Guidance document
GD 14 -2023

CHINA CLASSIFICATION SOCIETY

GUIDELINES FOR STRUCTURE OF NON-HIGH-SPEED ALL-ALUMINUM ALLOY SEA-GOING SHIPS

2023

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Beijing

CONTENTS

CHAPTER 1 GENERAL PROVISIONS

1.1 General requirements

1.1.1 These Guidelines are applicable to the following sea-going ships of 20 meters and above in length and engaged in restricted service that are not high-speed and whose main hull is made of aluminum alloy:

(1) passenger ship;

(2) ferry;

(3) traffic ship;

(4) public affair ship.

1.1.2 The hull material and welding are to meet the applicable requirements of CCS Rules for Materials and Welding or other standards accepted by CCS.

1.1.3 The design of hull welds is to meet the requirements of Section 12, Chapter 4 of CCS Rules for Construction and Classification of Sea-going High Speed Craft.

1.1.4 Equivalence or substitution to those methods of calculation, criteria and means of evaluation specified by these Guidelines may be accepted subject to agreement of CCS, when relevant tests, theoretical basis or service experience are provided. CCS also accepts other recognized standards as equivalent standards.

1.1.5 The "ALY" notation may be assigned to non-high-speed aluminum alloy ships that meet the requirements of these Guidelines.

1.1.6 Those not specified in these Guidelines are to comply with the relevant provisions of PART TWO of CCS Rules for Classification of Sea-going Steel Ships.

1.2 Plans and documents

1.2.1 Plans and documents are to comply with the requirements of Section 1, Chapter 2, PART TWO of CCS Rules for Classification of Sea-going Steel Ships.

1.3 Definitions and symbols

1.3.1 Unless expressly provided otherwise, for the purpose of these Guidelines:

(1) Non-high-speed means the maximum speed V is less than $3.7\nabla^{0.1667}$ m/s.

(2) Maximum speed V is the speed, in kn, achieved at the maximum continuous propulsion power for which the ship is certified at its full-load displacement and in smooth water.

(3) Full load displacement Δ, in t, is the weight of sea water displaced by a ship floating on an even keel under a full loaded condition.

(4) Full load displacement volume ∇, in m^3, is the volume of sea water displaced by a ship under a full loaded condition.

(5) Length L is the rule length, in m, i.e. the distance measured on the waterline at the scantling draught, from the forward side of the stem to the after side of the rudder post, or to the centre of

the rudder stock where there is no rudder post. L is to be not less than 96% and need not exceed 97% of the extreme length on the waterline at the scantling draught. In ships with unusual stem or stern arrangements, the rule length L is to be specially considered. In ships without rudder stock (e.g. ships fitted with azimuth thrusters), the rule length L is to be taken equal to 97% of the extreme length on the waterline at the scantling draught.

(6) Breadth B is the maximum moulded breadth, in m, measured amidships at the scantling draught. For multihull ships, B means the sum of the maximum breadth of each hull at the waterline corresponding to the scantling draught.

(7) Moulded depth D (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 uppermost continuous deck. When a rounded gunwale is arranged, the moulded depth is to be measured to the point of intersection of the continued moulded lines of the deck and side shell plating.

(8) Draught T is the scantling draught, in m, i.e. the vertical distance measured at the middle of the length L from top of keel to the waterline at the scantling draught. At scantling draught, the strength requirements for the scantlings of the ship are met and represents the full load condition. The scantling draught is to be not less than that corresponding to the assigned freeboard.

(9) Block coefficient C_B means a ship form coefficient calculated according to the following:

$$C_B = \frac{\nabla_1}{LBT}$$

where: ∇_1——moulded displacement volume at the scantling draught, in m^3.

(10) Uppermost continuous deck is the uppermost deck which extends from the stem to the stern.

(11) Bulkhead deck is the highest deck to which the transverse watertight bulkheads extend.

(12) Reference coordinate system: the origin is taken as the intersection of a perpendicular at the end of the full-load waterline with the baseline in way of longitudinal centerline, and x, y and z are considered positive respectively in the forward, left and up directions.

(13) Amidships means at half length of L.

(14) Strength deck means: ① the uppermost continuous deck; ② the superstructure deck extending within $0.5L$ amidships, and having a length not less than $0.15L$, and the uppermost continuous deck extending outside the region of such a superstructure.

(15) Superstructure and deckhouse: Superstructure is an enclosed structure on the uppermost continuous deck, extending from side to side of the ship or with the side plating not being inboard of the shell plating more than 4% of the breadth B. Forecastle, bridge and poop are regarded as superstructures. All other enclosed structures are to be termed as deckhouses.

(16) Long superstructure and short superstructure: A superstructure having a length greater than $0.15L$ and not less than 6 times its height is to be termed as a long superstructure, otherwise it is to be regarded as a short superstructure.

(17) Long deckhouse and short deckhouse: A deckhouse having a length greater than $0.15L$ and not less than 6 times its height is to be termed as a long deckhouse, otherwise it is to be regarded

as a short deckhouse.

(18) Secondary members: The stiffeners of the plate are generally regarded as secondary members, i. e. frames, longitudinals, beams, bulkhead stiffeners and members of bracket floors, etc.

(19) Primary members: The primary supporting members of hull are regarded as primary members, such as web frames, side stringers, transverses, deck girders, plate floors, bottom girders, bulkhead webs, etc.

(20) Restricted service is a generic term of the service categories 1, 2 and 3 as shown in Table 1.3.1(20) below.

Table 1.3.1(20)

Category	Limitation for navigation	
	Distance to land (n mile)	
Service category 1	200 (summer/tropical*)	100 (winter*)
Service category 2	20 (summer/tropical*)	10 (winter*)
Service category 3	Sheltered waters**	

* Seasonal areas as specified in Annex II to the International Convention on Load Lines, 1966.

** Sheltered waters include the sea areas between an island and the shore and between islands with a distance of less than 10 n miles in between, which forms a comparatively good sheltered or similar condition with a little wave.

(21) $R'_{\lim}$: the minimum yield stress $R'_{p0.2}$ of parent material which could be guaranteed under welding condition, in N/mm^2, to be taken not greater than 70% minimum tensile strength R'_m of parent material which could be guaranteed under welding condition:

$$R'_{p0.2} = \eta_1 R_{p0.2}$$

$$R'_m = \eta_2 R_m \; ;$$

$R_{p0.2}$ ——the minimum yield stress of parent material which could be guaranteed under delivery condition, in N/mm^2;

R_m ——the minimum tensile strength of parent material which could be guaranteed under delivery condition, in N/mm^2. η_1 and η_2 are given in Table 1.3.1(21)a.

Aluminum Alloy used for Welded Structure Table 1.3.1(21)a

Aluminum alloy	η_1	η_2
Not treated by hardening (5000 series under annealed condition O or annealing leveling condition H111)	1	1
Treated by hardening (5000 series other than O or H111)	$R'_{p0.2} / R_{p0.2}$	R'_m / R_m
Heat treated and hardened (6000 series)(1)	$R'_{p0.2} / R_{p0.2}$	0.6

Note: (1) If information is not provided, the factor η_1 is to be taken as metallographic efficiency coefficient β defined in Table 1.3.5.3(2);

$R'_{p0.2}$ — the minimum yield stress of material which could be guaranteed under welding condition, in N/mm^2;

R'_m — the minimum tensile strength of material which could be guaranteed under welding condition, in N/mm^2.

Alunimun Alloy — Metallographic Efficiency Coefficient β Table 1.3.1(21)b

Aluminum alloy	Tempering condition	Total thickness (mm)	β
6005A(opening section)	T5 or T6	$t \le 6$	0.45
		$t > 6$	0.40
6005A(closed section)	T5 or T6	All	0.50
6061 (section)	T6	All	0.53
6082 (section)	T6	All	0.45

CHAPTER 2 STRUCTURE DESIGN PRINCIPLES

2.1 General requirements

2.1.1 The design of hull structure is to be such as to ensure that the structural strength is sufficient to withstand the design loads as specified in Chapter 3 of these Guidelines for ships navigating in the full-load departure condition.

2.1.2 Longitudinal members of longitudinal framings are to be continuous. Where the longitudinal secondary members are cut in way of transverse bulkheads, connecting brackets are to be provided at both sides of transverse bulkheads. The longitudinal secondary members and the brackets at both sides of the transverse bulkheads are to be in line as to ensure the structural continuity.

2.1.3 Transverse members of transverse framings are to be continuous as far as practicable. Where the transverse secondary members are cut in way of longitudinal bulkheads or longitudinal primary members, connecting brackets are also to be provided at both sides of secondary members, and the members and the brackets are to be in line as to ensure the structural continuity.

2.1.4 Primary members are to be so arranged as to ensure effective continuity of strength, and abrupt changes of depth or section are to be avoided.

2.1.5 The plate floors are to be effectively connected with the side web frames and deck transverses in the same section,forming a complete ring system.

2.1.6 Where openings are cut in the web of primary members, openings are to have smooth edges and well rounded corners. The depth of opening is not to exceed 50% of the web depth, and the opening is to be so located that the edges are not less than 25% of the web depth from the web root or face plate. The length of opening is not to exceed the web depth or 60% of the spacing of stiffeners passing through the web, whichever is the greater, and the ends of the openings are to be equidistant from the corners of cut-outs for stiffeners. Openings are in general not to be cut within 200 mm from the ends of primary members.

2.1.7 Where the depth of openings in the web of primary members exceeds one third of the web depth, they are to be strengthened.

2.2 Bulkhead arrangements

2.2.1 A watertight collision bulkhead is to be provided at the fore end of the hull, which in general is to extend up to the bulkhead deck. Where a long forecastle is provided, it is to extend up to the forecastle deck. The distance l (m) of collision bulkhead aft of the forward perpendicular is to be as follows:

(1) For ships without bulbous bow, $l = 0.035L \sim (3+0.05L)$;

(2) For ships with bulbous bow, $l = (0.035L - f) \sim (3+0.05L - f)$;

where: f ——G/2 or $0.015L$, whichever is the lesser, where G is horizontal distance from the forward end of bulbous bow to forward perpendicular, in m.

The watertight collision bulkhead located within the range above may be stepped or recessed.

2.2.2 A transverse watertight bulkhead is to be provided at each end of the engine room. The aft peak bulkhead may form the aft transverse watertight bulkhead of the engine room, where the engine room is aft.

2.3 Bottom, side and deck structures

2.3.1 The bottom girders are to comply with the following requirements:

(1) Bottom keel and longitudinal girders are in general to pass through transverse watertight bulkheads and extend towards bow and stern.

(2) Holes are not permitted in way of the girder ends within 1.5 times the depth of the girders from bulkheads.

(3) Girders supporting the main engine seating are in general to extend over the full length of the engine room and directly to extend from the bottom to the face plate of the engine seating. Brackets are to be fitted for strength and tripping of girders.

(4) Girders in way of the thrust bearing are to be strengthened.

2.3.2 The plate floors are to be fitted on each frame in the engine room, and additional strengthening is to be provided in way of the gear box and thrust bearing.

2.3.3 For hulls of longitudinal framing, the height of web plates of bottom floors is in general not to be less than 2.5 times that of the holes which longitudinals pass through; the height of web plates of side web frames and deck web beams is in general not to be less than 2.2 times that of the holes which longitudinals pass through.

2.3.4 Where a double bottom is fitted, the double bottom height is to be sufficient to ensure access to all parts and, in way of the centre girder, is to be not less than 0.76 m. Adequate tapering is to be provided between double bottom and adjacent single bottom structures. The inner bottom plating of the double bottom is to be gradually tapered to the face plate of longitudinal girders of the single bottom. Where the height of the double bottom varies, the variation is generally to be made gradually and over an adequate length but not to occur within 0.5*L* amidships.

2.3.5 Where a rounded sheer strake is adopted, the radius is, in general, to be not less than 15 times the thickness of the sheer strake.

2.3.6 The corners of openings in the side shell plating are to be rounded. The openings are to be kept well clear of the ends of superstructure and to be compensated.

2.3.7 The corners of large openings in the strength deck within 0.5*L* amidships are to be elliptical or parabolic and comply with the provisions of Figure 2.3.7(1). Where the corners of openings are rounded, insert plates are required, and the radius of the rounded corner is not to be less than 1/20 of the breadth of the opening. The dimensions of the insert plates are to comply with the provisions of Figure 2.3.7(2). The thickness of insert plates is not to be less than 1.5 times the thickness of strength deck plating.

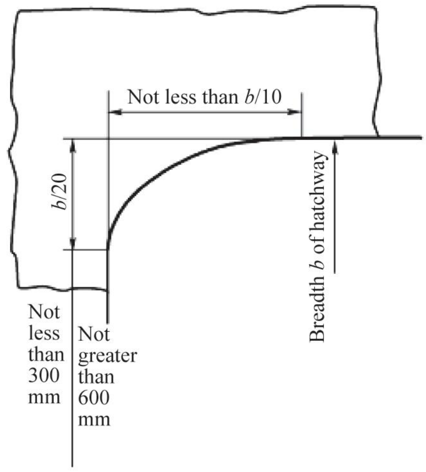


Figure 2.3.7(1)

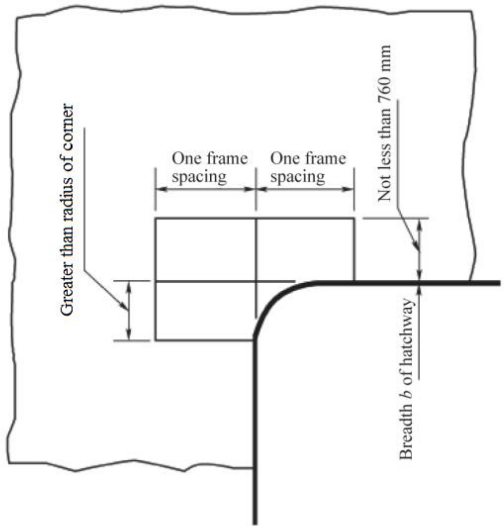


Figure 2.3.7(2)

2.3.8 The deck plating and supporting structure are to be suitably reinforced in way of cranes, masts or heavy units on the deck.

2.3.9 Where swimming pools and bathing platforms and cockpits are provided on the weather deck, they are to be watertight with care being taken to ensure continuity of strength of the surrounding deck structure, so as to avoid stress concentration due to abrupt structural changes.

2.4 Fore and aft end arrangements

2.4.1 Special attention is to be given to ensure continuity of structural strength and the avoidance of abrupt structural changes with regard to fore and aft end arrangements.

2.4.2 Where a bulbous bow is fitted, the bow crumple zone is to be forward of the collision bulkhead. At the fore end of the bulb the structure is generally consisted of horizontal diaphragm plates in conjunction with a deep centreline web. Vertical transverse diaphragm plates of bulbous bow and frames within forepeak are to be arranged in same planes.

2.4.3 The shell plating is to be increased in thickness at the bulb likely to be damaged by the anchors and chain cables.

2.5 Superstructures and deckhouses

2.5.1 The first tier superstructure/deckhouse front and aft end bulkheads above the weather deck are to be aligned with the transverse bulkheads in the deck below in so far as practicable. Where it is impracticable, the end bulkheads are to be supported by web beams or pillars.

2.5.2 The transition in way of the ends of the superstructure/deckhouse is to be smooth and without local discontinuities so as to avoid stress concentration.

2.5.3 Webs of the deck girders and web beams under the bulkheads of the superstructure/deckhouse are not to be provided with any openings for a distance of 0.5 m from each side of the deckhouse corners.

2.5.4 The structures are to be suitably reinforced in way of cranes, masts or heavy units provided on superstructure/deckhouse.

2.6 Tank structures

2.6.1 The fore peak is not to be used for carrying fuel oil.

2.6.2 Fresh water tanks are to be separated from other tanks such as waste water tanks by cofferdams.

2.6.3 Lubricating oil tanks are to be separated from hydraulic oil tanks by cofferdams.

CHAPTER 3 DESIGN LOADS

3.1 Definitions and symbols

3.1.1 The load calculation point is defined as follows:

(1) For plates, the load calculation point is generally to be taken at the middle lower point or close to ship side of the panel length along the ship length.

(2) For stiffeners, the load calculation point is generally to be taken at the middle of the full length of the considered stiffener. For non-horizontal stiffeners, the lateral pressure P is to be taken as the greater of the middle of the full length l and the value obtained from the following formulae:

$P=\frac{p_U+p_L}{2}$ when the upper end of the vertical stiffener is below the lowest zero pressure level

$P=\frac{l_1}{l}\frac{p_L}{2}$, when the upper end of the vertical stiffener is at or above the lowest zero pressure level, see Figure 3.1.1.

where: l_1——distance, in m, between the lower end of vertical stiffener and the lowest zero pressure level;

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

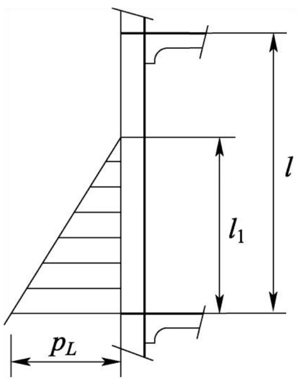


Figure 3.1.1

(3) For primary members, it is to be taken at the midpoint of load area. Where the loads on the area are not uniformly distributed, it is to be specially considered.

3.1.2 T_x (m) means the hull draught at the transverse section of coordinate x.

3.1.3 Z_{kx} (m) means the vertical distance of the underside of the keel from the baseline at the transverse section of coordinate x, positive (+) for keel above baseline and negative (-) for keel below baseline.

3.1.4 Bottom area means the area below the chines where the transverse section has bilge chines or the area below the tangential points formed by the round bilge line with the tangents with horizontal angle of 50° where the transverse section is of round bilge form.

3.1.5 Side area means the area extending from the bottom area defined in 3.1.4 to the uppermost complete weather deck.

3.1.6 g means the acceleration of gravity, $g = 9.81\text{m/s}^2$.

3.2 Hull motion

3.2.1 While a ship navigates in wave, the relative vertical motion factor H_{rm} at the transverse section of coordinate x is to be calculated in accordance with the following formula:

$$H_{rm} = C_W \frac{1 + C_m \left(x / L - X_m \right)^2}{1 + C_m \left(0.5 - X_m \right)^2}$$

where: $C_W = 0.0771L\left(C_B + 0.2\right)^{0.3} e^{-0.0044L}$;

$$C_m = \frac{C_r}{C_B + 0.2}$$

where: for mono-hull ships, $C_r = 1.95$, for catamarans, $C_r = 2.55$;

$X_m = 0.45 - 0.6F_r$ but not less than 0.2;

$F_r = \dfrac{0.515V_H}{\sqrt{gL}}$;

V_H ——the speed of ship navigating at sea, in kn, to be taken as $V_H = \dfrac{2}{3}V$.

3.3 Hull girder design loads

3.3.1 The hull girder design loads (including vertical bending moment and vertical shear force) are to be calculated in accordance with the loading condition of full-load displacement.

3.3.2 The sign conventions of the still water bending moments and shear forces at any transverse section of hull are as shown in Figure 3.3.2:

The still water bending moments M_S or vertical wave bending moments M_W are to be taken as positive values when tensile stress is generated on the strength deck (hogging bending moment) and negative values when compressive stress is generated on the strength deck (sagging bending moment);

The verticle shear forces Q are positive in the case of downward resulting forces acting aft of the transverse section and upward resulting forces acting forward of the transverse section under consideration, the opposite are negative.

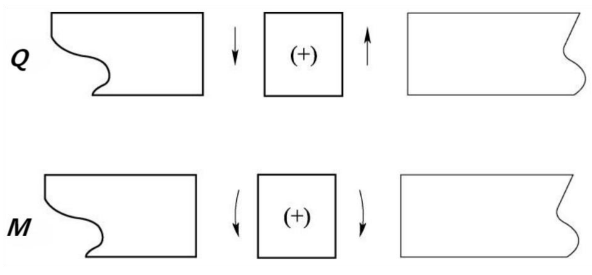


Figure 3.3.2

3.3.3 The still water vertical bending moment M_S and shear force Q_S are to be calculated for ships in the still water condition.

3.3.4 For mono-hull ships, the vertical wave bending moment M_W at any transverse section of hull is to be determined in accordance with the following formulae:

For hogging: $M_{WH} = 0.19 F_M L_f C_1 L^2 B C_B$ kN • m

For sagging: $M_{WS} = -0.11 F_M L_f C_1 L^2 B (C_B + 0.7)$ kN • m

where: F_M ——distribution factor of bending moment, see Table3.3.4;

L_f ——coefficient, $L_f = 0.0412L + 4$;

C_1 ——reduction coefficient of service category, to be taken as follows:

$C_1 = 0.8$ Service category 1

$C_1 = 0.7$ Service category 2

$C_1 = 0.6$ Service category 3;

Distribution factor of bending moment Table 3.3.4

Position of transverse section	Distribution factor F_M
$0 \le x < 0.4L$	$2.5\frac{x}{L}$
$0.4L \le x < 0.65L$	1.0
$0.65L \le x < L$	$2.86(1-\frac{x}{L})$

3.3.5 For checking the hull girder strength of mono-hull ships, the design value of vertical bending moment M_R at any transverse section, is to be taken as $(M_S + M_W)$.

3.3.6 For mono-hull ships, the vertical wave shear force Q_W at any transverse section of hull is to be determined in accordance with the following formula:

$$Q_W = 0.3 F_Q L_f C_1 L B (C_B + 0.7) \quad \text{kN}$$

where: F_Q ——distribution factor of shear forces, see Table 3.3.6, where $A = \frac{190C_B}{110(C_B + 0.7)}$;

L_f and C_1 ——same as 3.3.4.

Distribution factor of positive and negative shear forces Table 3.3.6

Position of transverse section	Distribution factor F_Q	
	Positive shear force	Negative shear force
$0 \le x < 0.2L$	$4.6A\frac{x}{L}$	$-4.6\frac{x}{L}$
$0.2L \le x < 0.3L$	0.92A	−0.92
$0.3L \le x < 0.4L$	$(9.2A-7)(0.4-\frac{x}{L})+0.7$	$-2.2(0.4-\frac{x}{L})-0.7$
$0.4L \le x < 0.6L$	0.7	-0.7
$0.6L \le x < 0.7L$	$3(\frac{x}{L}-0.6)+0.7$	$-(10A-7)(\frac{x}{L}-0.6)-0.7$
$0.7L \le x < 0.85L$	1	−A

Position of transverse section	Distribution factor F_Q	
	Positive shear force	Negative shear force
$0.85L \le x < L$	$6.67(1-\frac{x}{L})$	$-6.67A(1-\frac{x}{L})$

3.3.7 For checking the hull girder strength of mono-hull ships, the design value of vertical shear force Q_R at any transverse section, is to be taken as $(Q_S + Q_W)$.

3.3.8 For catamarans, the vertical bending moment M_{WR} at any transverse section of hull, including wave and hydrostatic effects, is to be determined in accordance with the following formulae:

For hogging: $M_{WRH} = 0.22 F_M C_1 L^{2.5} B_{WL} C_{WP}$ kN • m

For sagging: $M_{WRS} = -0.1375 F_M C_1 L^{2.5} B_{WL} C_{WP}$ kN • m

where: F_M and C_1 ——same as 3.3.4;

C_{WP} ——the water plane coefficient, to be taken as not less than 0.5.

3.3.9 For checking the hull girder strength of catamarans, the design value of vertical bending moment M_R at any transverse section, is to be taken as M_{WR} .

3.3.10 For catamarans, the vertical wave shear force Q_{WR} at any transverse section of hull, including wave and hydrostatic effects, is to be determined in accordance with the following formula:

$$Q_{WR} = 0.66 F_Q C_1 L^{1.5} B_{WL} C_{WP} \quad \text{kN}$$

where: F_Q ——distribution factor of shear forces, same as 3.3.6;

C_1 ——reduction coefficient of service category, same as 3.3.4;

C_{WP} ——the water plane coefficient, same as 3.3.8.

3.3.11 For checking the hull girder strength of catamarans, the design value of vertical shear force Q_R at any transverse section, is to be taken as Q_{WR} .

3.3.12 For catamarans, the vertical shear force Q_t at longitudinal section of cross deck, is to be determined in accordance with the following formula:

$$Q_t = 9.81 C_1 C_2 C_3 \Delta \quad \text{kN}$$

where: C_1 ——reduction coefficient of service category, same as 3.3.4;

C_2 ——coefficient, $C_2 = 0.164(\frac{b}{D})^2 - 0.874(\frac{b}{D}) + 0.974$;

C_3 ——coefficient, $C_3 = -1.958(\frac{b_1}{B}) + 1.783$;

where: b ——breadth of the demi-hull, in m, at the midpoint of L, the maximum horizontal distance between outer surfaces of side walls of a demi-hull;

b_1 ——breadth of the cross deck, in m, at the midpoint of L, the horizontal distance between outer surfaces of inner side walls of two demi-hull along the wet deck.

3.4 Local design loads

3.4.1 The design load P_R acting on the shell may be determined in accordance with the position of load point for calculation as follows:

(1) for mono-hull ships

① P_R acting on the bottom and side areas below the design waterline, in kN/m^2, to be taken as the greater of :

water pressure P_1 acting on the bottom and side areas of hull, in kN/m^2, to be determined in accordance with 3.4.2;

slamming pressure P_{bs} acting on the hull due to waves, in kN/m^2, to be determined in accordance with 3.4.4;

impact pressure P_{fs} acting on the hull due to waves, in kN/m^2, to be determined in accordance with 3.4.5.

② P_R acting on the side area above the design waterline, in kN/m^2, to be taken as the greater of :

water pressure P_2 acting on the side area of the hull, in kN/m^2, to be determined in accordance with 3.4.3;

slamming pressure P_{bs} acting on the hull due to waves, in kN/m^2, to be determined in accordance with 3.4.4;

impact pressure P_{fs} acting on the hull due to waves, in kN/m^2, to be determined in accordance with 3.4.5.

(2) for catamarans

① the hull bottom and side areas are to be determined in accordance with (1);

② the wet deck area is to be taken as the greater of:

slamming pressure at the bottom of the cross deck, in kN/m^2, to be determined in accordance with 3.4.6;

the side design pressure outside the hull of the hull section of the calculation point at the same water line, in kN/m^2, to be determined in accordance with (1).

3.4.2 The water pressure P_1 acting on the bottom and side areas of hull below the design waterline is to be determined by the following formula:

$$P_1 = 10.5\left[T_x - \left(z - z_{kx}\right)\right] + P_W \qquad \text{kN/m}^2$$

where: z —— z coordinate of load point;

P_W ——hydrodynamic wave pressure at load point due to relative vertical motion of hull, which may be obtained by the following formula:

$$P_W = 10.5 F_z H_{rm} \qquad \text{kN/m}^2$$

where: H_{rm} ——relative vertical motion factor at the transverse section of coordinate x, to be calculated in accordance with 3.2.1;

F_z ——vertical distribution factor of hydrodynamic wave pressure at the transverse section of coordinate x, to be calculated in accordance with the following formula:

$$F_z = e^{-u} + (1 - e^{-u})(\frac{z - z_{kx}}{T_x}) \text{, where } u = \frac{2\pi T_x}{L}.$$

3.4.3 The water pressure P_2 acting on the side area of hull above the deign waterline is to be determined by the following formula:

$$P_2 = (10.5 H_{rm} - P_{Rd}) \frac{z_{dx} - z}{z_{dx} - T} + P_{Rd} \qquad \text{kN/m}^2$$

where: H_{rm} ——relative vertical motion factor at the transverse section of coordinate x, to be calculated in accordance with 3.2.1;

P_{Rd} ——design loads on upper weather deck at the transverse section of coordinate x, to be taken according to the value of P_R in 3.4.7(1);

z_{dx} ——vertical distance, in m, measured from baseline to the upper weather deck beams at side at the transverse section of coordinate x.

3.4.4 The bottom impact pressure P_{bs} due to slamming is to be determined as follows:

(1) between $x = 0.8L$ and $0.9L$, to be taken as slamming pressure P_{sl} calculated according to the following formula, and not to be greater than P_{fs} at $x = 1.0L$ calculated according to 3.4.5:

$$P_{sl} = C_1 \left[3.59 - 514 \left(\frac{T_x}{L} \right)^2 \right] \sqrt{L V_H} \qquad \text{kN/m}^2$$

where: C_1 ——reduction coefficient of service category, to be taken as:

$C_1 = 1.0$ Service category 1

$C_1 = 0.85$ Service category 2

$C_1 = 0.75$ Service category 3;

V_H ——the speed of ship navigating at sea, in kn, same as 3.2.1.

(2) $P_{bs} = 0.5 P_{sl}$ at $x = 1.0L$;

(3) $P_{bs} = 0$ between $x = 0$ and $0.5L$;

(4) P_{bs} in other areas are obtained by linear interpolation.

Vertically, the slamming pressure is to be taken as P_{bs} from the bottom keel to the lowest point at the side and $0.4 P_{bs}$ at the open freeboard deck; for other areas the slamming pressure is obtained by linear interpolation.

3.4.5 The bow impact pressure P_{fs} is to be determined as follows:

(1) at $x = 1.0L$, to be taken as the impact pressure P_{im} calculated according to the following formula:

$$P_{im} = C_1 C_h L\left(0.82 + 0.154\frac{V_H}{\sqrt{L}}\right)^2 \quad \text{kN/m}^2$$

where: C_1 ——reduction coefficient of service category, same as 3.4.4;

C_h ——coefficient, to be taken as:

$C_h = 0.89$ for mono-hull ships

$C_h = 1.0$ for catamarans;

V_H ——the speed of ship navigating at sea, in kn, same as 3.2.1.

(2) at $x = 0.9L$, to be taken as P_{bs} calculated according to 3.4.4;

(3) at $x = 0.75L$, to be taken as P_w calculated according to 3.4.2;

(4) between $x = 0.75L$ and $1.0L$, P_{fs} may be obtained by linear interpolation;

(5) between $x = 0$ and $0.75L$, $P_{fs} = 0$.

Vertically, the impact pressure is to be taken as P_{fs} from the bottom keel to the waterline and $0.4P_{fs}$ at the open freeboard deck; for other areas the impact pressure is obtained by linear interpolation.

3.4.6 The slamming pressure P_{cd} at the bottom of the cross deck is to be determined according to the following formula, but not to be less than 0:

$$P_{cd} = 0.35 F_{cd} V_H (1 + 4\frac{H_S}{\sqrt{L}})(1 - 0.78\frac{H_{tx}}{H_S}) \quad \text{kN/m}^2$$

where: F_{cd} ——longitudinal distribution factor of the impact force acting on the bottom of the cross deck, to be taken as follows:

at $x = 1.0L$, $F_{cd} = 2.0$

between $x = 0$ and $0.75L$, $F_{cd} = 1.0$

for other areas, F_{cd} may be obtained by linear interpolation;

V_H ——the speed of ship navigating at sea, in kn, same as 3.2.1;

H_S ——the design significant height selected by the design unit or ship owner from the range of significant heights corresponding to the service category of the ship, in m; this value is not to be less than the significant height H_S corresponding to the service category of the ship (see Table 3.4.6 below);

H_{tx} ——the distance from the pressure calculation point at the bottom of the cross deck to the deign waterline, in m.

Service category and the corresponding H_S **Table 3.4.6**

Service category	H_S (m)
1	6.0
2	4.0
3	2.0

3.4.7 The design load P_R on weather deck and superstructure/deckhouse is to be determined as follows:

(1) The water pressure on the upper weather deck is taken as design load P_R, and to be calculated in accordance with the following formula, but not to be less than 7:

$$P_R = 1.05C_1\left\{F_d(0.01L+6)\left[1+0.05\left(\frac{V_H}{\sqrt{L}}\right)\right]+\frac{0.08L+0.7}{D-T}\right\} \quad \text{kN/m}^2$$

where: C_1 ——reduction coefficient of service category, see 3.4.4;

F_d ——longitudinal distribution factor, to be taken as follows:

at $x = 1.0L$, $F_d = 1.5$

between $x = 0$ and $0.5L$, $F_d = 1.0$

for other areas, F_d may be obtained by linear interpolation;

where: V_H ——the speed of ship navigating at sea, in kn, same as 3.2.1.

(2) The design load P_R on superstructure/deckhouse is to be determined by the following formula:

$$P_R = KP_{dlf} \quad \text{kN/m}^2$$

where: P_{dlf} ——design load on the upper weather deck in way of fore end wall of first tier superstructure/ deckhouse, in kN/m², to be taken according to P_R in 3.4.7(1). The longitudinal distribution factor F_d is to be determined by linear interpolation according to the longitudinal location of fore end wall;

K ——location factor, to be taken according to the position of load point:

$K = 1.50$ for fore end wall of first tier superstructure/deckhouse within $L/3$ from bow

$K = 1.30$ for fore end wall of first tier superstructure/deckhouse outside $L/3$ from bow

$K = 1.00$ for fore end wall of second tier superstructure/deckhouse

$K = 0.80$ for all side walls of superstructure/deckhouse

$K = 0.65$ for top, aft wall and other areas of superstructure/deckhouse.

3.4.8 The design load P_R on interior decks and bulkheads is to be determined as follows:

(1) Unexposed decks or platforms: $P_R = 1.05(0.01L + 6)\left[1 + 0.05\frac{V_H}{\sqrt{L}}\right]$ kN/m^2

(2) Watertight bulkheads: $P_R = 10h$ kN/m^2

where: h ——vertical distance from load point to the highest point of the bulkhead deck, in m.

(3) Collision bulkheads: $P_R = 12.5h$ kN/m^2

where: h ——vertical distance from load point to the highest point of the bulkhead deck, in m.

(4) For the design load P_R on the tank bulkheads, the greatest of the following is to be taken:

$$P_{bh1} = 10h + 6.7h_P \quad \text{kN/m}^2$$

$$P_{bh2} = 10(h + 1) \quad \text{kN/m}^2$$

where: h ——vertical distance from load point to top of tank, in m;

h_P ——vertical distance from load point to top of the air pipe, in m.

CHAPTER 4　HULL GIRDER STRENGTH

4.1　General requirements

4.1.1　The hull girder strength is to be checked in the following cases:

(1) ships of more than 40 m in *L*;

(2) ships having large openings in strength decks within 0.4*L* amidships, whose width is more than half of the width of strength decks.

4.2　Checking sections of hull girder

4.2.1　The following three transverse sections of hull girder are at least to be taken for checking the longitudinal strength:

(1) The midsection at the weakest part of the structure within 0.4*L* amidships is to be taken for checking the bending strength of hull girder.

(2) The section of forward amidship with the maximum vertical shear force is to be taken for checking the shear strength of hull girder.

(3) The section of aft amidship with the maximum vertical shear force is to be taken for checking the shear strength of hull girder.

4.2.2　Considerations are also to be given to the sections in way of large openings in strength decks and of abrupt changes areas of hull girder structures.

4.3　Strength characteristics of hull girder transverse sections

4.3.1　The hull girder transverse sections are to be considered to consist of members contributing to the longitudinal strength of hull girder, including strength decks and all the continuous longitudinal members below, taking into account the requirements of 4.3.2 and 4.3.3.

4.3.2　The longitudinal members having a length greater than moulded depth *D* on both sides of the checking section may be taken into account in the hull girder sections. However where openings having a depth greater than 25% of that of the web plate are cut in them, the sectional areas of these openings are to be deducted. Engine seating and bilge keel are not to be taken into account in the hull girder sections.

4.3.3　Within 0.25*L* to 0.75*L* from aft, where the first tier superstructure/deckhouse having a length greater than 0.15*L* and more than 6 times its own height is supported on at least 3 transverse bulkheads and the flexible connection is not adopted, it may be taken into account in the hull girder sections.

4.3.4　The superstructure or deckhouse not satisfying any of the conditions in 4.3.3 is not to be considered to make contribution to the longitudinal strength and is not to be taken into account in the hull girder sections. Where part of it is considered to make contribution to the longitudinal strength, it is to be determined by direct calculations.

4.3.5　Where there are a large amount of openings on the side walls of superstructure / deckhouse and the sum of length of all openings on each side wall exceeds half of the structure length or the flexible connection between the superstructure/deckhouse and the main hull is adopted, the structure is not to be considered to make contribution to the hull girder strength.

4.3.6 During the calculation of section modulus of hull girder, openings of more than 2.5 m in length or more than 1.2 m or 0.04*B* in width, whichever is lesser, in the strength deck at the section are to be deducted from the sectional areas of hull girder.

4.3.7 Openings (manholes, lightening holes, single scallops in way of seams, etc.) on the deck smaller than those specified in 4.3.6 need not be deducted provided that the sum b_c of their breadths or shadow area breadths (The shadow area will be obtained by drawing two tangent lines with an opening angle of 30°, see Figure 4.3.7).

$$b_c \leq 0.06\left(B_1 - \sum b\right)$$

where: B_1——breadth at the calculated section, in m;

$\sum b$ ——sum of the opening breadths at the calculated section that needs to be deducted according to 4.3.6 of this Section, in m.

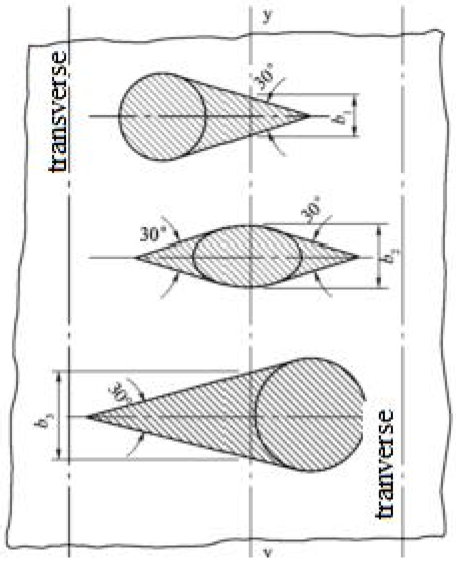


Figure 4.3.7

4.4 Section modulus of hull girder

4.4.1 The section modulus Z_A of any point (with vertical coordinate z) below the strength deck is to be calculated in accordance with the following formula:

$$Z_A = \frac{I_Y}{\left|z - N\right|} \quad \text{m}^3$$

where: I_Y——moment of inertia for the hull transverse section to its horizontal neutral axis, in m^4;

N——vertical distance from the horizontal neutral axis of hull section to the baseline, in m;

z——vertical coordinate of the point calculated, in m.

4.4.2 The section modulus Z_{AK} and Z_{AD} in way of bottom keel and strength deck are to be calculated in accordance with the following formulae respectively:

Bottom keel: $Z_{AK} = \dfrac{I_y}{|z_{kx} - N|}$ m^3

Strength deck: $Z_{AD} = \dfrac{I_y}{z_D - N}$ m^3

where: z_{kx}——see 3.1.3;

z_D——z coordinate of the edge line of strength deck in way of the hull section;

I_Y and N ——same as 4.4.1.

4.5 Static moment of height *z* above the baseline

4.5.1 Static moment S of height z above the baseline, in m^3, is the static moment to the horizontal neutral axis for all members above the point calculated where the point is above the horizontal neutral axis or the static moment to the horizontal neutral axis for all members below the point calculated where the point is below the horizontal neutral axis.

4.6 Stress of hull girder

4.6.1 The normal stress σ_L due to vertical bending moment is to be calculated as follows:

(1) For any point (with vertical coordinate z) below the strength deck at the checking section:

$$\sigma_L = \frac{|M_R|}{Z_A} \times 10^{-3} \quad \text{N/mm}^2$$

where: Z_A——section modulus calculated according to 4.4.1, in m^3;

M_R——design value of vertical bending moment at midship section according to 3.3.4 and 3.3.8, in kN·m.

(2) In way of the plate keel of bottom at the checking section (with vertical coordinate z_{kx}):

$$\sigma_L = \frac{|M_R|}{Z_{AK}} \times 10^{-3} \quad \text{N/mm}^2$$

where: Z_{AK}——section modulus calculated according to 4.4.2, in m^3;

M_R ——design value of vertical bending moment at midship section according to 3.3.4 and 3.3.8, in kN·m.

(3) In way of the strength deck at the checking section:

$$\sigma_L = \frac{|M_R|}{Z_{AD}} \times 10^{-3} \quad \text{N/mm}^2$$

where: Z_{AD}——section modulus calculated according to 4.4.2, in m^3;

M_R ——design value of vertical bending moment at midship section according to 3.3.4

and 3.3.8, in kN • m.

4.6.2 The shear stress τ_L due to the vertical shear force is calculated as follows:

(1) for transverse section without longitudinal bulkheads, the shear stress acting on the side shell is to be calculated as follows:

$$\tau_L = \frac{|Q_R| S}{I_y t} \qquad \text{N/mm}^2$$

where: Q_R——design value of vertical shear force according to 3.3.6 and 3.3.10, in kN;

t ——sum of the thickness of the shell plating at both sides at the height z above the baseline, in mm (for double hull ships, sum of the thickness of inner and outer skins at both sides);

S——static moment of height z above the baseline, in m^3, according to 4.5.1;

I_Y——moment of inertia for the hull transverse section under check to its horizontal neutral axis, in m^4, see 4.4.1.

(2) for transverse section with longitudinal bulkheads, the shear stress is to be calculated according to thin-wall shear flow theory.

(3) for longitudinal section of the cross deck structure, the shear stress is to be calculated according to the shear force specified in 3.3.12.

4.7 Hull girder yield strength assessment

4.7.1 The normal stress σ_L due to vertical bending moment calculated according to 4.6.1 is to comply with the following formula in both hogging and sagging conditions:

$$\sigma_L \le \sigma_{perm}$$

where: σ_{perm} ——permissible normal stress, in N/mm^2, to be taken as $\sigma_{perm} = 0.72\sigma_{SW}$, where:

σ_{SW} ——yield strength after welding of material, in N/mm^2, to be taken as R'_{lim}, see 1.3.1(21).

4.7.2 The shear stress τ_L calculated according to 4.6.2 is to comply with the following formula:

$$\tau_L \le \tau_{perm}$$

where: permissible shear stress, in N/mm^2, to be taken as $\tau_{perm} = 0.72\,\tau_{SW}$, where: τ_{SW} —— shear strength after welding of material, $\tau_{SW} = \frac{\sigma_{SW}}{\sqrt{3}}$ N/mm^2, where σ_{SW} is given in 4.7.1.

CHAPTER 5 HULL LOCAL SCANTLINGS

5.1 General requirements

5.1.1 The rounding tolerance of the plate calculated in this Chapter is to be determined in accordance with the following principles:

(1) For plates with thickness equal to or greater than 4 mm, where the decimal part of the calculated plate thickness is 0.25 mm or less, it may be neglected; where it is greater than 0.25 mm but less than 0.75 mm, it is to be taken as 0.5 mm; where it is 0.75 mm or more, a round number of 1.0 mm is to be taken.

(2) For plates with thickness less than 4 mm, where the decimal part is 0.15 mm or less, it may be neglected; where it is greater than 0.15 mm but less than 0.65 mm, it is to be taken as 0.5 mm; where it is 0.65 mm or more, a round number of 1.0 mm is to be taken.

5.2 Symbols and definitions

5.2.1 Unless expressly provided otherwise, for the purpose of this Chapter:

(1) Local design load P_R (kN/m^{2}): the load determined in accordance with 3.4 of Chapter 3;

(2) Rule thickness of plating t (mm): the thickness of plating calculated in accordance with relevant requirements of this Chapter;

(3) Spacing of stiffeners/primary supporting members s (m): the spacing of adjacent stiffeners for stiffeners, and the average spacing of adjacent primary supporting members for primary supporting members;

(4) Span of members l (m): Where there is no end bracket for stiffeners, the span point is to be taken at the end of the stiffener. Where end brackets are fitted, the span point may be taken at the middle of length of the end bracket. Where end brackets are generally fitted for primary supporting members, the span point is to be taken at the point distant k_e, from the end of the member as shown in Figure 5.2.1(4). k_e is calculated in accordance with the following formula:

$$K_e = K_b \left(1 - \frac{d_w}{d_b}\right)$$

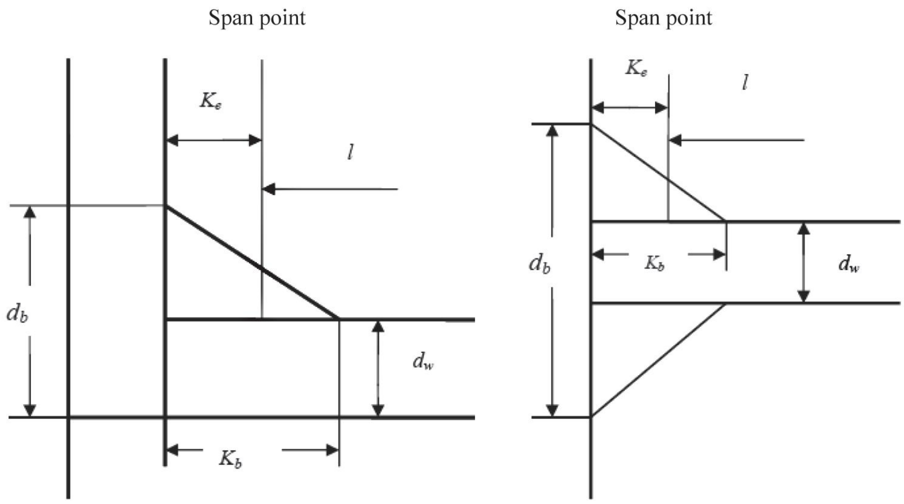


Figure 5.2.1(4)

Where deck primary supporting members are supported by pillars, the supporting point of pillar may be taken as the span point of the member. If the supporting structure at both ends of the member cannot effectively prevent rotation or displacement, the effective span used by the member is to be considered separately.

(5) Rule section modulus W (cm^3): During calculation, the attached plating with effective width b_e determined by (6) below is to be considered. The thickness of attached plating is to be taken as the weighted average of different plate thicknesses within the effective width of attached plating.

(6) Effective width of attached plating b_e (m):

For stiffeners, $b_e = s$, but not to be greater than $l/5$;

For primary members, $b_e = 0.3\left(\frac{l}{s}\right)^{\frac{2}{3}} s$, but not to be greater than $l/5$.

(7) Yield stress of material σ_s (N/mm^2): For aluminum alloy, $\sigma_s = R_{p0.2}$, see 1.3.1(21).

(8) Yield stress of material in welded condition σ_{sw} (N/mm^2): R'_{lim} is to be taken for aluminum, see 1.3.1(21).

5.3 Minimum thickness

5.3.1 Minimum thickness t_{min} of plating is to be taken as follows:

$$t_{min} = K_0 K_1 \sqrt[3]{L} + 1.5 \text{ mm, but not less than 3mm} \quad (1)$$

where: k_0 — factor, see Table 5.3.1;

k_1 — factor, k_1=s/s$_b$, to be taken as not less than 0.5 nor greater than 1.0;

S — spacing of members, in m;

s_b — standard spacing of members, in m, $s_b = 0.0016L + 0.2$;

L — ship length, in m;

Factor K_0 **Table 5.3.1**

Item			K_0
Bottom			1.02
Cross deck bottom			0.82
Side			0.82
Strength deck forward amidship			0.68
Strength deck aft amidship			0.55
Unexposed deck plate			0.41
Collision bulkhead plate			0.68
Liquid tank bulkhead plate			0.61
Watertight bulkhead plate			0.55
Superstructure and deckhouse	Front	First tier	0.44
		Second tier	0.44
		Third tier and above	0.41
	Side, behind		0.41
	Top		0.41

Note (1) : 2.0 mm for superstructure, side, behind and top of deckhouse with stiffened plates.

5.3.2 Built-up sections of bottom, including engine seating, is to comply with the following requirements:

(1) The minimum thickness t_{min} of the face plate is not to be less than the value obtained from the following formula:

$$t_{min} = \frac{b}{16} \quad \text{mm}$$

where: b – face plate width, in mm.

(2) The minimum thickness t_{min} of the web is not to be less than the value obtained from the following formula:

$$t_{min} = \frac{h}{50} \quad \text{mm, but not less than 3 mm}$$

where: h – web depth or web stiffener spacing, in mm.

(3) The minimum thickness of the main engine seating, including face plate and web, is also not to be less than the value obtained from the following formula:

$$t_{min} = 1.9\sqrt[3]{L} \quad \text{mm}$$

5.3.3 The minimum wall thickness of the deck pillar is to comply with the following requirements:

(1) The minimum wall thickness for tubular pillar or built-up pillar is not to be less than 4 mm.

5.4 Thickness of plating

5.4.1 The thickness of plating t determined by bending strength of plating is to be calculated in accordance with the following formula:

$$t = 22.4 C_1 C_2 s \sqrt{\frac{P_R}{C_a \sigma_{sw}}} \quad \text{mm}$$

where: C_1 — curvature correction factor, $C_1 = 1 - 0.5s/r$, where r is radius of curvature, in m;

C_2 — correction factor for panel aspect ratio of long side ℓ to short side s, to be taken as follows:

$$C_2 = \frac{l}{s}(1 - 0.25\frac{l}{s}) \qquad \text{for } l/s \le 2;$$

$$C_2 = 1.0 \qquad \text{for } l/s > 2.$$

C_a— permissible bending stress coefficient of plating, see 5.8.1.

5.4.2 The shell plating is also to comply with the following requirements:

(1) The thickness of plate keel is to be increased by 2 mm over the adjacent bottom shell plating. The width of plate keel is not to be less than $0.1B$.

where: for catamarans, B is the molded width of one hull; for mono-hull crafts, B is the molded width.

(2) The bilge plate thickness is not to be less than that of adjacent bottom shell plating.

(3) The thickness of the stern or transom is to be not less than that of bottom shell plating.

(4) The thickness of shell plating over the propeller and in way of the rudder post at stern is to be increased by at least 2 mm.

(5) The shell plating at the hawse pipe and the plate below it are to be thickened or fitted with doubling plates.

(6) Where a forecastle is fitted, the plating thickness of weather deck is to be increased by 20% in way of the end of the forecastle if this occurs at a position aft of $0.25L$ from the forward perpendicular. No increase is required if the forecastle end bulkhead lies forward of $0.2L$ from the forward perpendicular. The increase at intermediate positions of the forecastle end bulkhead is to be obtained by interpolation if the forecastle end bulkhead lies $0.2L \sim 0.25L$ behind from the forward perpendicular.

5.5 Section modulus of members

5.5.1 The section modulus W of stiffeners /primary supporting members subjected to lateral local pressure is not to be less than the value obtained from the following formula:

$$W = \frac{P_R s l^2}{f_{bdg} C_s \sigma_{sw}} \times 10^3 \qquad \text{cm}^3$$

where: f_{bdg}— bending moment factor:

$f_{bdg} = 12$, for the upper end of horizontal and vertical members

$f_{bdg} = 10$, for the lower end of vertical members

C_s— permissible bending stress coefficient, see 5.8.1;

σ_{sw} — yield stress of material in welded condition, see 5.2.1(8).

5.6 Effective shear area at end of members

5.6.1 The effective shear area *Ae* of stiffeners /primary supporting members subjected to lateral local pressure is not to be less than the value obtained from the following formula:

$$A_{e\min} = \frac{f_{shr} P_R s l}{C_t \tau_{sw}} \quad \text{cm}^2$$

where: f_{shr} — shear distribution factor:

$f_{shr} = 5$, for the upper end of horizontal and vertical members

$f_{shr} = 7$, for the lower end of vertical members

C_t — permissibleshear stress coefficient, see 5.8.1;

τ_{sw} — shear strength of material in welded condition, see 4.7.1.

For stiffeners, A_e is calculated as follows:

$$A_e = 0.01ht \quad \text{cm}^2$$

where: h — web depth of stiffeners, in mm;

t — web thickness of stiffeners, in mm.

For primary supporting members, A_e is calculated as follows:

for no bracket at end $A_e = 0.01 h_w t_w$ cm^2

for bracket at end $A_e = 0.01 h_w t_w + \Delta A_e$ cm^2

where: h_w — net web height after deduction of cutouts in the cross section considered;

T_w — web thickness, in mm;

$\triangle A_e$— additional shear area at end of primary members with bracket, in cm^2, obtained according to the horizontal angle of the bracket's face plate, see Figure 5.6.1. $\Delta A_e = 0.9 f_1$, where θ =45°; ΔA_e = 0, where θ =0°; ΔA_e may be obtained by interpolation where θ = 0° ~ 45°; f_1 is area of the bracket's face plate in the cross section considered, in cm2 .

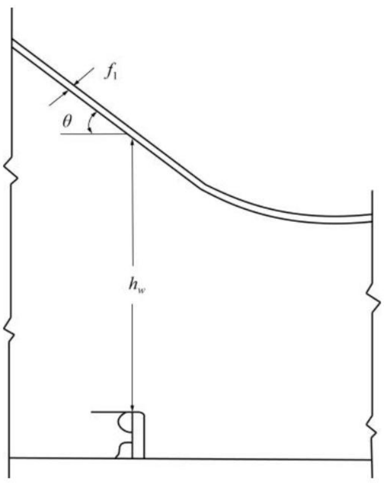


Figure 5.6.1

5.7 Pillars

5.7.1 Section area A of the deck pillar is not to be less than the value obtained from the following formula:

$$A = \frac{P}{(6 - 0.0349\frac{l}{r})\sigma_s} \times 10^2 \qquad \text{cm}^2$$

where: P — pillar load, in kN;

l — length of pillar, in cm;

r — minimum radius of inertia of the cross-section of pillar, in cm.

5.8 Permissible stress coefficient of local load

5.8.1 The permissible stress coefficients of plates, primary supporting members and secondary members subjected to lateral local loads are shown in Table 5.8.1.

Permissible stress coefficient **Table 5.8.1**

Item	Permissible stress coefficient		
	C_a	C_s	C_t
Bottom area and side area in the bow region (forward of x = 0.75L)	0.75	0.65	0.65
Side area outside the bow region (aft of x = 0.75L)	0.75	0.65	0.65
Cross-deck	0.75	0.65	0.65
Strength deck	0.75	0.65	0.65
Other decks (including plate of superstructure/deckhouse)	0.75	0.6	0.6
Watertight bulkhead/collision bulkhead	1.0	0.9	0.9
Liquid tank bulkhead	0.65	0.65	0.65
Superstructure/deckhouse wall	0.75	0.75	0.75
All primary supporting members	-	0.65	0.65

CHAPTER 6 DIRECT CALCULATION OF CATAMARANS

6.1 General requirements

6.1.1 The overall strength of catamaran (including longitudinal strength, transverse strength and torsional strength) is to be checked by the global finite element analysis. The global finite element analysis is to be carried out in accordance with the relevant requirements of Appendix 1 of Chapter 18 of PART TWO of CCS Rules for Classification of Sea-going Steel Ships.

6.1.2 The global ship model is to contain all structural members of shell plating, longitudinal/transverse bulkheads, deck structure, cross-deck, struts, etc., of the hull structure. The as-built thicknesses are to be applied for FE model scantlings, no additional thickness given by the shipowner is to be taken into consideration.

6.1.3 The member stress is not to be greater than the permissible stress in Table 6.1.3. If finer meshes are used, the average stress value of all fine meshes under the specified mesh size is to be taken.

Permissible stress **Table 6.1.3**

Member	Permissible stress
Permissible equivalent stress of plate element	$0.75\sigma_{sw}$ (1)
Permissible shear stress of plate element	$0.41\sigma_{sw}$ (1)
Permissible normal stress of beam and rod element	$0.73\sigma_{sw}$ (1)

Note (1): σ_{sw} (N/mm^2): for aluminum, it is to be taken as R'_{lim}, see1.3.1(21).

6.1.4 The requirements for buckling strength assessment are given in 7.6.

CHAPTER 7　BUCKLING STRENGTH

7.1　General requirements

7.1.1　The check of buckling strength is to be carried out for aluminum alloy hull members in accordance with the requirements of 7.1.2~7.1.4 of this Chapter.

7.1.2　The slenderness requirements of members, tripping bracket of primary supporting members and web stiffeners are to comply with the requirements of 7.4.

7.1.3　For aluminum alloy ships which comply with 4.1.1 of the Guidelines, the buckling check of hull girder longitudinal compressive and shear is to be carried out for members taken into account in longitudinal strength in accordance with 7.5.

7.1.4　For aluminum alloy ships applicable to the requirements of 6.1.1 of the Guidelines, the buckling check of FEA is to be carried out for the stiffened panels, primary supporting members and stiffeners of hull structure in accordance with 7.6.

7.2　Symbols and definitions

7.2.1　Unless expressly provided otherwise, for the purpose of this Chapter:

(1) Modulus of elasticity of aluminum alloy $E=0.69\times10^5$ (N/ mm²);

(2) Poisson's ratio for aluminum alloy $\nu=0.33$;

(3) Yield stress of material in welded condition R'_{lim}(N/ mm²), see 1.3.1(21);

(4) Shear strength of material in welded condition, τ'_{lim}(N/ mm²). $\tau'_{lim}=\frac{R'_{lim}}{\sqrt{3}}$.

(5) Ideal elastic axial buckling stress and shear stress of panels σ_{Ep_x}, σ_{Ep_y}, τ_{Ep} (N/ mm²), see 7.7.1;

(6) Critical buckling axial stress and shear stress of panels σ_{cr_x}, σ_{cr_y}, τ_{cr} (N/ mm²), see 7.7.1 and 7.7.2, and the x and y coordinate axes correspond to the long and short sides of panels;

(7) Ideal elastic buckling axial compressive stress of stiffeners/primary supporting members σ_{Ea} (N/ mm²), see 7.7.5(1);

(8) Critical buckling axial compressive stress of stiffeners/primary supporting members σ_{cr_a} (N/ mm²), see 7.7.5;

(9) Ideal elastic torsional buckling stress of stiffeners/primary supporting members σ_{Et} (N/ mm²), see 7.7.5(2);

(10) Critical torsional buckling stress of stiffeners/primary supporting members σ_{cr_t} (N/ mm²), see 7.7.5;

(11) Ideal compressive buckling stress of stiffeners/primary supporting members, web and face plate σ_{E_web}, σ_{E_flange}, (N/ mm²), see 7.7.5(3);

(12) Critical buckling stress of stiffeners/primary supporting members $\sigma_{cr\_stiffener}$, (N/ mm²), see 7.5.3(2);

(13) Axial stress and shear stress of panels σ_x、σ_y、τ_{xy} (N/ mm²);

(14) Maximum axial compressive stress of stiffeners/primary supporting members σ_a (N/ mm²);

(15) Maximum bending stress of stiffeners/primary supporting members σ_b (N/ mm^2);
(16) Length of shorter side of panel s (mm);
(17) Length of longer side of panel b (mm);
(18) Attached plating thickness of panels/members t_p (mm);
(19) Face plate width of stiffeners/primary supporting members b_f (mm);
(20) Face plate thickness of stiffeners/primary supporting members t_f (mm);
(21) Web height of stiffeners/primary supporting members h_w (mm);
(22) Web thickness of stiffeners/primary supporting members t_w (mm);
(23) Section area of member not including attached plating A_s（cm^2）；
(24) Effective section area of stiffeners A_{eff} (cm^2);
(25) Total section area of beam-column model of stiffeners/primary supporting members A (cm^2);
(26) Length of stiffeners/primary supporting members l (m), arranged according to the direction of the member, and equal to the length of longer side b or the length of shorter side s of panel;
(27) Axial direction of longer side of panel: x; axial direction of shorter side of panel: y;
(28) Allowable buckling utilization factor of members η_{all}, see Table 7.3.1;
(29) Buckling utilization factor of members η_{act}, $\eta_{act} = 1/\gamma$;
(30) Stress multiplier factors at failure of the limit state γ, is to be calculated according to different limit state equations.

7.3 Allowable buckling utilization factor

7.3.1 Allowable buckling utilization factor of members η_{all}, see Table 7.3.1;

Allowable buckling utilization factor of members η_{all} Table 7.3.1

Structural component	Allowable buckling utilization factor η_{all}
a. Plate; b. stiffener; c. Primary supporting member web (except d)	1.0; for static load + dynamic load conditions 0.8; only for static load condition
d. Column and pillar, cross tie	0.75; for static load + dynamic load conditions 0.65; only for static load condition

7.4 Slenderness requirements of stiffeners, tripping brackets and web stiffeners of primary supporting members

7.4.1 The slenderness requirements of stiffeners are to comply with Table 7.4.1.

Slenderness requirements of stiffeners Table 7.4.1

	Flat bar	Other section
Height to thickness ratio of web	$h_w/t_w \leq 15\sqrt{k}$	$h_w/t_w \leq 33\sqrt{k}$
Width to thickness ratio of face plate	—	$b_f/t_f \leq 21\sqrt{k}$: symmetrical face plate $b_f/t_f \leq 10.5\sqrt{k}$: asymmetric face plate

	Flat bar	Other section
Ratio of web to panel	—	$b_f t_f \geq h_w t_w/6$
Note: $k = 100/R'_{lim}$, for the stiffeners assembled with different aluminum materials, k is to be taken as the maximum value.		

7.4.2 The tripping bracket is to be welded to the face plate of primary supporting member in order to prevent buckling of the face plate of primary supporting member, as shown in Figure 7.4.2. The tripping bracket spacing is generally to be no more than 2 m, and fitted in the following position (if applicable) :

(1) rounded and knuckle face plate;

(2) the toe of the end bracket;

(3) the position of cross tie;

(4) concentrated load;

(5) Every 4^{th} spacing of web stiffeners of primary supporting members.

Where the width of the symmetrical face plate is greater than 200 mm, backing bracket are to be fitted in way of the tripping brackets.

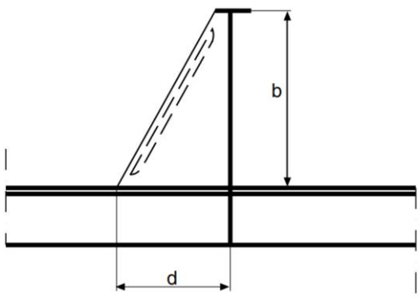


Figure 7.4.2 Tripping bracket of primary supporting members

7.4.3 The arm length of the tripping bracket *d*, as shown in Figure 7.4.2, is not to be less than the value obtained from the following formula:

$$d = \max\,(0.38b, 0.85b\sqrt{S_t/t}) \quad \text{m}$$

where: b— height of tripping bracket, in m, see Figure 7.4.2;

S_t— spacing of tripping bracket, in m;

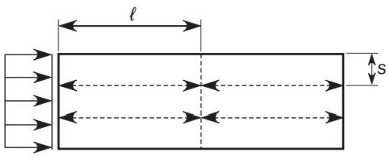
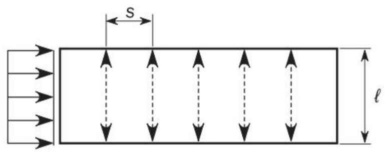
t— thickness of tripping bracket, in mm.

7.4.4 Where the thickness of tripping bracket (in mm) is less than 22 times the length of its free edge (in m), it is to be or stiffened by a welded face plate. The sectional area of folded flange or face plate, in cm^2, is not to be less than 10 times the length of the free edge of tripping brackets (in m).

7.4.5 If $h_w/t_w > 60$, the web stiffener of the primary supporting member is to be fitted, and the spacing of the web stiffeners is generally not to be greater than $65t_w$(h_w and t_w are the height and thickness of the web of the primary supporting member respectively, in mm). The spacing of web stiffeners is to be properly densified within 0.2l of the end of the primary supporting member (l is the length of the primary supporting member) and where the high stress is. For primary supporting members supporting other primary supporting members, the spacing of web stiffeners is generally not to be greater than $60t_w$.

7.4.6 The moment of inertia of section for the web stiffener of the primary supporting member with attached plating I_{st} is not to be less than I_{st_min} given in Table 7.4.6:

Requirements for rigidity of web stiffener **Table 7.4.6**

Arrangement form of stiffener	Minimum moment of inertia of section for web stiffener with attached plating I_{st_min}, in cm^4
(1) Web stiffeners along the span direction of the primary supporting member 	$I_{st\_min} = Cl^2 A_{eff} \frac{R'_{lim}}{100}$
(2) Web stiffeners perpendicular to the span direction of the primary supporting member 	$I_{st\_min} = \left[1.14ls^2 t_w (2.5\frac{1000l}{s} - 2\frac{s}{1000l})\frac{R'_{lim}}{100}\right] \times 10^{-5}$
Note: C — slenderness ratio coefficient, to be taken as follows: 1.43, for longitudinal stiffeners, including sniped stiffeners; 0.72, for other stiffeners; l — length of web stiffener, in m; For the web stiffener welded to the local supporting member, the length is the distance between the flange of the local supporting member ; For the sniped web stiffener, the length is taken as the total distance between the lateral supports, such as the flange of the primary support member, as shown in arrangement of stiffener (2); A_{eff}— net cross-sectional area of web stiffeners, see 7.6.4 s— spacing of web stiffeners of primary supporting members, in m; t_w — thickness of web of primary supporting members, in mm; R'_{lim}— yield stress of primary supporting member in welded condition	

7.5 Hull girder longitudinal buckling strength

7.5.1 The check of HG longitudinal buckling strength is to be carried out for longitudinal hull girder members (bottom, deck and side shell, as well as longitudinal primary support members and longitudinals) of mono-hull and multi-hull crafts under total longitudinal bending moments and shear forces and the checked section is to include at least the transverse section within 0.4L selected in 4.2.1 and 4.2.2.

7.5.2 The calculation of total longitudinal bending compressive stress and shear stress are shown in 4.6.

7.5.3 The HG longitudinal buckling strength is to meet the following criteria:

$$\eta_{act} \le \eta_{all}$$

where: $\eta_{act} = 1/\min(\gamma_1, \gamma_2)$;

γ_1, γ_2—are to be obtained from the limit state equations in (1) and (2) of this Article respectively.

(1) Panel:

$$(\gamma_1 \sigma_x/\sigma_{cr\_x})^2 + (\gamma_1 \tau_{xy}/\tau_{cr})^2 = 1 \quad \text{for longitudinal framings}$$

$$(\gamma_1 \sigma_y/\sigma_{cr\_y})^2 + (\gamma_1 \tau_{xy}/\tau_{cr})^2 = 1 \quad \text{for transverse framings}$$

(2) Longitudinals/longitudinal girder

$$(\gamma_2 \sigma_a/\sigma_{cr\_stiffener}) = 1$$

where: $\sigma_{cr\_stiffener} = \min(\sigma_{cr\_a}, \sigma_{cr\_t}, \sigma_{cr\_web}, \sigma_{E\_flange})$, see 7.7.5 for the symbols.

7.6 Buckling strength of finite element analysis

7.6.1 The buckling check of FEA is to be carried out for the stiffened/unstiffened panels, primary supporting members and stiffener elements in the FE model in accordance with the requirements of 7.6.2~7.6.5 respectively, and is to meet the following criteria:

$$\eta_{act} \le \eta_{all}$$

where: $\eta_{act} = 1/\min(\gamma_3, \gamma_4, \gamma_5, \gamma_6)$;

$\gamma_3, \gamma_4, \gamma_5, \gamma_6$— are to be obtained from the limit state equations in 7.6.2, 7.6.3, 7.6.4 and 7.6.5 respectively, where: γ_3, γ_4 are applicable to stiffened and unstiffened panels, and γ_5, γ_6 are applicable to stiffened panels.

7.6.2 The buckling/ultimate strength of the panel is to meet the following criteria:

$$\left(\frac{\gamma_3 \sigma_x}{\sigma_{xu}}\right)^2 + \left(\frac{\gamma_3 \sigma_y}{\sigma_{yu}}\right)^2 + \left(\frac{\gamma_3 \tau_{xy}}{\tau_u}\right)^2 = 1$$

where: σ_{xu}、σ_{yu}、τ_u — see 7.7.3(1), (2) and (3).

7.6.3 The ultimate strength subjected to lateral pressure of the panel is to meet the following criteria:

$$\gamma_4 p_p/p_u = 1$$

where: p_p — uniformly distributed lateral pressure acting on panel (can be obtained from the load data of FE model by taking from the pressure difference value due to both two sides (internal and external) of the panel in the same load condition), in N/mm^2;

p_u — see 7.7.4.

7.6.4 For stiffened panels, the ultimate compressive-bending strength of stiffener/primary supporting member is to meet the following criteria:

$$\frac{\gamma_5 \sigma_a}{\varphi_c \sigma_{cr\_a} \frac{A_{eff}}{A}} + \frac{m\sigma_b}{\varphi_c R'_{lim} \frac{W_{eff}}{W}} = 1$$

where: φ_c— coefficient, 0.7 for aluminum flat bar; 0.80 for aluminum bulb flat; 0.75 for aluminum angle and T profiles;

$A_{eff} = A_s + 0.01(b_{eff}t_p)$ cm^2,

where: $b_{eff} = C_{\beta_y}s$, see 7.7.2 for C_{β_y};

$A = A_s + 0.01(st_p)$ cm^2,

where: A_s is the sectional area of stiffener (not included in the effective attached plating), in cm^3;

$m = \max\left(\frac{1}{1-\gamma_5\sigma_a/\sigma_{Ea}},\ 1\right)$; see 7.7.5(1) for σ_{Ea};

$\sigma_b = (M_{max}/W_{eff}) \times 10^{-3}$ N/mm^2;

M_{max} — maximum bending moment of stiffeners due to lateral load in ultimate limit state, to be calculated by the following formula:

$$M_{max} = \frac{\gamma_5 p_p s l^2}{c_m} \times 10^6 \quad \mathrm{N \cdot mm}$$

$$c_m = \begin{cases} 24 & \text{Fixed support at both ends} \\ 8 & \text{Sniped at both ends} \\ 14.2 & \text{Fixed support at one end, sniped at the other end} \end{cases}$$

p_p — see 7.6.3;

W_{eff} — section modulus of stiffener at panel, taking into account of effective breadth b_{eff} of attached plating, in cm^3;

W — section modulus of stiffener at panel (not taking into account of effective breadth b_{eff} of attached plating) in cm^3;

L — length of stiffener, in m.

7.6.5 For stiffened panels, the torsional ultimate strength of stiffener/primary supporting member is to meet the following criteria:

$$\frac{\gamma_6\sigma_a}{\varphi_c\sigma_{cr\_t}\frac{A_{eff}}{A}} = 1$$

where: φ_c — coefficient, 0.55 for aluminum flat bar; 0.80 for aluminum bulb flat; 0.85 for aluminum angle and T profiles;

A_{eff} and A — see 7.6.4;

σ_{cr_t} — see 7.7.5.

7.7 Critical buckling stress and ultimate stress

7.7.1 The critical buckling stress of the panel under uniaxial compression is to be taken as follows:

(1) Critical buckling stress of panel subjected to axial compression $\sigma_{cr\_x,y}$:

$$\sigma_{cr\_x,y} = \begin{cases} \sigma_{Ep\_x,y} & \sigma_{Ex,y} \le \frac{R'_{lim}}{2} \\ \sigma_s\left(1 - \frac{\sigma_{sw}}{4\sigma_{Ep\_x,y}}\right) & \sigma_{Ex,y} > \frac{R'_{lim}}{2} \end{cases}$$

where: $\sigma_{cr\_x,y}$— σ_{cr_x} or σ_{cr_y};

$\sigma_{EP\_x,y}$— σ_{Ep_x} or σ_{Ep_y}, to be calculated as follows:

① Ideal elastic buckling stress σ_{Ep_x} of the panel, of which the shorter side in compressive, is defined as follows:

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

where: k_x— buckling factor of shorter side in compression and bending, see Table 7.7.1(1);

C_1— boundary coefficient, see Table 7.7.1 (2).

② Ideal elastic buckling stress σ_{Ep_y} of the panel, of which the longer side in compressive, is defined as follows:

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

where: k_y— buckling factor of longer side in compression and bending, see Table 7.7.1(1);

C_2— boundary coefficient, see Table 7.7.1 (2).

(2) The critical buckling stress τ_{cr} of the panel, which is subjected to shear force, is defined as follows:

$$\tau_{cr} = \begin{cases} \tau_E & \tau_E \le \dfrac{\tau'_{lim}}{2} \\ \tau_s\left(1 - \dfrac{R'_{lim}}{4\tau_E}\right) & \tau_E > \dfrac{\tau'_{lim}}{2} \end{cases}$$

where: τ_E— ideal elastic buckling stress τ_E of the panel, which is subjected to shear force, is defined as follows:

$$\tau_E = k_\tau C_1 \frac{\pi^2 E}{12(1-\nu^2)}\left(\frac{t_p}{s}\right)^2 \quad \text{N/mm}^2$$

where: k_τ— shear buckling factor, see Table 7.7.1 (1).

7.7.2 For panels subjected to bi-axial compression, the critical buckling stresses of the panel are to be calculated as follows:

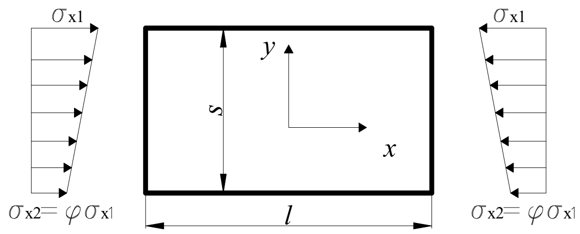
(1) Compression on shorter side: $\sigma_{cr\_x} = C_{\beta_x} R'_{lim}$ N/mm²;

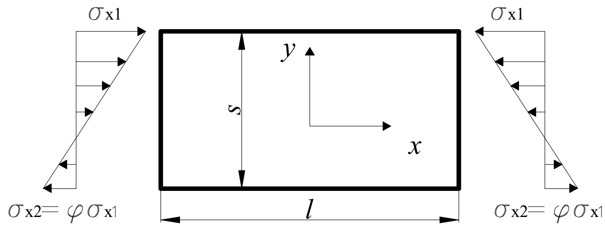
(2) Compression on longer side: $\sigma_{cr\_y} = C_{\beta_y} R'_{lim}$ N/mm²;

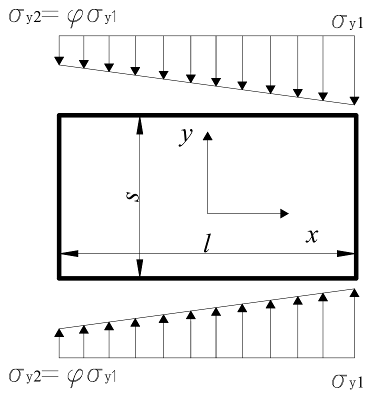
where: $C_{\beta_x} = \begin{cases} \dfrac{2.25}{\beta_x} - \dfrac{1.25}{\beta_x^2} & \beta_x \ge 1.25 \\ 1.0 & \beta_x < 1.25 \end{cases}$, $C_{\beta_y} = \begin{cases} \dfrac{2.25}{\beta_y} - \dfrac{1.25}{\beta_y^2} & \beta_y \ge 1.25 \\ 1.0 & \beta_y < 1.25 \end{cases}$

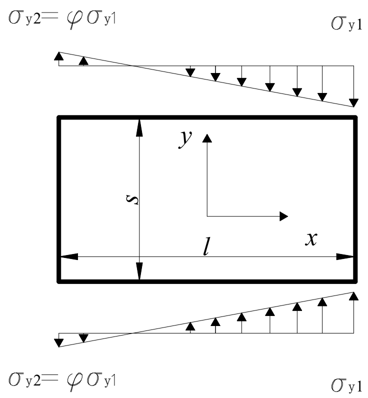
where: $\beta_x = \frac{s}{t_p}\sqrt{\frac{R'_{lim}}{E}}$, $\beta_y = \frac{b}{t_p}\sqrt{\frac{R'_{lim}}{E}}$

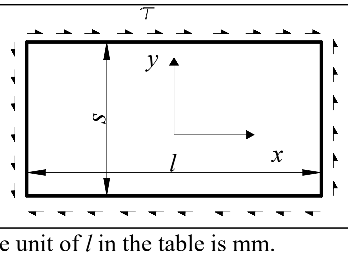
Buckling Factor of Panel **Table 7.7.1(1)**

<table>
<tr><th colspan="2">Model of panel in compressive, bending and shear</th><th>Buckling factor</th></tr>
<tr><td rowspan="2">Compression on shorter side</td><td>


where: 0≤ φ ≤1</td><td>$k_x = \frac{8.4}{\varphi+1.1}$</td></tr>
<tr><td>


where: -1≤ φ <0</td><td>$k_x = 7.6 - 6.4\varphi + 10\varphi^2$</td></tr>
<tr><td rowspan="2">Compression on longer side</td><td>


where: 0≤ φ ≤1</td><td>$k_y = \left[1+(\frac{s}{\ell})^2\right]^2 \frac{2.1}{\varphi+1.1}$</td></tr>
<tr><td>


where: -1≤ φ <0</td><td>$k_y = 1.909(1+\varphi)\left[1+(\frac{s}{\ell})^2\right]^2 - k_p\varphi$
$+10\varphi(1+\varphi)(\frac{s}{\ell})^2$
where:
$k_y = \begin{cases} 24(\frac{s}{\ell})^2 & \frac{\ell}{s} \leqslant \frac{3}{2} \\ 2+16(\frac{s}{\ell})^2+8(\frac{s}{\ell})^4 & \frac{\ell}{s} > \frac{3}{2} \end{cases}$</td></tr>
<tr><td>Edges subjected to shear stress</td><td>


</td><td>$k_t = 5.34 + 4(\frac{s}{\ell})^2$</td></tr>
<tr><td colspan="3">Note: The unit of *l* in the table is mm.</td></tr>
</table>

Boundary coefficients C_1, C_2 of the Panel **Table 7.7.1(2)**

Boundary condition	C_1	C_2
Hollow profile, s/l<500， and the closed area of the hollow profile is greater than $20(s \times t)$	1.1	2.50
Primary supporting member		1.30
Aluminum T profiles and angle		1.21
Aluminum bulb flat		1.10
Aluminum Flat bar	1.0	1.05

7.7.3 The ultimate stress of the panel subjected to the combination of bi-axial compression and shear is to be calculated as follows:

(1) Ultimate stress of panel along axis x σ_{xu}:

$$\sigma_{xu}=\sigma_{cr\_x} \qquad \text{N/mm}^2$$

where: σ_{cr_x}— see 7.7.2(1).

(2) Ultimate stress of panel along axis y σ_{yu}:

$$\sigma_{yu}=R'_{lim}\frac{b_{eff\_y}}{b} \qquad \text{N/mm}^2\text{, and to be taken as not less than } \sigma_{cr\_y}\text{。}$$

where: $b_{eff\_y} = C_{\beta_x}s + 0.115l\left(1-\frac{s}{b}\right)\left(1+\frac{1}{{\beta_x}^2}\right)^2$

β_x — see 7.7.2;

σ_{cr_y} — see 7.7.1(1).

(3) Shear ultimate stress of panel τ_u:

$$\tau_u = \tau_{cr} + \left[0.5\left(R'_{lim}-\sqrt{3}\tau_{cr}\right)\Big/\sqrt{1+\frac{b}{s}+\left(\frac{b}{s}\right)^2}\right] \qquad \text{N/mm}^2\text{, and to be taken as not less than } \tau_{cr}.$$

where: τ_{cr} — see 7.7.1(2).

The above formulae for ultimate stress of panel is only used to check the FE ultimate strength of the panels in 7.6.2.

7.7.4 Ultimate stress of panel subjected to uniformly distributed lateral pressure p_u, is to be calculated as follows:

$$p_u = 4R'_{lim}\left(\frac{t_p}{s}\right)^2\left[1+\left(\frac{s}{b}\right)^2\right]\sqrt{1-\left(\frac{\sigma_{VM}}{R'_{lim}}\right)^2} \qquad \text{N/mm}^2$$

where: σ_{VM} — Von Mises stress of panel's element, N/mm^2.

7.7.5 Unless expressly provided otherwise, the critical buckling stress of the stiffener/primary supporting member is to be specified as follows:

$$\textit{Column}\text{ buckling:} \qquad \sigma_{cr\_a} = \begin{cases} \sigma_{Ea} & \sigma_{Ea} \le \dfrac{R'_{lim}}{2} \\ \sigma_s\left(1-\dfrac{R'_{lim}}{4\sigma_{Ea}}\right) & \sigma_{Ea} > \dfrac{R'_{lim}}{2} \end{cases}$$

Torsional buckling: $\sigma_{cr\_t} = \begin{cases} \sigma_{Et} & \sigma_{Et} \le \frac{R'_{lim}}{2} \\ \sigma_s\left(1 - \frac{R'_{lim}}{4\sigma_{Et}}\right) & \sigma_{Et} > \frac{\sigma_{sw}}{2} \end{cases}$

Local buckling of web: $\sigma_{cr\_web} = \begin{cases} \sigma_{E\_web} & \sigma_{E\_web} \le \frac{R'_{lim}}{2} \\ \sigma_{sw}\left(1 - \frac{R'_{lim}}{4\sigma_{E\_web}}\right) & \sigma_{E\_web} > \frac{R'_{lim}}{2} \end{cases}$

Local buckling of face plate: $\sigma_{cr\_flange} = \begin{cases} \sigma_{E\_flange} & \sigma_{E\_flange} \le \frac{R'_{lim}}{2} \\ \sigma_{sw}\left(1 - \frac{R'_{lim}}{4\sigma_{E\_flange}}\right) & \sigma_{E\_flange} > \frac{R'_{lim}}{2} \end{cases}$

where: σ_{Ea}, σ_{Et}, σ_{E_web}, σ_{E_flange} — see (1), (2), (3) below;

(1) Ideal elastic beam-column compressive buckling stress of stiffener/primary supporting members σ_{Ea}:

$$\sigma_{Ea} = C_{end}\frac{\pi^2 E}{(l/r_{eff})^2} \qquad \text{N/mm}^2$$

where: r_{eff} — $10\sqrt{I_{eff}/A_{eff}}$, in mm, I_{eff} (cm^4) and A_{eff} (cm^2) are the moment of inertia of section and sectional area of member respectively, taking into account of effective breadth of attached plating, where: breadth of attached plating may be taken as the member spacing. If the plate extends only on one side, it is to be taken as half of the member spacing;

C_{end} — end constraint coefficient of member, is to be taken as follows:

$$C_{end} = \begin{cases} 1 & \text{Simple support at both ends} \\ 2 & \text{Simply support at one end, fixed support at the other end} \\ 4 & \text{Fixed support at both ends} \end{cases}$$

(2) Ideal elastic torsional buckling stress of stiffener/primary supporting members σ_{Et}:

$$\sigma_{Et} = \frac{\pi^2 E I_\omega}{I_p l^2 \times 10^4}\left(n^2 + \frac{K_B}{n^2}\right) + 0.385E\frac{I_t}{I_p} \qquad \text{N/mm}^2$$

where: n — number of half waves, see Table 7.7.5(1);

I_t, I_p, I_ω— see Table 7.7.5(2);

$K_B = \frac{C_T l^4}{\pi^4 E I_\omega} \times 10^6$;

$C_T = \frac{E t_p^3}{2.73 s} \times 10^{-3}$.

Number of half waves *n* **Table 7.7.5(1)**

	$0 < K_B \le 4$	$4 < K_B \le 36$	$36 < K_B \le 144$	$(n-1)^2 n^2 < K_B \le n^2(n+1)^2$
n	1	2	3	*n*

Moments of inertia **Table 7.7.5(2)**

Type of inertia moment of section	(1) Aluminum Flat bar	(2) Aluminum flange/angle / Aluminum bulb flat	(3) T profile
I_t, cm^4 St Venant's inertia moment of profile (not including attached plating)	$\frac{h_w t_w^3}{3} \times 10^{-4}$	$\frac{1}{3}\left[h_w t_w^3 + b_f t_f^3\left(1 - 0.63\frac{t_f}{b_f}\right)\right] \times 10^{-4}$	Same as (2)
I_p, cm^4 Polar moment of inertia of section about connection of member to plate	$\frac{h_w t_w^3}{3} \times 10^{-4}$	$\left(\frac{h_w t_w^3}{3} + h_w^2 b_f t_f\right) \times 10^{-4}$	Same as (2)
I_ω, cm^6 Sector moment of inertia of section about connection of member to plate	$\frac{h_w t_w^3}{36} \times 10^{-6}$	$\frac{b_f^3 h_w^2}{12(b_f + h_w)^2}(t_f b_f^2 + 2b_f h_w + 4h_w^2 + 3t_w b_f h_w) \times 10^{-6}$	$\frac{t_f b_f^3 h_w^2}{12} \times 10^{-6}$

(3) Ideal compressive buckling stress of web and face plate of stiffener/primary supporting membersσ_{E_web}、 σ_{E_flange} :

① Aluminum Flat bar: $\sigma_{E\_web} = 5.5(t_w/h_w)^2 \times 10^4$ N/mm^2;

② Welded profiles of symmetrical face plates: $\sigma_{E\_web} = 27(t_w/h_w)^2 \times 10^4$ N/mm^2;

③ Face plates: $\sigma_{E\_flange} = 11(t_f/b_f)^2 \times 10^4$ N/mm^2.

7.7.6 For the calculation of critical buckling stress and ultimate stress, the calculated thickness of aluminum alloy members is to be deducted at least 0.15 mm of the standard deduction of thickness.