Based on Spectrum Analysis.

9.1.4 The normative quasi-static wave load is based on the North Atlantic wave environment. It is determined by the equivalent design wave (EDW) corresponding to the probability level of 10^{-2}. If the ship operates mainly in a non-North Atlantic wave environment, the environmental factor f_e can be taken as 0.8.

9.1.5 The as-built thickness is adopted in modelling. In the simplified stress analysis, the corrosion correction factor f_c is according to the Guidelines for Fatigue Strength of Ship Structure. In finite element stress analysis, the corrosion correction factor f_c is taken as 1.0.

9.1.6 If not specified in this Section, the relevant requirements of CCS Guidelines for Fatigue Strength of Ship Structures are to be met.

9.2 Structure details for assessment

9.2.1 Simplified stress analysis method is to be adopted, and the critical structure details for fatigue assessment check within 0.5L amidship are:

(1) connection of longitudinal and transverse bulkhead ends;

(2) connection of longitudinal and floor or web frame ends.

9.2.2 The global finite element method is to be used for fatigue assessment of following components mainly constraining transverse deformation:

(1) connection of bulkhead, inner bottom plate and transverse web frame;

(2) connection of deck web frame flange and side web frame flange;

(3) connection of pillar and deck web frame flange;

(4) connection of pillar, inner bottom plate and solid floor;

(5) intersection of pillar in way of transverse bulkhead and vehicle deck;

(6) connection of front wall of engine room and main deck;

(7) opening corner of transverse bulkhead;

(8) connection of engine casing and bulkhead deck;

(9) connection of stairway/elevator enclosure and bulkhead deck;

(10) connection of other rigid structure (e.g. air duct wall) and deck;

(11) other high stress area.

9.3 Structural modeling

9.3.1 The methods for finite element hot spot stress analysis are applicable to fatigue strength assessment for both welded and non-welded details, taking into account structural discontinuities due to the structural detail of the welded joint, but not taking into account the notch effect at the weld toe.

9.3.2 Fatigue strength assessment based on finite element stress analysis is carried out by very fine mesh analysis. These very fine mesh models may be incorporated into the global model. Alternatively, this very fine mesh analysis can be carried out by means of sub-models with very fine mesh in conjunction with the boundary conditions obtained from a global model of the cargo holds.

9.3.3 For the requirements for global modelling adopted in fatigue strength assessment, see paragraph 8.2, Section 8.

9.3.4 For the requirements of very fine model of the details, see paragraph 5.2, Chapter 5 of Guidelines for Fatigue Strength of Ship Structures.

9.3.5 For model balance and boundary conditions, see paragraph 8.5, Section 8.

9.4 Loading condition and load case

9.4.1 In general, the loading conditions considered in fatigue strength analysis are full load conditions and normal ballast conditions, and the time distribution factor is shown in Table 9.4.1. The designer may also submit time distribution factor for approval by CCS.

Time distribution factor Table 9.4.1

Loading condition	Time distribution factor
Full load	0.5
Normal ballast	0.5

9.4.2 Under full load condition, the worst full load condition for rolling condition is to be selected from the Loading Manual.
9.4.3 In the fatigue analysis, two conditions of rolling to the left and rolling to the right are to be considered. The fatigue load can be calculated by hydrodynamic analysis or prescriptive load.
9.4.4 The specific method for calculating fatigue load through hydrodynamic analysis is shown in paragraph 8.4.2, Section 8, where the probability level of exceedance of load is taken as 10^{-2}. In general, the condition with the maximum transverse acceleration is selected as the predominant load case for fatigue analysis.
9.4.5 When the prescriptive load analysis is used, the load is to include the weight of the vehicle and the hull structure, the horizontal inertia force of the vehicle and the hull structure, and the external sea water pressure, as shown in Appendix 1 Fatigue Load Calculation.

9.5 Fatigue reference stress calculation
9.5.1 The fatigue reference stress is the relevant stress for fatigue assessment, i.e.
(1) Considering the maximum hot spot principal stress at the weld toe which is modified by average stress and thickness effect;
(2) Considering the local stress at free edge which is modified by base material surface finishing, average stress effect, thickness effect and material strength.
9.5.2 For hot spot stress ranges and hot spot mean stress based on finite element analysis, see paragraph 5.5, Chapter 5 of Guidelines for Fatigue Strength of Ship Structures.
9.5.3 For fatigue reference stress range, see paragraph 3.3, Chapter 3 of Guidelines for Fatigue Strength of Ship Structures.

9.6 Fatigue assessment
9.6.1 The survival probability of design S-N curve is 97.7%, which is applicable to mild steel and high tensile steel of minimum yield stress not more than 390 N/mm^2 . For steel with minimum yield strength greater than 390N/mm^2 or steel with improved fatigue properties, special consideration is to be given to the S-N curve.
9.6.2 For welded details, D curve is to be selected for fatigue strength assessment. For base material free edge, C curve is to be selected for fatigue strength assessment.
9.6.3 The fatigue damage of each fatigue loading condition (k) is calculated according to following formula:

$$D_k = \frac{N_D \alpha_k}{K} \frac{S_{D(k)}{}^m}{\left(\ln N_L\right)^{m/\xi_k}} \mu_k \Gamma\left(1+\frac{m}{\xi_k}\right)$$

where:

N_D—— total number of wave cycles experienced by the ship in design fatigue life, to be taken as

$$N_D = 31.557\times10^6\left(f_0 T_{DF}\right)\cdot\frac{2.3kr}{\sqrt{GM}}$$

f_0—— factor taking into account time at sea, excluding loading and unloading, maintenance, etc., f_0=0.85;

T_{DF}—— design fatigue life, specified by the designer;

α_k—— time distribution factor of each loading condition, see Table 9.4.1;

$S_{D(k)}$ —— fatigue reference stress range corresponding to probability level of exceedance 10^{-2}, in N/mm^2;

N_R—— number of cycles corresponding to probability level of exceedance 10^{-2};

N_R =100。

ξ_k—— Weibull shape parameter, ξ_k=1;

$\Gamma(x)$—— complete Gamma function;

K—— design S-N curve constant, see Table 9.6.3;

$\mu_{(k)}$—— factor that takes into account the change of S-N curve slope m.

$$\mu_{(k)} = 1 - \frac{\gamma\left(1+\frac{m}{\xi}, \nu_{(k)}\right) - \nu_{(k)}^{-\Delta m/\xi} \cdot \gamma\left(1+\left(\frac{m+\Delta m}{\xi}\right), \nu_{(k)}\right)}{\Gamma\left(1+\frac{m}{\xi}\right)}$$

$$\nu_{(k)} = \left(\frac{\Delta\sigma_q}{\Delta\sigma_{FS,(k)}}\right)^{\xi} \ln N_R$$

$\gamma(a,x)$—— incomplete Gamma function;

m —— inverse slope of S-N curve, taken as 3;

$\Delta\sigma_q$ —— the value of the stress range at the intersection of two line segments when the design S-N curve cycle number N=10^7, in N/mm^2, see Table 9.6.3;

Δm —— change of inverse slope of S-N curve at N=10^7 cycle.

Δm = 2

The value of the stress range at the intersection of two line segments

Table 9.6.3

S-N curve	K	$\Delta\sigma_q$
C	3.464×10^{12}	70.2305
D	1.520×10^{12}	53.3680

9.6.4 Total cumulative damage of structural details is to be calculated according to the following formula:

$$D = \sum D_k$$

where: D_k ——cumulative damage of structural details in each loading condition, see 9.6.3 of this Section.

9.6.5 Total cumulative damage D of structural details in its design service life is to meet the requirements of the following formula:

$$D \le 1$$

Appendix 1 FATIGUE LOAD CALCULATION

1 General Provisions

1 General requirements

1.1 Application

1.1.1 Scope of application

This Appendix provides design load for fatigue assessment.

1.1.2 Equivalent design wave

The dynamic loads associated with each dynamic load case are based on the Equivalent Design Wave (EDW) concept. The EDW concept applies a consistent set of dynamic loads to the ship such that specified dominant load response is equivalent to the required long term response value.

1.1.3 Probability level for fatigue assessments

Fatigue assessment means the fatigue assessment for the loads corresponding to the probability level of 10^{-2}.

1.1.4 Dynamic load components

All dynamic load components are to be concurrent values calculated for each dynamic load case.

1.1.5 Loads for fatigue assessment

Each design load scenario for fatigue assessment is composed of a Static + Dynamic (S+D) load case, where the static and dynamic loads are dependent on the loading condition being considered.

1.2 Definitions

1.2.1 Coordinate system

The geometric dimensions, loads and load effects of the ships are to be defined in the following right-hand coordinate system (see Figure 1.2.1).

Origin: At the intersection among longitudinal plane of symmetry of ship, the aft perpendicular of length and the baseline;

X-axis measured in the longitudinal direction, positive forward;

Y-axis measured in the transverse direction, positive to port from the centerline;

Z-axis measured in the vertical direction, positive upwards.

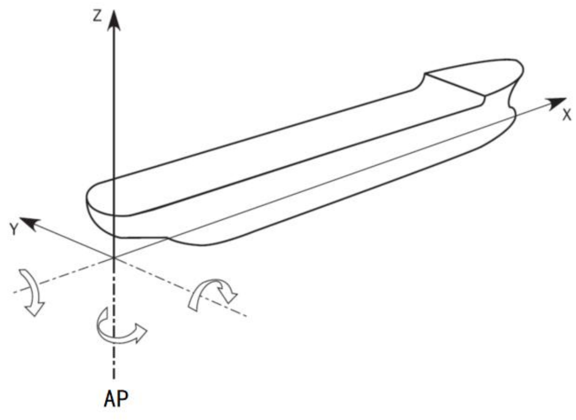


Figure 1.2.1 Reference coordinate system

1.2.2 Sign convention for ship motions

The ship motions are defined with respect to the ship's centre of gravity (COG) as shown in Figure 1.2.2, where:

• Positive surge is translation in the X-axis direction (positive forward);
• Positive sway is translation in the Y-axis direction (positive towards port side of ship);
• Positive heave is translation in the Z-axis direction (positive upwards);
• Positive roll motion is positive rotation about a longitudinal axis through the COG (starboard down and port up);
• Positive pitch motion is positive rotation about a transverse axis through the COG (bow down and stern up);
• Positive yaw motion is positive rotation about a vertical axis through the COG (bow moving to port and stern to starboard).

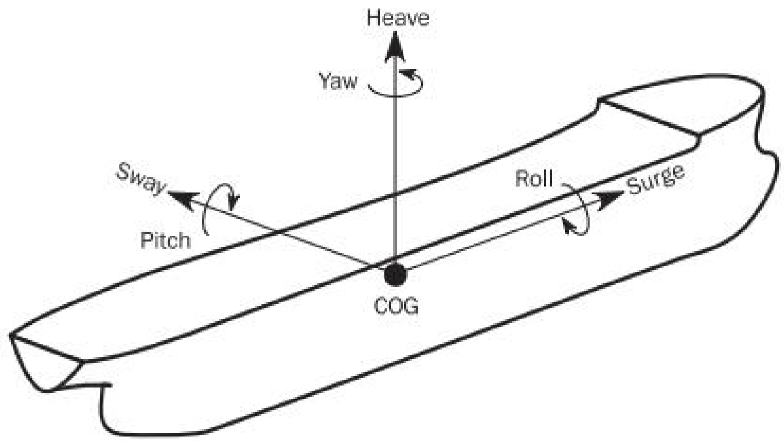


Figure 1.2.2 Definition of positive motions

2 Dynamic Load Cases

Symbols

a_{surge}, $a_{pitch\text{-}x}$, a_{sway}, $a_{roll\text{-}y}$, a_{heave}, $a_{roll\text{-}z}$, $a_{pitch\text{-}z}$: Acceleration components, as defined in Section 3 of this Appendix;

f_{xL} — ratio between X-coordinate of the load point and L, to be taken as:

$$f_{xL} = \frac{x}{L}$$, but not to be taken less than 0.0 or greater than 1.0.

f_{TL} — ratio between draught at a loading condition and L, to be taken as:

$$f_{TL} = \frac{T_{LC}}{L}$$

f_{lp} — factor depending on longitudinal position along the ship, to be taken as:

$f_{lp} = 1$, for $x/L \le 0.4$

$f_{lp} = -1$, for $x/L \ge 0.6$

Intermediate values of f_{lp} are obtained by linear interpolation.

WS— weather side, side of the ship exposed to the incoming waves.

LS— lee side, sheltered side of the ship away from the incoming waves.
M_{wv}— vertical wave bending moment, in kNm.
Q_{wv} — vertical wave shear force, in kN.
M_{wh} — horizontal wave bending moment, in kNm.
Q_{wh}— horizontal wave shear force, in kN.
LCF—combination factor to be applied to dynamic load cases.
C_{WV}— load combination factor to be applied to the vertical wave bending moment.
C_{QW}— load combination factor to be applied to the vertical wave shear force.
C_{WH}— load combination factor to be applied to the horizontal wave bending moment.
C_{QH}— load combination factor to be applied to the horizontal wave shear force.
C_{XS}— load combination factor to be applied to the surge acceleration.
C_{XP}— load combination factor to be applied to the longitudinal acceleration due to pitch.
C_{XG}— load combination factor to be applied to the longitudinal acceleration due to pitch motion.
C_{YS}— load combination factor to be applied to the sway acceleration.
C_{YR}— load combination factor to be applied to the transverse acceleration due to roll.
C_{YG}— load combination factor to be applied to the transverse acceleration due to roll motion.
C_{ZH}— load combination factor to be applied to the heave acceleration.
C_{ZR}— load combination factor to be applied to the vertical acceleration due to roll.
C_{ZP}— load combination factor to be applied to the vertical acceleration due to pitch.
θ— roll angle, in deg, as defined in 2.1.1, Section 3 of this Appendix.
φ— pitch angle, in deg, as defined in 2.1.2, Section 3 of this Appendix.
ω_R— roll angle frequency, to be taken as:

$$\omega_R = \frac{2\pi}{T_\theta}, \ \text{rad/s}$$

T_R— roll period non-dimensional coefficient, to be taken as:

$$T_R = T_\theta \sqrt{g/L}$$

T_θ — roll period, as defined in 2.1.1, Section 3 of this Appendix.

1 General requirements

1.1 Definition of dynamic load cases

1.1.1 The following Equivalent Design Waves (EDW) are to be used to generate the dynamic load cases for fatigue assessment:
(1) BSR load cases:
BSR-1P and BSR-2P: Beam sea EDWs that minimize and maximize the roll motion downward and upward on the port side respectively with waves from the port side.
BSR-1S and BSR-2S: Beam sea EDWs that maximize and minimize the roll motion downward and upward on the starboard side respectively with waves from the starboard side.

1.2 Application

1.2.1 These dynamic load cases are to be applied to the following structural assessments:
(1) Fatigue assessment:

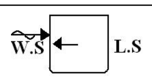
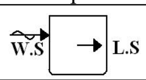
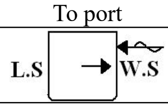
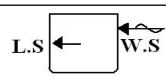
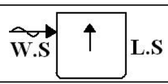
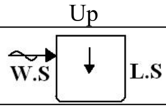
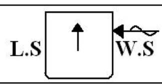
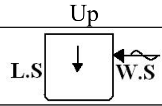
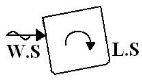
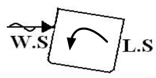
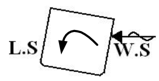
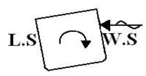
- For structural details covered by simplified stress analysis;
- For structural details covered by FE stress analysis.

2 Dynamic load cases for fatigue assessment

2.1 Description of dynamic load cases

2.1.1 Table 1.1.1 describes the ship motion responses and the global loads corresponding to each dynamic load case to be considered for the fatigue assessment.

Ship responses for BSR load case - Fatigue assessment **Table 2.1.1**

Load case	BSR-1P	BSR-2P	BSR-1S	BSR-2S
EDW	BSR		BSR	
Heading	Beam			
Effect	Maximum rolling			
VWBM	-	-	-	-
VWSF	-	-	-	-
HWBM	Starboard tensile	Port tensile	Port tensile	Starboard tensile
HWSF	-	-	-	-
TM	-	-	-	-
Surge	-	-	-	-
a_{surge}	-	-	-	-
Sway	To starboard	To port	To port	To starboard
a_{sway}				
Heave	Down	Up	Down	Up
a_{heave}				
Roll	Port down	Port up	Starboard down	Starboard up
a_{roll}				
Pitch	-	-	-	-
a_{pitch}	-	-	-	-

2.2 Load combination factor

3.2.1 The load combination factor LCF for the global loads and inertia load components for fatigue assessment is defined in Table 2.2.1: LCF for BSR load case.

Load combination factor LCF for BSR load case - Fatigue assessment **Table 2.2.1**

Load component		LCF	BSR-1P	BSR-2P	BSR-1S	BSR-2S
Hull girder loads	M_{wv}	C_{WV}	0	0	0	0
	Q_{wv}	C_{QW}	0	0	0	0
	M_{wh}	C_{WH}	1.3-16f_{TL}	16f_{TL}-1.3	16f_{TL}-1.3	1.3-16f_{TL}
	Q_{wh}	C_{QH}	0	0	0	0
Longitudinal accelerations	a_{surge}	C_{XS}	0	0	0	0
	$a_{pitch-x}$	C_{XP}	0	0	0	0
	$g\sin\varphi$	C_{XG}	0	0	0	0
Transverse	a_{sway}	C_{YS}	0.74-1.72 ω_R	1.72 ω_R-0.74	1.72 ω_R-0.74	0.74-1.72 ω_R

Load component		LCF	BSR-1P	BSR-2P	BSR-1S	BSR-2S
accelerations	a_{roll-y}	C_{YR}	1	-1	-1	1
	$g\sin\theta$	C_{YG}	-1	1	1	-1
Vertical accelerations	a_{heave}	C_{ZH}	0.8-11.8f_{TL}	11.8f_{TL}-0.8	0.8-11.8f_{TL}	11.8f_{TL}-0.8
	a_{roll-z}	C_{ZR}	1	-1	-1	1
	$a_{pitch-z}$	C_{ZP}	0	0	0	0

3 Ship Motion and Acceleration

Symbols

a_0— acceleration parameter, to be taken as:

$$a_0 = (1.58 - 0.47C_b)\left(\frac{2.4}{\sqrt{L}} + \frac{34}{L} - \frac{600}{L^2}\right)$$

T_θ— roll period, in s, as defined in 2.1.1 of this Section.

θ— roll angle, in deg, as defined in 2.1.1 of this Section.

T_φ— pitch period, in s, as defined in 2.1.2 of this Section.

φ— pitch angle, in deg, as defined in 2.1.2 of this Section.

R— vertical coordinate, in m, of the ship rotation centre, to be taken as:

$R = 6.7322e^{0.0419D}$, for full load condition

$R = 0.9858D^{0.7733}$, for ballast condition

a_{roll-y}— transverse acceleration due to roll, in m/s², as defined in 3.3.2 of this Section.

$a_{pitch-x}$— longitudinal acceleration due to pitch, in m/s², as defined in 3.3.1 of this Section.

a_{roll-z}— vertical acceleration due to roll, in m/s², as defined in 3.3.3 of this Section.

$a_{pitch-z}$— vertical acceleration due to pitch, in m/s², as defined in 3.3.3 of this Section.

f_T— ratio between draught at a loading condition and scantling draught, to be taken as:

$f_T = \frac{T_{LC}}{T_{SC}}$, but is not to be taken less than 0.5.

T_{LC}— draught, in m, amidships for the considered loading condition.

f_{BL}— ratio between ship breadth and rules length, to be taken as:

$$f_{BL} = \frac{B}{L}$$

x, y, z—*X*, *Y* and *Z* coordinates, in m, of the considered point with respect to the coordinate system, as defined in 1.2.1, Section 1 of this Appendix.

x_G— longitudinal coordinate of center of gravity of ship, in m, to be taken as:

$x_G = 0.55C_{b-LC}^{0.37}L$, when $C_{b-LC}=C_b$

$x_G = 0.51C_{b-LC}^{0.14}L$, when $C_{b-LC}=C_{b-BAL}$

C_{b-LC}— block coefficient for the considered loading condition, as defined in Table 2.1.1.

$C_{W\text{-}LC}$— waterplane coefficient for the considered loading condition, as defined in Table 2.1.1.

f_{fa}— fatigue coefficient, to be taken as:

$$f_{fa} = 0.9$$

f_{nl}— non-linear coefficient, to be taken as 1.0.

1 General requirements

1.1 Definition

1.1.1 The ship motions and accelerations are assumed to be sinusoidal. The motion values defined by the formulae in this section are single amplitudes, i.e. half of the 'crest to trough' height.

2 Ship motions and accelerations

2.1 Ship motions

2.1.1 Roll motion

The roll period T_θ, in s, to be taken as:

$$T_\theta = \frac{2.3\pi\, k_r}{\sqrt{gGM}}$$

The roll angle θ, in deg, to be taken as:

$$\theta = \frac{9000(1.25 - 0.025T_\theta) f_p f_{BK}}{(B+75)\pi}$$

where:

f_p— coefficient to be taken as:

$$f_p = f_{fa}(0.24 - 5.56 f_T B \times 10^{-4}) \quad \text{for fatigue assessment;}$$

f_{RO}— navigation factor, to be taken as:

$$f_{RO} = 0.78$$

f_{BK}— to be taken as:

$f_{BK} = 1.2$ for ships without bilge keel;

$f_{BK} = 1.0$ for ships with bilge keel;

$f_{BK} = 0.8$ for ships with active stabilizer;

k_r— roll radius of gyration, in m, in the considered loading condition. The values in Table 2.1.1 are to be adopted;

GM— metacentric height, in m, in the considered loading condition. The values in Table 2.1.1 are to be adopted.

K_r and GM values **Table 2.1.1**

Loading condition	T_{LC}	k_r	GM	$C_{b\text{-}LC}$	$C_{W\text{-}LC}$
Full load condition	T_{SC}	0.35B	Actual value	C_b	C_W
Ballast condition	T_{BAL}	0.45B	Actual value	$C_{b\text{-}BAL}$	$C_{W\text{-}BAL}$

2.1.2 Pitch motion

The pitch period T_φ, in s, to be taken as:

$$T_\varphi = \sqrt{\frac{2\pi\lambda_\varphi}{g}}$$

where: $\lambda_\varphi = 0.6(1 + f_T)L$

The pitch angle φ, in deg., to be taken as:

$$\varphi = 1350 f_{nl} f_p f_\varphi L^{-0.94} \left\{ 1.0 + \left(\frac{2.57}{\sqrt{gL}} \right)^{1.2} \right\}$$

where:

f_p— coefficient to be taken as:

$$f_p = f_{RO} f_{fa} \left[\left(0.34 - 0.05 f_T\right) - \left(3.7 - 2.59 f_T\right) L \times 10^{-4} \right],$$ for fatigue assessment

f_{RO}— navigation factor, to be taken as:

$f_{RO}=0.78$

f_φ— coefficient to be taken as:

$f_\varphi=2.27-1.38C_{W-LC}$ for fatigue assessment

2.2 Ship accelerations at the centre of gravity

2.2.1 Surge acceleration

The longitudinal acceleration due to surge, in m/s^2, is to be taken as:

$$a_{surge} = 0.2 f_p f_{s1} f_{nl} a_0 g$$

where:

f_p— coefficient to be taken as:

$f_p = f_{fa}(0.26-1.11 f_T L \text{x} 10^{-4})$ for fatigue assessment

f_{s1}— coefficient to be taken as:

$f_{s1}=22.3f_{TL}+0.3$ for full load condition for fatigue assessment

$f_{s1}=35.2f_{TL}+0.81$ for ballast condition for fatigue assessment

2.2.2 Sway acceleration

The transverse acceleration due to sway, in m/s^2, is to be taken as:

$$a_{sway} = 0.3 f_p f_{s2} f_{nl} a_0 g$$

where:

f_p— coefficient to be taken as:

$f_p = f_{fa}[(0.28-0.02f_T)-(9.6-5.1f_T)B\text{x}10^{-4}]$ for fatigue assessment

f_{s2}— coefficient to be taken as:

$f_{s2}=2.16-5.98f_{TL}$ for fatigue assessment

2.2.3 Heave acceleration

The vertical acceleration due to heave, in m/s^2, is to be taken as:

$$a_{heave} = f_p f_{s3} f_{nl} a_0 g$$

where:

f_p— coefficient to be taken as:

$f_p = f_{fa}[(0.34+0.09f_T)-(1.86+2.59f_T)L\text{x}10^{-4}]$, for fatigue assessment

f_{s3}— coefficient to be taken as:

$f_{s3}=1.25-1.62f_{BL}$, for fatigue assessment

2.2.4 Roll acceleration

The roll acceleration, a_{roll}, in rad/s^2, is to be taken as:

$$a_{roll} = f_p f_{s4} \theta \frac{\pi}{180} \left(\frac{2\pi}{T_\theta} \right)^2$$

where:

θ — roll angel using f_p equal to 1.0

f_p — coefficient to be taken as:

$f_p = f_{fa}\left(0.24 - 6.67 f_T B \times 10^{-4}\right)$ for fatigue assessment

f_{s4}— coefficient to be taken as:

$f_{s4}=1.0$ for fatigue assessment

2.2.5 Pitch acceleration

The pitch acceleration, a_{pitch}, in rad/s^2, is to be taken as:

$$a_{pitch} = f_p f_{s5} f_{nl}\left(\frac{3.1}{\sqrt{gL}} + 1.0\right)\varphi\frac{\pi}{180}\left(\frac{2\pi}{T_\varphi}\right)^2$$

where:

φ — pitch angel using f_p equal to 1.0

f_p — coefficient to be taken as:

$f_p = f_{fa}\left[(0.42 - 0.05 f_T) - (9 + 2 f_T) L \times 10^{-5}\right]$ for fatigue assessment

f_{s5}—coefficient to be taken as:

$f_{s5}=5.75-6.87 f_{BL}^{0.2} C_{b-LC}^{0.2}$ for full load condition for fatigue assessment

$f_{s5}=3.72-4.75 f_{BL}^{0.2} C_{b-LC}^{0.5}$ for ballast condition for fatigue assessment

3 Acceleration at any position

3.1 General

3.1.1 The accelerations used to derive the inertial loads at any position are defined with respect to the ship fixed coordinate system. Hence the acceleration values defined in 3.2 and 3.3 include the gravitational acceleration components due to the instantaneous roll and pitch angles.

3.1.2 The accelerations to be applied for the dynamic load cases defined in Section 2 of this Appendix are given in 3.2.

3.2 Accelerations for dynamic load cases

3.2.1 General

The accelerations to be applied for the dynamic load cases defined in Section 2 of this Appendix are given in 3.2.2 to 3.2.4.

3.2.2 Longitudinal acceleration

The longitudinal acceleration at any position for each dynamic load case, in m/s^2, is to be taken as:

$$a_X = -C_{XG} g \sin\varphi + C_{XS} a_{surge} + C_{XP} a_{pitch}(z - R)$$

3.2.3 Transverse acceleration

The transverse acceleration at any position for each dynamic load case, in m/s^2, is to be taken as:

$$a_Y = C_{YG} g \sin\theta + C_{YS} a_{sway} - C_{YR} a_{roll}(z - R)$$

3.2.4 Vertical acceleration

The vertical acceleration at any position for each dynamic load case, in m/s^2, is to be taken as:

$$a_Z = C_{ZH} a_{heave} + C_{ZR} a_{roll} y - C_{ZP} a_{pitch}(x - x_G)$$

3.3 Envelope accelerations

3.3.1 Longitudinal acceleration

The envelope longitudinal acceleration, $a_{x\text{-}env}$, in m/s^2 , at any position, is to be taken as:

$$a_{x-env} = 0.7\sqrt{a_{surge}^2 + \left[\frac{L}{325}\left(g\sin\varphi + a_{pitch-x}\right)\right]^2}$$

where:

$a_{pitch\text{-}x}$— longitudinal acceleration due to pitch, in m/s^2

$$a_{pitch-x} = a_{pitch}\left(z - R\right)$$

3.3.2 Transverse acceleration

The envelope transverse acceleration, $a_{y\text{-}env}$, in m/s^2 , at any position, is to be taken as:

$$a_{y-env} = \sqrt{a_{sway}^2 + \left(g\sin\theta + a_{roll-y}\right)^2}$$

where:

$a_{roll\text{-}y}$— transverse acceleration due to roll, in m/s^2

$$a_{roll-y} = a_{roll}\left(z - R\right)$$

3.3.3 Vertical acceleration

The envelope vertical acceleration, $a_{z\text{-}env}$, in m/s^2 , at any position, is to be taken as:

$$a_{z-env} = \sqrt{a_{heave}^2 + \left(\left(0.3 + \frac{L}{325}\right)a_{pitch-z}\right)^2 + \left(1.2a_{roll-z}\right)^2}$$

where:

$a_{pitch\text{-}z}$— vertical acceleration due to pitch, in m/s^2

$$a_{pitch-z} = a_{pitch}\left(x - x_G\right)$$

$a_{roll\text{-}z}$— vertical acceleration due to roll, in m/s^2

$$a_{roll-z} = a_{roll}\, y$$

4 External Loads

Symbols

λ— wave length, in m.

B_x— moulded breadth at the waterline, in m, at the considered cross section.

f_{yB}— ratio between Y-coordinate of the load point and B_x, to be taken as:

$$f_{yB} = \frac{|2y|}{B_x}$$, but not greater than 1.0, and when $B_x = 0.0$ $f_{yB} = 0.0$

f_{yB1}— ratio between Y-coordinate of the load point and B, to be taken as:

$$f_{yB1} = \frac{|2y|}{B}$$, but not greater than 1.0

C_s— wave coefficient

$$C_s = 10.75 - \left(\frac{300 - L}{100}\right)^{1.5}$$ for ships of 90m≤L≤300m

$P_{W,WL}$— wave pressure at the waterline, in kN/m^2, for the considered dynamic load case.

$$P_{W,WL} = P_W \quad , z = T_{LC}$$

h_W— water head equivalent to the pressure at waterline, in m, to be taken as:

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

1 Sea pressure

1.1 Total pressure

1.1.1 The external pressure P_{ex} at any load point of the hull is to be derived from each dynamic load case and is to be taken as:

$$P_{ex} = P_S + P_W \text{ but not less than 0}$$

where:

P_S— hydrostatic pressure, in kN/m^2, defined in 1.2;

P_W— wave pressure, in kN/m^2, defined in 1.3.

1.2 Hydrostatic pressure

1.2.1 The hydrostatic pressure, P_S at any load point, in kN/m^2, is obtained from Table 1.2.1. See also Figure 1.2.1.

Hydrostatic pressure P_S **Table 1.2.1**

Location	Hydrostatic pressure, P_S, in kN/m^2
$z \le T_{LC}$	$\rho g(T_{LC} - z)$
$z > T_{LC}$	0

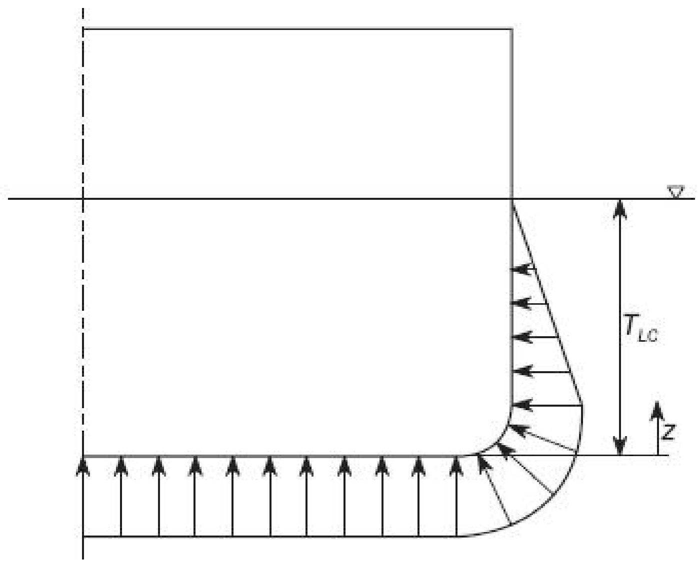


Figure 1.2.1 Hydrostatic pressure, P_S

1.3 External dynamic pressures for fatigue assessment

1.3.1 General

The external pressure P_{ex} at any load point of the hull for the fatigue static plus dynamic (F:S+D) design load scenario, is to be derived for each fatigue dynamic load case and is to be taken as:

$$P_{ex} = P_S + P_W \quad \text{but not less than 0}$$

where:

P_S— hydrostatic pressure, in kN/m^2, defined in1.2;

P_W— hydrodynamic pressure, in kN/m^2, defined in 1.4.2 to 1.4.8.

1.3.2 Hydrodynamic pressures for BSR load cases

The hydrodynamic pressures, P_W, for load cases BSR-1 and BSR-2, at any load point, in kN/m^2, are to be obtained from Table 1.4.4.

Hydrodynamic pressures for BSR load cases Table 1.4.4

Load case	Hydrodynamic pressure, in kN/m^2		
	$z \le T_{LC}$	$T_{LC} < z \le 2h_W + T_{LC}$	$z > 2h_W + T_{LC}$
BSR-1P	$P_W = \max(P_{BSR}, \rho g(z-T_{LC}))$	$P_W = P_{W,WL} - \frac{1}{2}\rho g(z - T_{LC})$	$P_W = 0$
BSR-2P	$P_W = \max(-P_{BSR}, \rho g(z-T_{LC}))$		
BSR-1S	$P_W = \max(P_{BSR}, \rho g(z-T_{LC}))$		
BSR-2S	$p_W = \max(-P_{BSR}, \rho g(z-T_{LC}))$		

where:

for BSR-1P and BSR-2P,

$$P_{BSR} = 10y\sin\theta + 0.88 f_p C_s \sqrt{\frac{L_0 + \lambda - 125}{L}}\left(f_{yB1} + 1\right)$$

for BSR-1S and BSR-2S,

$$P_{BSR} = -10y\sin\theta + 0.88 f_p C_s \sqrt{\frac{L_0 + \lambda - 125}{L}}\left(f_{yB1} + 1\right)$$

f_p—— coefficient to be taken as:

$$f_p = f_{fa}\left[\left(0.21 + 0.04 f_T\right) - \left(12 f_T - 2\right)B \times 10^{-4}\right]$$

λ —— wave length of the dynamic load case, in m, to be taken as:

$$\lambda = \frac{g}{2\pi} T_\theta^2$$

5 Internal Loads

Symbols

For symbols not defined in this section, refer to Section 4, Chapter 1.

Z_{top}— Z coordinate of the highest point of tank, excluding small hatchways, in m.

ρ_L— density of liquid in the tank, in t/m^3, but not less than:

ρ_L=0.98， for fuel oil

ρ_L=1.025，for other liquids

f_β— heading correction factor, to be taken as:

f_β =1.0

1 Pressures due to liquids

1.1 Application

1.1.1 Pressures for fatigue assessments

The internal pressure due to liquid acting on any load point of a tank boundary, in kN/m^2, is to be derived for each dynamic load case and is to be taken as:

$$P_{in} = P_{ls} + P_{ld}\text{, but not less than 0.}$$

where:

P_{ls}— static pressure due to liquid in tanks, in kN/m^2, as defined in 1.2;

P_{ld}— dynamic pressure due to liquid in tanks, in kN/m^2, as defined in 1.3.

1.2 Static liquid pressure

1.2.1 Static liquid pressure for the fatigue assessment

The static pressure due to liquid in tanks, P_{ls} to be used for the fatigue assessment, in kN/m^2, is to be taken as:

$$P_{ls} = \rho_L g(z_{top} - z)$$ for all tanks (ballast tanks, fuel oil tanks and other liquid tanks).

1.3 Dynamic liquid pressure

1.3.1 The dynamic pressure due to liquid in tanks, P_{ld} , in kN/m^2, is to be taken as:

$$P_{ld} =[f_\beta \rho_L a_Z (z_0 - z) + a_X (x_0 - x) + a_Y (y_0 - y)]$$

x_0— X coordinate, in m, of the reference point;

y_0— Y coordinate, in m, of the reference point;

z_0— Z coordinate, in m, of the reference point.

The reference point is to be taken as the point with the highest value of V_j , calculated for all points that define the upper boundary of the tank as follows:

$$V_j = a_X\left(x_j - x_G\right) + a_Y\left(y_j - y_G\right) + \left(a_Z + g\right)\left(z_j - z_G\right)$$

where:

x_j— X coordinate, in m, of the point j on the upper boundary of the tank;

y_j— Y coordinate, in m, of the point j on the upper boundary of the tank;

z_j— Z coordinate, in m, of the point j on the upper boundary of the tank.

2 Cargo load

2.1 Cargo load

Loads acting on the vehicle decks are to be calculated in accordance with the following formulae:

X direction: $P_X = -Pa_X$ kN/m^2

Y direction: $P_Y = -Pa_Y$ kN/m^2

Z direction: $P_C = -f_z Pg - Pa_Z$ kN/m^2

where: P —— actual load on the vehicle deck, in t/m^2 ;

a_X , a_Y , a_Z —— gravitational acceleration of vehicles in cargo hold, in m/s^2 ;

f_z —— vertical static load factor of vehicle deck, to be calculated according to the following formula:

$f_z = \cos\theta$, for R1P, R1S, R2P and R2S conditions

where: θ —— maximum rolling angle, see 2.3.1 of this Appendix.

3 Loads on non-exposed decks and platforms other than cargo hold area

3.1 Application

3.1.1 General requirements

The loads defined in 3.2 and 3.3 are applicable to non-exposed decks, accommodation decks and platforms.

3.2 Pressure due to distributed load

3.2.1 If a distributed load is carried on a deck, the static and dynamic pressures due to this distributed load are to be considered.

The static distributed load is to be defined by the designer without being less than 3 kN/m^2 for accommodation decks and 10 kN/m^2 for other decks and platforms.

The pressure P_{dl}, in kN/m^2, due to this distributed load is to be derived for the envelope of dynamic load cases and is to be taken as:

$$P_{dl} = P_{dl-s} + P_{dl-d} \quad \text{but not less than 0}$$

where:

P_{dl-s}— static pressure, in kN/m^2, due to the distributed load;

P_{dl-d}— dynamic pressure, in kN/m^2, due to the distributed load, to be taken as:

$$P_{dl-d} = f_\beta \frac{a_{Z\text{-env}}}{g} P_{dl-s}$$

a_{z-env}— envelope of vertical acceleration, in m/s^2, at the load position being considered, for the dynamic load cases, given in 3.3.3, Section 3 of this Appendix.

3.3 Concentrated force due to unit load

3.3.1 If a unit load is carried on an internal deck, the static and dynamic forces due to the unit load carried are to be considered. The force F_U, in kN, due to this concentrated load is to be derived for the envelope of dynamic load cases and is to be taken as:

$$F_U = F_{U-s} + F_{U-d} \quad \text{but not less than 0}$$

where:

F_{U-s}— static force, in kN, due to the unit load to be taken as $F_{U-s}=m_U g$.

F_{U-d}— dynamic force, in kN, due to unit load to be taken as $F_{U-d}=m_U f_\beta a_{z-env}$.

m_U— mass of the unit load carried, in t.

$a_{z\text{-}env}$— envelope of vertical acceleration, in m/s^2, at the centre of gravity of the unit load carried for the dynamic load cases, given in 3.3.3, Section 3 of this Appendix.