GUIDANCE NOTES
GD 05-2004

GUIDELINES FOR DIRECT STRENGTH ANALYSIS OF DOUBLE SIDE SKIN BULK CARRIERS

2004

Contents

Chapter 1 General

1.1 General requirements

1.1.1 For double side skin (DSS) bulk carriers by assigning corresponding harmonised notations of IACS UR S25, direct strength analysis of hull structure is to be carried out in accordance with the Guidelines. If other requirements are involved, the corresponding Rules and Regulations for the Construction and Classification of Sea-going Steel Ships (hereinafter referred to as the Rules) and Guidelines of ISC can be referred.

1.1.2 For bulk carriers of 150m or more in length, which are arranged with the double side skin within the cargo holds and the distance between the outer and inner side skin being 1000mm or more, direct strength analysis of hull structure is to be carried out in accordance with the Guidelines.

1.1.3 For the double side skin structure, the net breadth between the face plates of the transverse frames (for transverse frame type) on the outer and inner skin is not less than 600mm, and that between the face plates of the longitudinal stiffeners (for longitudinal frame type) is not less than 800mm within the parallel middle body and not less than 600mm for the others.

1.1.4 The Guidelines present detailed requirements and methods for direct strength analysis of primary structural members of DSS bulk carriers.

1.1.5 Harmonized notations, additional notations and annotations

This resolution is applicable to "Bulk Carrier" as defined in UR Z11.2.2, having length as defined in UR S2.1 of 150 m or above and contracted for new construction on or after 1 July 2003, harmonized notations as following (1) ～ (3) and annotations as (4) ～ (5):

(1) BC-A: for bulk carriers designed to carry dry bulk cargoes of cargo density 1.0 tonne/m^3 and above with specified holds empty at maximum draught in addition to BC-B conditions.

(2) BC-B: for bulk carriers designed to carry dry bulk cargoes of cargo density 1.0 tonne/m^3 and above with all cargo holds loaded in addition to BC-C conditions.

(3) BC-C: for bulk carriers designed to carry dry bulk cargoes of cargo density less than 1.0 tonne/m^3.

(4) Additional notations:

{maximum cargo density *x.y* (in tonnes/m^3)} for notations BC-A and BC-B if the maximum cargo density is less than 3.0 tonnes/m^3.

{no MP}for all notations when the vessel has not been designed for loading and unloading in multiple ports.

(5) Annotations:

{allowed combination of specified empty holds *a*, *b*, …}for notation BC-A.

1.1.6 The structural FE model and applied loads are to be capable of fully reflecting the following responses of the structure resulting from the local loads and the global longitudinal bending moment:

(1) stresses of longitudinal members;

(2) stresses of primary transverse members, including transverse bulkheads; and

(3) buckling of primary members.

1.1.7 Documents of direct strength analysis submitted for approval:

(1) list of drawings used;

(2) detailed description of FE model of hull structure;

(3) the structural model and relevant physical properties;

(4) material properties;

(5) detailed description of boundary conditions;

(6) details of applied loads;

(7) figures and results showing responses of loads-related with structural FE model;

(8) summary, including figures, of the global and local deformations;

(9) summary, including figures, showing von Mises stress, stresses in x and y directions, and shear stresses of all structural members in compliance with the strength criteria;

(10) analysis and results of plate buckling;

(11) output of the strength assessment;

(12) proposed structure modifications, including yielding and buckling strength , if necessary.

1.2 Definitions

1.2.1 Units

Mass:	t;
Length:	m;
Time:	s;
Force:	N or kN;
Stress:	N/mm^2;
Pressure:	kN/m^2.

1.2.2 Symbols

L — length of ship, in m, as defined in Section 1, Chapter 1, Part two of the Rules;
B — breadth of ship, in m, as defined in Section 1, Chapter 1, Part two of the Rules;
D — moulded depth, in m, as defined in Section 1, Chapter 1, Part two of the Rules;

d — draft, in m, as defined in Section 1, Chapter 1, Part two of the Rules;

C_b — block coefficient, as defined in Section 1, Chapter 1, Part two of the Rules;

V — speed, in kn;

g — gravitational acceleration, $g = 9.81 \text{m/s}^2$;

C_w — wave coefficient;

ρ — seawater specific gravity , $\rho = 1.025 \text{t/m}^3$;

σ_e — von Mises stress (N/mm^2),$=\sqrt{\sigma_x^2 + \sigma_y^2 + \sigma_x\sigma_y + 3\tau_{xy}^2}$

σ_x — stress of element in x direction (N/mm^2);

σ_y — stress of element in y direction (N/mm^2);

τ_{xy} — shear stress of element in xy planes (N/mm^2);

σ_l — stress in longitudinal direction of hull girder (N/mm^2);

σ_w — stress in transverse or vertical direction of hull girder (N/mm^2);

τ — mean shear stress of full depth of the web plate (N/mm^2);

k — material conversion factor;

E — elastic modulus of material, $E = 2.06\times10^5$ N/mm^2 for steel;

ν — Poisson's ratio of material, $\nu = 0.3$ for steel.

Chapter 2 Direct Loads Analysis

2.1 General requirements

2.1.1 While at sea, ships are subjected to wave-induced load, in addition to buoyancy, cargo loads and corresponding inertial loads. This section defines the basic principles for calculation of still water loads and wave loads.

The still water loads and wave loads may be calculated by the codes approved by the Society.

2.2 Still water loads

2.2.1 Weight distribution curve

Breaking up the weight of various items (hull steel, equipments, fittings and cargoes) along ship's length into the trapezoid weight distribution blocks and superimposing the blocks, the weight distribution curve $w(x)$ will be formed in the given conditions.

In general, for bulk carriers of 150 m in length and over, frame spacing is to be as a block for calculating weight distribution curve.

2.2.2 Buoyancy curve

In the balanced floating condition of the ship, the buoyancy of the ship in still water can be determined by the draft. Therefore the buoyancy curve $b(x)$ along ship's length can be obtained based on the ship's lines.

2.2.3 Shear and bending moment curves

The still water shear force $N_s(x)$ and still water bending moment $M_s(x)$ acting on hull girder are obtained from following equations:

$$N_s(x) = \int_0^x [w(x) - b(x)]\mathrm{d}x \qquad \text{kN}$$

$$M_s(x) = \int_0^x N_s(x)\mathrm{d}x = \int_0^x \int_0^x [w(x) - b(x)]\mathrm{d}x\mathrm{d}x \qquad \text{kN}\cdot\text{m}$$

As both fore and aft ends of the hull are free ends, the shear and bending moment curves are to be corrected while shear force and bending moment at end points are not equal to zero.

2.3 Wave loads

2.3.1 Applications

The methods recommended in this section are applied to the ships of:

$$L \leqslant 500\ \text{m}$$
$$L/D \leqslant 17$$

2.3.2 Methods and assumed conditions

(1) Wave loads may be calculated by two-dimensional strip theory or three-dimensional theory.

(2) Sea conditions:

① The P-M spectrum is recommended, described by the following expression:

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

where: θ — relative spreading around the main wave leading, in rad;

$\frac{2}{\pi}\cos2\theta$ — energy spreading function;

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

T_2 — the average zero up-crossing wave period, in s;

ω — angular wave frequency, in rad/s.

② For making a long-term prediction of wave loads, the distribution of wave height for each period is assumed as Rayleigh distribution and all wave headings can be assumed to have an equal probability of occurrence.

(3) Speed is assumed as 0 knot when calculating wave bending moment and as 2/3 the ship's design speed when calculating wave pressure.

(4) Exceedance probability level is taken as 10^{-8} when calculating wave bending moment and as 10^{-4} when calculating wave pressure.

2.3.3 Ship's roll radius of gyration and critical roll damping coefficient:

For design of the ship, the roll radius of gyration may be taken as:	0.35 *B* (full load) 0.32 *B* (ballast)
The critical roll damping coefficient may be taken as:	0.10

2.3.4 Wave loads

(1) Vertical wave bending moment M_v and shear force F_v

Base on the above method and definitions, the vertical wave bending moment M_W in way of mid-ship section can be obtained, and the design wave bending moment M_v along ship's length obtained from the following equations:

hogging $M_V(+) = M \cdot C_{HB} \cdot M_W$ kN·m

sagging $M_V(-) = -M \cdot C_{SB} \cdot M_W$ kN·m

where: M_W — vertical bending moment in way of midship section by the codes, in kN·m;

M — distribution factor of bending moment along ship's length, generally by the Rules;

C_{HB}, C_{SB} — nonlinear correction coefficient, to be obtained from the following equations:

$$C_{SB} = \frac{110(C_b + 0.7)}{95C_b + 55(C_b + 0.7)}$$

$$C_{HB} = \frac{190C_b}{95C_b + 55(C_b + 0.7)}$$

where: C_b — block coefficient, but not less than 0.6.

The vertical wave shear force F_W is to be obtained by the codes, so the design vertical wave shear force F_V along ship's length can be obtained from following equations:

hogging $F_V(+) = F_1 \cdot C_S \cdot F_W$ kN

sagging $F_V(-) = -F_2 \cdot C_S \cdot F_W$ kN

Where: F_W — vertical wave shear force in way of mid-ship section, to be obtained by the codes, in kN;

F_1, F_2 — distribution factor of shear force, to be obtained by the Rules;

C_s — correction coefficient, to be determined by Table 2.3.4.

Correction Coefficient C_s **Table 2.3.4**

Ship's length (m)	C_s	Ship's length (m)	C_s	Ship's length (m)	C_s	Ship's length (m)	C_s
90	1.5212	200	1.2727	320	1.3348	420	1.3471
100	1.4573	220	1.2771	340	1.3474	440	1.3536
120	1.3705	240	1.2870	350	1.3313	460	1.3604
140	1.3190	260	1.3003	360	1.3327	480	1.3674
160	1.2900	280	1.3152	380	1.3365	500	1.3743
180	1.2760	300	1.3276	400	1.3414		

Chapter 3 Design loads

3.1 Cargo pressure in hold

The cargo pressure in hold is to be obtained by the following equation:

$$P_i = 10\rho_c(1+0.35\frac{a_0}{C_b})k_b h_d \qquad \text{kN/m}^2$$

Where: ρ_c — cargo density, in t/m³;

$$\alpha_0 = \frac{3}{L}\left[10.75 - \left(\frac{300-L}{100}\right)^{1.5} + 0.067V\sqrt{L}\right] \qquad 150\text{ m} \leqslant L < 300\text{ m}$$

$$= \frac{1}{L}\left[32.75 + 0.2V\sqrt{L}\right] \qquad 300\text{ m} \leqslant L < 350\text{ m}$$

= additional requirement 350m ⩽ L < 500 m

$$k_b = \sin^2\alpha\tan^2(45° - 0.5\delta) + \cos^2\alpha$$

α— included angle betwe plate and horizontal plane, e.g. 90° for bulkhead and side plate, and 0° for inner bottom plating.

δ — repose angle of cargoes, 35° for ore and coal cargoes, 30° for salt, sand, stone and grain cargoes, and 25° for bulk cement.

h_d— vertical distance from calculating point to cargo top surface, in m. For transverse shape of cargo top surface, see Fig. 3.1, it is assumed that the cargo in hold is uniformly distributed along ship's length.

On cargo top surface, it is uniformly distributed longitudinally; and it is distributed as parabolic curve of the following equation transversely:

$$z_s = h\times(1-\frac{y_s^2}{b^2})$$

where: $b = B_1/2$
B_1 is the breadth of ship;

maximum distance (h) between top surface and connection line, see Fig 3.1:

$$h = \frac{b}{2}\tan\delta \quad (\delta = 35°)$$

area(A) between the parabolic curve and the connection line:

$$A = \frac{2}{3}b^2\tan\delta$$

$$h_d = z_s + h_0 + h_{db} - z$$

where: h_d — distance from cargo top surface to calculating point, in m;

z_s — distance from cargo top surface to connection line, in m;

h_{db} — height of double bottom, in m;

z — vertical height of calculating point, measured from baseline, in m;

h_o — to be calculated according to loading capacity, cargo density and shape of cross section of the hold, but to be not less than distance from top of sloping plate in hopper tank to inner bottom plating, in m.

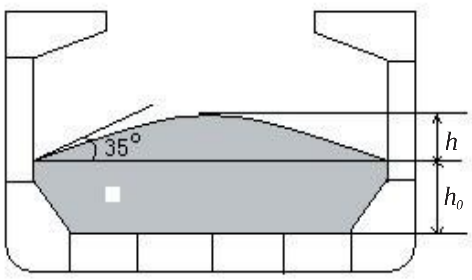


Figure 3.1 Shape of cargo top surface

The pressure-head is up to the top of the air pipe for the ballast tank or fuel oil tank, and the top of the hatch coaming for the cargo hold.

3.2 External sea pressure

The external sea pressure may be determined by direct strength analysis as required in 2.3 or by either of the following methods.

3.2.1 Method 1

(1) Full loading condition

External sea pressure includes hydrostatic pressure and dynamic pressure, and is determined as follows:

At baseline:	$P_b = 10d + 1.5C_w$	kN/m²
At waterline:	$P_w = 3C_w$	kN/m²
At side top:	$P_s = 3P_0$	kN/m²
Dynamic pressure on deck:	$P_d = 2.4P_0$	kN/m²

where: $P_0 = C_w - 0.67(D - d)$

$$C_w = 10.75 - \left(\frac{300 - L}{100}\right)^{1.5} \qquad 90\text{ m} \leqslant L \leqslant 300\text{ m}$$

$$= 10.75 \qquad 300\text{ m} < L < 350\text{ m}$$

$$= 10.75 - \left(\frac{L - 350}{100}\right)^{1.5} \qquad 350\text{ m} \leqslant L \leqslant 500\text{ m}$$

(2) Other loading conditions:

At baseline: $P_b = 10d_a$ kN/m^2

At waterline: $P_w = 0.0$ kN/m^2

Where: d_a is actual draft corresponding to the loading condition, in m.

The formula for dynamic pressure at baseline, waterline and side top are given above. The external sea pressure at other side positions is to be determined by linear interpolation.

3.2.2 Method 2

(1) Hydrostatic pressure

At baseline: $P_b = 10d_a$ kN/m^2

At waterline: $P_w = 0.0$ kN/m^2

(2) Dynamic pressure

① Dynamic pressure at waterline（kN/m^2）:

$$P_{WL} = \frac{f}{4}\max(p_1, p_2)$$

$$p_1 = p_{11} + 135\frac{|\bar{y}|}{B+75} - 1.2(T_1 - Z_w)$$

$$p_{11} = 3k_s C + k$$

$$p_2 = 13\left[|\bar{y}|\frac{50c}{2(B+75)} + C_B\frac{|\bar{y}| + k_f}{14}\left(0.7 + 2\frac{Z_w}{T_1}\right)\right]$$

at waterline $|\bar{y}| = B/2$; $Z_w = T_1$。

② Dynamic pressure at bilge（kN/m^2）:

$$P_{BS} = \frac{f}{4}\max(p_1, p_2)$$

p_1 and p_2 are the same as in the formula for waterline, but $|\bar{y}| = B/2$; $Z_w =$ 0.0.

③ Dynamic pressure at bottom (kN/m^2):

$$P_B = l_f\frac{f}{4}\max(p_1, p_2)$$

p_1 and p_2 are the same as in the formula for waterline, but $|\bar{y}| = B/4$; $Z_w =$ 0.0.

④ Dynamic pressure above side waterline:

$$P_{DK\text{-}side} = P_{WL} - \frac{h}{2}\cdot\frac{f}{4}$$

where: h — height from still waterline to the point considered, in m.

⑤ Dynamic pressure on deck (hatch cover)

$$P_{dk} = 19.6 \cdot \sqrt{H}$$

where: $H = 0.14 \cdot A_i \cdot \sqrt{\frac{V \cdot L}{C_B}} - d_f$

where: A_i — coefficient depending on the longitudinal position of the hatch mid length given in Table 3.2.2(2) ⑤

V — design speed, in kn, but not less than 13 kn;

L — rule length of ship, in m, as defined in URS2;

C_B — block coefficient;

d_f — vertical distance from summer load line to the top of hatch coaming, in m.

Table 3.2.2(2) ⑤

Distance to FP	A_i
FP	2.70
0.05 *L*	2.16
0.10 *L*	1.70
0.15 *L*	1.43
0.20 *L*	1.22
0.25 *L*	1.00

where: T_1 — draft, in m;

$C = 10.75 - [(300 - L)/100]^{3/2}$ $90\text{ m} \leqslant L \leqslant 300\text{ m}$

$= 10.75$ $300\text{ m} < L \leqslant 350\text{ m}$

$= 10.75 - [(L - 350)/150]^{3/2}$ $350\text{ m} < L \leqslant 500\text{ m}$;

$c = (1.25 - 0.025 \frac{2k_r}{\sqrt{GM}})\, k$;

k = 1.2 (without bilge keel)

= 1.0 (with bilge keel)

= 0.8 (with active roll damping facilities);

k_r — roll radius of gyration;

GM — metacentric height, in m;

$k_r = 0.39\, B$ (even distribution of mass)

$= 0.25\, B$ (ore carriers);

$GM = 0.12\, B$;

y — transverse horizontal distance from centerline to the load point, $B/4 \leqslant y \leqslant B/2$;

V — minimum service speed, in kn;

f — indicator of probability level

= 4 (at probability 10^{-4} per cycle)

= 8 (at probability 10^{-8} per cycle, approximately the largest pressure in 20 years);

$k_s = C_B + \frac{0.83}{\sqrt{C_B}}$ (at AP and aft)

$= C_B$ (between 0.2 L and 0.6 L from AP)

$= C_B + \frac{1.33}{C_B}$ (at FP and forward)

Between the specific point, k_s is to be varied linearly;

l_f = 1.0 (at AP and aft)

= 0.5 (between 0.2 L and 0.6 L from AP)

= 1.0 (at FP and forward)

Between the specific point, l_f is to be varied linearly;

k_f — Minimum of T_l and T_f;

T_f — vertical distance from the waterline to the side top at the considered cross section, but not greater than 0.8C.

3.3 Bending moment on end planes

3.3.1 The bending moment applied on end planes of the FE model is to be the actual moment of the planes, including still water bending moment M_s and wave bending moment M_w. When the actual bending moment is not available, alternative one may be taken as 3.3.2 – 3.3.5.

3.3.2 The wave bending moment M_w is to be determined in accordance with the Rules, positive as hogging.

3.3.3 Still water bending moment M_s is to take the maximum bending moment of the model corresponding to the loading condition. If the condition is not available, the condition with full load draft of maximum (or minimum) bending moment that occurs is to be applied subject to correction according to 3.3.4, positive as hogging.

3.3.4 The bending moment applied on the end planes of the FE model is composed of the still water bending moment M_s, wave bending moment M_w and corrected bending moment M_r:

$$M = M_s + M_w - M_r$$

3.3.5 Corrected bending moment M_r:

The corrected bending moment is an additional bending moment due to local loads.

(1) When $L_1 \approx L_2 \approx 0.5\, L_m$ as shown in Figure 4.1

Q_m as the uniformly distributed linear pressure of middle hold model, and Q_e as the uniformly distributed linear pressure of both end holds, positive in upwards direction along vertical coordinate Z:

$Q_m = P_b \times b - W_{mcargo} / L_m$

$Q_e = P_b \times b - W_{ecargo} / L_e$

where: P_b — external pressure on bottom, in kN/m^2, see 3.2;

W_{mcargo}— cargo weight, including weight of ballast water, in the middle hold, taking half of total weight in the hold for half-breadth model, in kN;

W_{ecargo}— cargo weight, including weight of ballast water, in end holds, taking half of total weight in the hold for half-breadth model, in kN;

L_e — Length of end hold corresponding to W_{ecargo}, in m;

L_m — Length of middle hold, in m;

L_0 — overall length of FE model, in m;

b — breadth of model, b = B/2 when half-breadth model is applied, where B is moulded breadth of ship, in m;

$$M_r = \frac{3}{32} \times Q_m L_0^2 + \frac{1}{32} \times Q_e L_0^2 \text{ kN·m}$$

(2) When $L_1 \neq L_2 \neq 0.5\, L_m$ as shown in Figure 4.1, the simple beam calculation method may be applied. In this case the pressure may be obtained by item (1) in the section, and the maximum M_r is to be taken.

Chapter 4 Structural model

4.1 Coordinate definitions

x —— the longitudinal direction, positive forward;
y —— the transverse direction, positive to port from the center line;
z —— the vertical direction, positive upwards from the baseline.

4.2 Model meshing

4.2.1 The 3-D FE model is applied for direct strength analysis of primary members strength of bulk carriers. The extent of 1/2 hold length forward and 1 hold length in the middle and 1/2 hold length aft within mid-ship cargo area in longitudinal direction, and full depth of the ship in vertical direction, (see figure 4.1&4.2). In general, the results of the middle hold, including bulkhead, are applied for strength assessment. The light cargo hold, heavy cargo hold and heavy ballast hold are assessed respectively.

4.2.2 While both primary members and loads are symmetrical to longitudinal centerline plane, only half breadth, port or starboard side, of the ship hull is required to be modeled. In the case of the asymmetrical loads applied, it can be equivalently divided into symmetrical and anti-symmetrical loads (see Fig.4.2); otherwise, a full-breadth model is to be required.

4.2.3 The meshing of the 3-D FE model of hull structure is to be carried out as the longitudinal spacing or similar spacing transversely along the hull envelop, and the frame spacing or similar spacing along hull length. The meshes are to be as square as possible.

4.2.4 In general, all areas of shell plates, deep webs of transverse rings, stringers, plane bulkhead web stiffeners, frames, other members as well as corrugation bulkheads and bulkhead stools are to be modeled by 4-node plate (shell) elements. Triangular elements are to be minimized. In high stress areas and areas of significant stress changes, such as lightening holes, manholes, connection of stool to bulkhead, positions adjacent to brackets or structural discontinuities, triangular elements are to be avoided as practicable as possible.

4.2.5 All stiffeners of plates, which are subject to external sea pressure and cargo pressure, are modeled by eccentric beam elements. The stiffeners and/or face plates of web transverses, frames, floors, girders and brackets may be modeled by rod elements. In view of difficulty in meshing, one line element may represent more than one beam or rod elements.

4.2.6 Not less than 3 plate elements are to be arranged in vertical direction for bottom girders and floors. In general, the elements at the lowest end of bulkhead are to be divided as square as possible.

4.2.7 In general, the web of side frame may be modeled by plate element. In case the ratio of web height of frame against size of grid at side is less than 1/3, beam element may be applied.

4.2.8 Corrugated bulkhead and bulkhead stools: each flange plate or web plate is to be taken at least as a plate element; for the plate elements at the lower end of corrugated bulkhead in the vicinity of lower stool and for the elements adjacent to stool plate, the aspect ratio of sides of grid is to be close to 1.

4.2.9 For lightening holes and manholes of primary members, in particular the openings on girders adjacent to bulkhead and bracket floors adjacent to lower stool in double bottom, plate elements of equivalent plate thickness may be used to consider the effect of these openings.

4.2.10 One independent point is set respectively in way of intersection of neutral axis with longitudinal centerline in fore and aft end planes, and the degree of freedom δ_x, δ_z, θ_y, θ_z for nodes of longitudinal members in end planes are related to the relevant independent points.

4.2.11 The built scantlings are to be applied for the FE model.

4.2.12 Membrane stress, i.e. mid-surface stress of bending plate element, is applied as permissible stress criteria for plate element. Axial stress is employed for beam element.

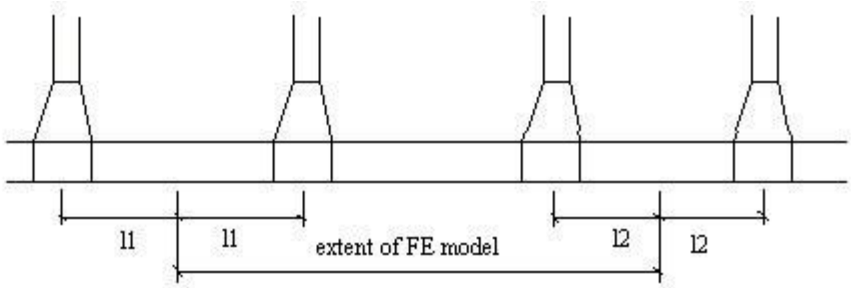


Figure 4.1 Extent of 3D FE Model

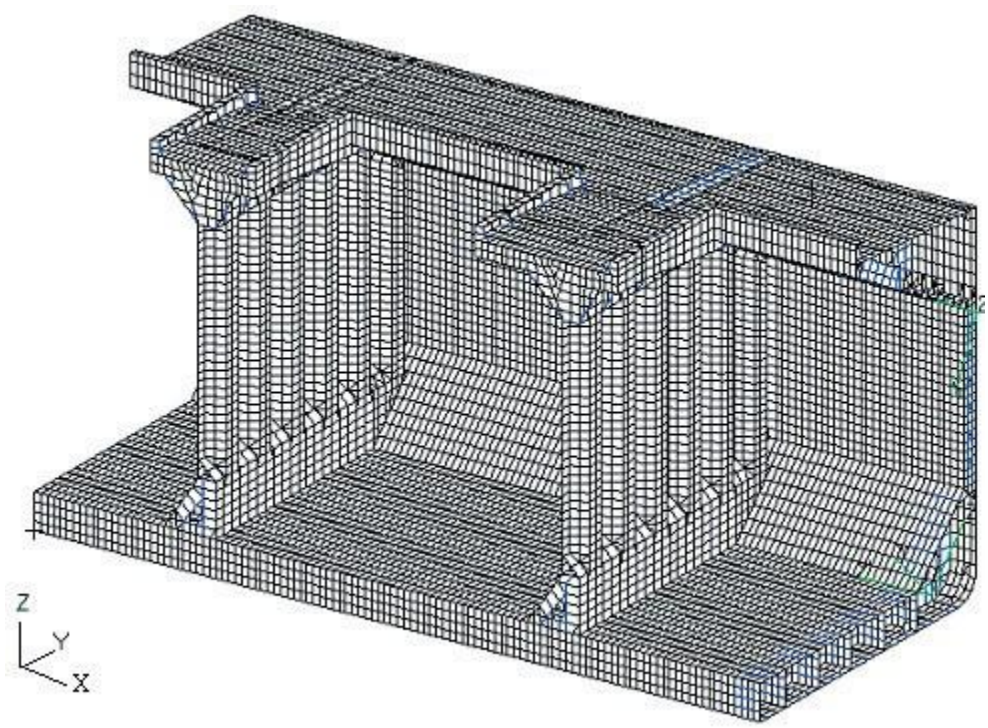


Figure 4.2 3D FE Model

Chapter 5 Boundary conditions

5.1 If the loads are symmetrical on port and starboard sides, the displacements in transverse direction of nodes on longitudinal centerline plane are constrained, and the rotations about the two coordinate axes on longitudinal centerline plane are constrained, i.e. $\delta y = \theta x = \theta z = 0$.

5.2 If the loads are anti-symmetrical on port and starboard sides, the displacements in the directions along the two coordinate axes of nodes on longitudinal centerline plane are constrained, and the rotations about the coordinate axis perpendicular on longitudinal centerline are constrained, i.e. $\delta x = \delta z = \theta y = 0$.

5.3 Constraint of end planes: the independent point at one end constraint δx, δy, δz, θx, θz, and the independent point at the other end constraint δy, δz, θx, θz , as indicated in Table 5.1.

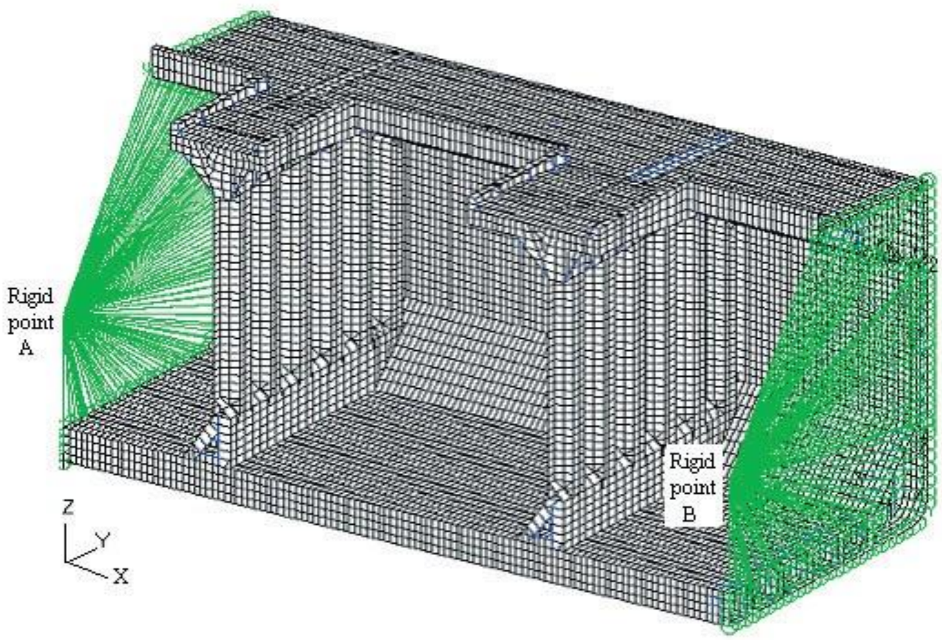


Figure 5.1 Constraint of End Planes

Application of Boundary Conditions

(Boundary with Symmetrical Load) **Table 5.1**

Position	displacement constraint			rotation constraint		
	δx	δy	δz	θx	θy	θz
Longitudinal centerline section	-	Cons.	-	Cons.	-	Cons.
End plane A	Link	-	Link	-	Link	Link
End plane B	Link	-	Link	-	Link	Link
Rigid point A	Cons.	Cons.	Cons.	Cons.	BM	Cons.
Rigid point B	-	Cons.	Cons.	Cons.	BM	Cons.

Notes:

Cons. — constraint corresponding to displacement;
Link — displacement of relevant nodes within end plane linked to independent node
BM — global bending moment applied on end plane

Chapter 6 Loading Conditions

6.1 Design loading conditions (General)

6.1.1 General

(1) BC-C

Homogeneous cargo loaded condition where the cargo density corresponds to all cargo holds, including hatchways, being 100% full at maximum draught with all ballast tanks empty.

(2) BC-B

As required for 6.1.1(1), plus:

Homogeneous cargo loaded condition with cargo density 3.0 tonnes/m^3, and the same filling rate (cargo mass/hold cubic capacity) in all cargo holds at maximum draught with all ballast tanks empty.

In cases where the cargo density applied for this design loading condition is less than 3.0 tonnes/m^3, the maximum density of the cargo that the vessel is allowed to carry is to be indicated with the additional notation {maximum cargo density x.y tonnes/m^3} (see 1.1.5(4)), and the actual cargo density is applied.

(3) BC-A

As required for 6.1.1(2), plus:

At least one cargo loaded condition with specified holds empty, with cargo density 3.0 tonnes/m^3, and the same filling rate (cargo mass/hold cubic capacity) in all loaded cargo holds at maximum draught with all ballast tanks empty.

The combination of specified empty holds shall be indicated with the annotation {holds *a*, *b*, … may be empty}.

In such cases where the design cargo density applied is less than 3.0 tonnes/m^3, the maximum density of he cargo that the vessel is allowed to carry shall be indicated within the annotation, e.g. {holds *a*, *b*, … may be empty, with maximum cargo density *x.y* tonnes/m^3}, and the actual cargo density is applied.

6.1.2 Ballast conditions

(1) Normal ballast condition

① The ballast tanks may be full, partially full or empty. Where partially full option is exercised, the conditions in the last paragraph of S11.2.1.2 are to be complied.

② Any cargo hold or holds adapted for the carriage of water ballast at sea are to be empty.

③ The propeller is to be fully immersed.

④ The trim is to be by the stern and is not to exceed $0.015L$, where L is the length between perpendiculars of the ship.

(2) Heavy ballast condition

① The ballast tanks may be full, partially full or empty. Where partially full option is exercised, the conditions in the last paragraph of S11.2.1.2 are to be complied.

② At least one cargo hold adapted for carriage of water ballast at sea, where required or provided, is to be full.

③ The propeller immersion I/D is to be at least 60%, where

I = the distance from propeller centerline to the waterline

D = propeller diameter.

④ The trim is to be by the stern and is not to exceed $0.015L$, where L is the length between perpendiculars of the ship.

⑤ The moulded forward draught in the heavy ballast condition is not to be less than the smaller of $0.03L$ or 8 m.

6.2 Design loading conditions (for local strength)

6.2.1 Cargo mass definitions

M_H: the actual cargo mass in a cargo hold corresponding to a homogeneously loaded condition at maximum draught.

M_{Full}: the cargo mass in a cargo hold corresponding to cargo with virtual density (homogeneous mass/hold cubic capacity, minimum 1.0 tonne/m^3) filled to the top of the hatch coaming. M_{Full} is in no case to be less than M_H.

M_{HD}: the maximum cargo mass allowed to be carried in a cargo hold according to design loading condition(s) with specified holds empty at maximum draft.

6.2.2 Besides the load conditions of the loading manual, the following conditions should be considered:

Load condition 1: General conditions applicable for all notations.
Load condition 2: Condition applicable for all notations, except when notation {no MP} is Assigned.
Load condition 3: Additional conditions applicable for BC-A notation only.
Load condition 4: Additional conditions applicable for ballast hold(s)only.
Load condition 5: Additional conditions applicable during loading and unloading in harbour only.

6.2.3 The wave loads (pressure and bending moment) are not applied to the load conditions in harbour.

6.3 Load cases

6.3.1 Corresponding to the harmonised notations BC-C, BC-B and BC-A, the load cases include the load conditions in 6.2.2.

6.3.2 According to the load condition requirement, detailed load cases applied to the hull structure strength assessment are in table 6.1.

Load cases

Table 6.1

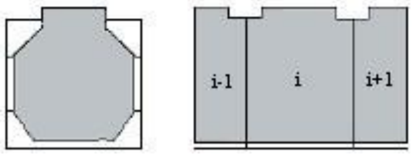
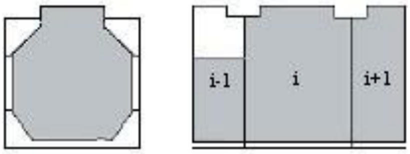
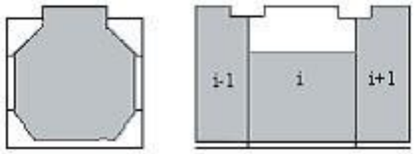
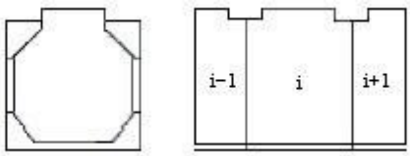
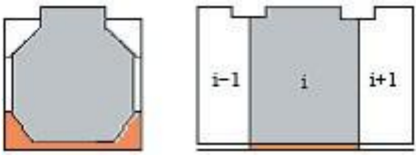
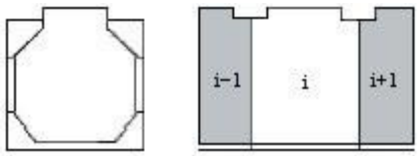
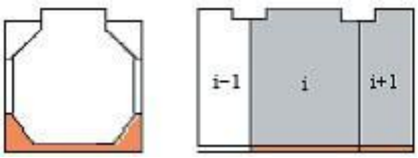
Load condition	No.	Load Case	Mass			Figures
General conditions applicable for all notations	1	LC01	Cargo Mass	i-1	M_{Full}	
				i	M_{Full}	
				i+1	M_{Full}	
			Ballast Mass	i-1	0	
				i	0	
				i+1	0	$d=T$
	2	LC02a	Cargo Mass	i-1	50%M_H	
				i	M_H	
				i+1	M_H	
			Ballast Mass	i-1	0	
				i	0	
				i+1	0	$d=T$
	3	LC02b	Cargo Mass	i-1	M_H	
				i	50%M_H	
				i+1	M_H	
			Ballast Mass	i-1	0	
				i	0	
				i+1	0	$d=T$
	4	LC03	Cargo Mass	i-1	0	
				i	0	
				i+1	0	
			Ballast Mass	i-1	0	
				i	0	
				i+1	0	d= the deepest ballast draught
Condition applicable for all notations, except when notation {no MP} is assigned	5	LC04	Cargo Mass	i-1	0	
				i	M_{Full}	
				i+1	0	
			Ballast Mass	i-1	0	
				i	M_{FO}	
				i+1	0	d=0.67T
	6	LC05	Cargo Mass	i-1	M_{Full}	
				i	0	
				i+1	M_{Full}	
			Ballast Mass	i-1	0	
				i	0	
				i+1	0	d=0.83T
	7	LC06a	Cargo Mass	i-1	0	
				i	M_{Full}	
				i+1	M_{Full}	
			Ballast Mass	i-1	0	
				i	M_{FO}	
				i+1	M_{FO}	d=0.67T

Table 6.1(Continued)

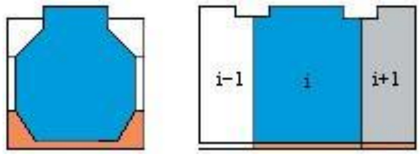
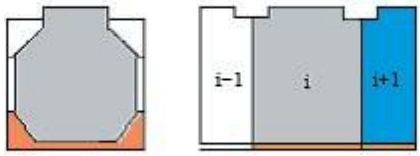
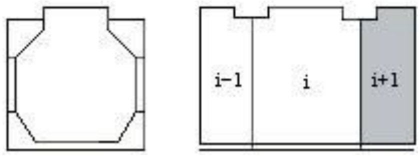
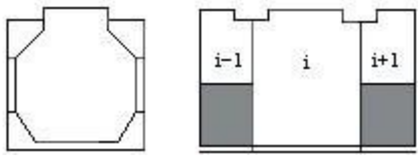
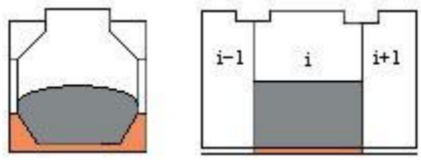
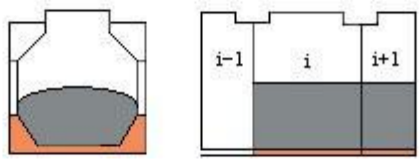
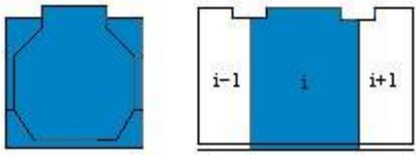
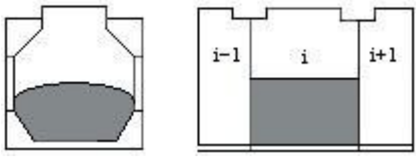
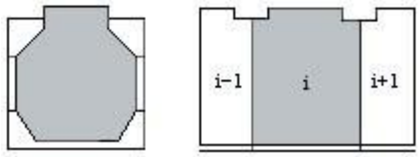
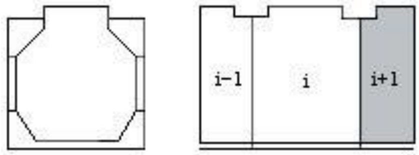
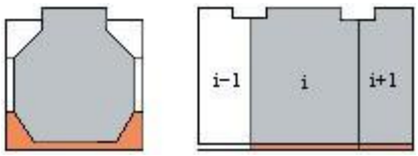
	8	LC06b	Cargo Mass	i-1	0	 d=0.67T
				i	M_{BW}	
				i+1	M_{Full}	
			Ballast Mass	i-1	0	
				i	M_{FO}	
				i+1	M_{FO}	
	9	LC06c	Cargo Mass	i-1	0	 d=0.67T
				i	M_{Full}	
				i+1	M_{Full}	
			Ballast Mass	i-1	0	
				i	M_{FO}	
				i+1	M_{FO}	
	10	LC07	Cargo Mass	i-1	0	 d=0.75T
				i	0	
				i+1	M_{Full}	
			Ballast Mass	i-1	0	
				i	0	
				i+1	0	
Additional conditions applicable for BC-A notation only	11	LC08	Cargo Mass	i-1	M_{HD}	 d=T Only for hold i being light cargo hold
				i	0	
				i+1	M_{HD}	
			Ballast Mass	i-1	0	
				i	0	
				i+1	0	
	12	LC09	Cargo Mass	i-1	0	 d=T Only for hold i being heavy cargo hold
				i	M_{HD}+10%M_H	
				i+1	0	
			Ballast Mass	i-1	0	
				i	M_{FO}	
				i+1	0	
	13	LC10	Cargo Mass	i-1	0	 d=T Only this case in design load condition
				i	M_{HD}+10%M_H	
				i+1	M_{HD}+10%M_H	
			Ballast Mass	i-1	0	
				i	M_{FO}	
				i+1	M_{FO}	

Table 6.1(Continued)

Additional conditions applicable for ballast hold(s) only	14	LC11	Cargo Mass	i-1	0	
				i	M_{BW}	
				i+1	0	
			Ballast Mass	i-1	0	*d*= any heavy ballast draught
				i	M_{DHBW}	Only for hold i being heavy ballast hold
				i+1	0	
Additional conditions applicable during loading and unloading in harbour only	15	LC12a (BC-A)	Cargo Mass	i-1	0	
				i	M_{HD}	
				i+1	0	
			Ballast Mass	i-1	0	
				i	0	d=0.67T
				i+1	0	Only for hold i being heavy cargo hold
	16	LC12b	Cargo Mass	i-1	0	
				i	M_{Full}	
				i+1	0	
			Ballast Mass	i-1	0	
				i	0	d=0.67T
				i+1	0	
	17	LC12c	Cargo Mass	i-1	0	
				i	0	
				i+1	M_{Full}	
			Ballast Mass	i-1	0	
				i	0	d=0.67T
				i+1	0	
	18	LC13	Cargo Mass	i-1	0	
				i	M_{Full}	
				i+1	M_{Full}	
			Ballast Mass	i-1	0	
				i	M_{FO}	d=0.67T
				i+1	M_{FO}	

Note: M_{BW} = ballast mass in the heavy ballast hold,
M_{DHBW} = ballast mass in the ballast tank,
M_{FO} = fuel oil mass in the fuel oil tank.

Chapter 7 Strength Criteria

7.1 Stresses at the mid surface of plate bending elements, and axial stress of beam elements are to be applied for assessment.

7.2 In general, the stress of primary members in the typical loading conditions should not exceed permissible stresses (or allowable stresses) specified in Table 7.1.

7.3 For bulkheads, the stress in way of corrugation end may be obtained by extrapolation of average stresses of bulkhead plating.

7.4 The average shear stress τ means the average shear stress over depth of the web of primary members.

7.5 For those elements of concentrated stress and poor shape, the stresses should not be taken into consideration.

Maximum Permissible Stresses

Table 7.1

Type of Structure	Permissible stresses			
	σ_e N/mm²	σ_l N/mm²	σ_w N/mm²	τ N/mm²
Main deck plating	220/k	210/k	-	-
Inner and outer bottom plating	220/k	210/k	145/k	-
Slope plate of top side tanks and hopper tanks, outer and inner side shell, side stringer or platform plating	220/k	210/k	145/k	115/k
Double bottom girder	235/k	210/k	-	115/k
Floor and transverse bulkhead	175/k	-	-	95/k
Stool plate, transverse web frame	195/k	-	-	95/k
others	195/k	-	-	

Symbols

σ_e = von Mises stress, given by

$$\sigma_e = \sqrt{\sigma_x^2 + \sigma_y^2 - \sigma_x \sigma_y + 3\tau_{xy}^2}$$

where: σ_x = stress of element in direction x;
σ_y = stress of element in direction y;
τ_{xy} = shearing stress of element in xy planes.

In this table: σ_l = stress in longitudinal direction of hull girder
σ_w = stress in transverse or vertical direction of hull girder.
τ = shear stress; taken by the average shear stress full depth of the web for girders and floors;
k = conversion ratio of material

Axial stress of beam element (N/mm²)	
Beam on transverse members	176/k
Beam on longitudinal members	206/k

Chapter 8 Evaluation of Buckling Strength

8.1 General requirements

8.1.1 All primary members are to be subjected to flat plate buckling evaluation. Special attention shall be given to following areas:

(1) double-bottom floors, especially those in mid-length of hold

(2) double-bottom girders, especially those in way of both ends of hold adjacent to bulkhead or stool and the plate in way of the first opening from bulkhead or stool in double bottom mid-length of hold

(3) top side tank, deck and side shell plate

(4) bottom plate and inner-bottom plating, especially those in way of both ends of hold adjacent to bulkhead or stool and mid-length of hold

(5) bulkhead and stool, especially those in way of mid-span and area adjacent to stool and side plating of stool

8.1.2 The evaluation of plate buckling is based on the standard thickness deduction as given in Table 8.1.1.

8.1.3 While determining buckling, bi-directional axial compressing stress and shear stress are to be considered, and the stress at mid surface of the plate is generally applied for buckling evaluation.

8.1.4 While determining buckling safety factor, boundary constraint coefficient "c" as defined in paragraph 2.2.7, Part two of the Rules, is taken into consideration.

8.1.5 The required minimum buckling safety coefficient λ given in Table 8.1.2 should be satisfied for buckling check.

Standard Thickness Deduction for Critical Buckling Strength

Table 8.1.1

Location		Thickness deduction (mm)
Ballast tank within 1.5m of weather deck	Connected with ballast water on one side	1.0
	Connected with ballast water on both sides	2.0
Other areas		1.0

Required Safety Factor λ for Buckling **Table 8.1.2**

Structure	Buckling safety factor λ
Deck and top side tank plating	1.0
Bottom plating, inner bottom and hopper tank plating	1.0
Double bottom girder	1.0
Double-bottom floor and web transverse in top side tank and hopper tank	1.1
Transverse water-tight bulkhead and stool	1.2
Transverse bulkhead and stool in deep tank	1.2
Note: λ = critical buckling stress/applied stress	

8.2 Methods of buckling evaluation

Either of the following methods may by applied:

8.2.1 Method 1: FE Method

(1) Modeling
When addressing the issue of stability based on the net scantlings, the thickness of the panel selected for buckling is deduced as specified in Table 8.1.1. The requirements of meshing are not less than 8 meshes at each side, preferably in square shape.

(2) Loads and boundary conditions
Loads: the results of σ_x, σ_y, τ_{xy} (i.e. applied stress) for stresses at mid surface of the panel, as calculated by FE model, are taken in the specified conditions and multiplied respectively by the original thickness without deduction to get the corresponding loads.

$$Nx = \sigma_x \times t_o$$
$$Ny = \sigma_y \times t_o$$
$$Nxy = \tau_{xy} \times t_o$$

where:

t_o is original plate thickness.
The loads are to be applied on relevant boundaries.
Where compressive stresses being significantly variable between plate panels, the loads may be applied as linearly distribution, and the average shear stress is to be taken.

Boundary conditions:
The displacements in x-direction at the midpoints of longitudinal boundaries and in y-direction at the midpoints of transverse boundaries should be constrained. The displacement in z-direction at the 4 sides boundaries should be constrained, as shown in Figures 8.2.1 and 8.2.2.

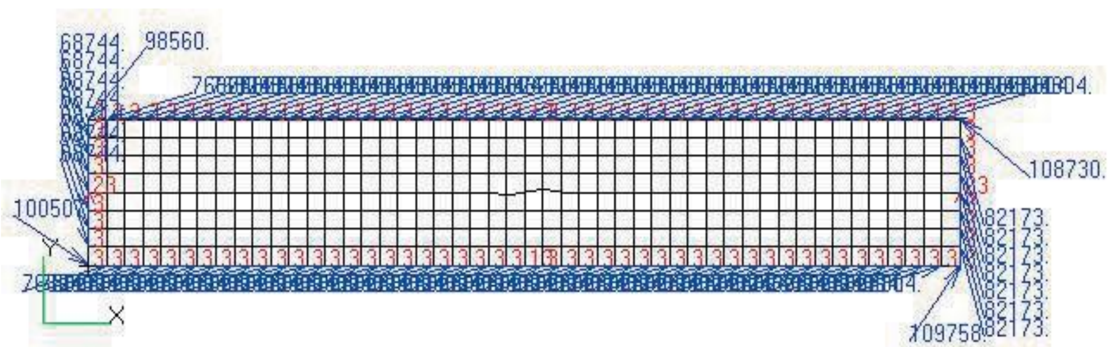


Figure 8.2.1 Model where bi-directional loads and shear force are applied

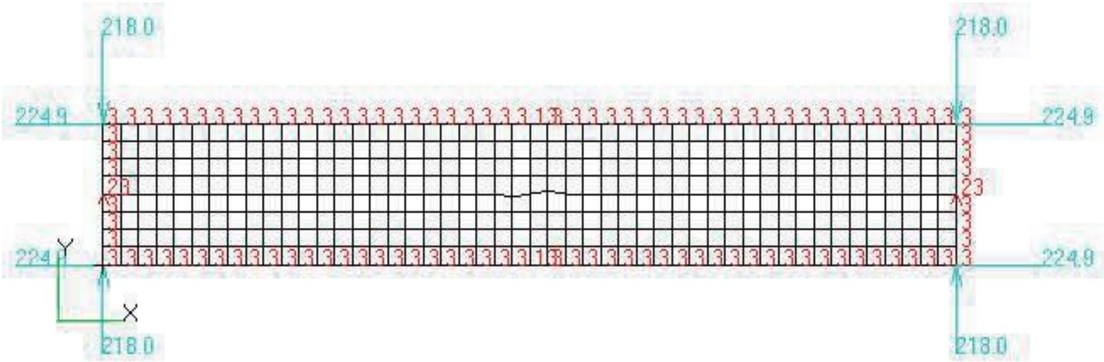


Figure 8.2.2 Model where bi-directional loads are applied

Notes: ① Either of applied pressures as shown in both Figure 8.2.1 and Figure 8.2.2 are acceptable.
② Figure 8.2.1 indicates the nodal loads, and Figure 8.2.2 indicates the edge pressure of the boundary loads.

(3) Buckling evaluation

The factor shown in FE analysis post-processing of is the critical buckling factor λ. The results can be obtained by multiplying with the boundary constraint coefficient as defined in 8.1.4, and should not be less than the safety factor specified in Table 8.1.2.

8.2.2 Method 2: Simplified Method

(1) The stresses at mid surface of the panel, by FE method, are corrected by the standard thickness deduction specified in Table 8.1.1:

$$\sigma_A = \sigma t/(t - t_r)$$

where: σ_A — working stress in buckling evaluation;
σ — stress obtained by FE analysis;
t — original plate thickness applied in FE analysis;
t_r — standard thickness deduction as specified in Table 8.1.1.

(2) Critical buckling stress and elasticity correction

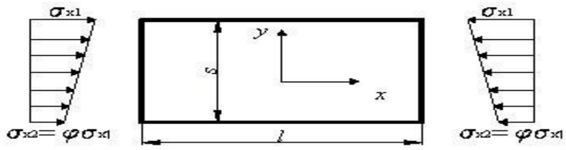
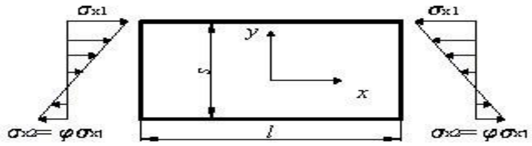
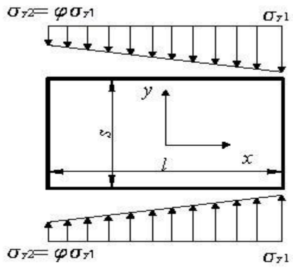
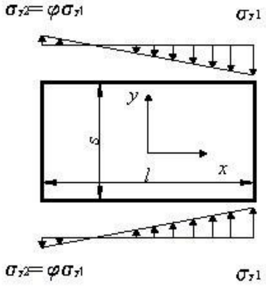
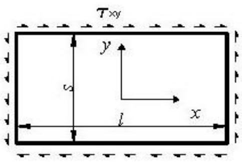
① The elastic critical buckling stress σ_{xcr_e} of the plate panel, of which the shorter side is subjected to compression, is defined as follows:

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

where: k_x — buckling coefficient for shorter side subjected to compression and bending specified in Table 8.2.1;
C_1 — boundary constraint coefficient specified in Table 8.2.2;
t — thickness of plate panel, in mm;
s — length of shorter side of plate panel, in mm, taken as spacing of longitudinals or stiffeners;
x — defined as axial direction of longer side of plate panel.

Buckling Coefficients of Plate Panel

Table 8.2.1

	Mechanical model of plate panel subjected to compression, bending and shearing	Buckling coefficient
Compression on shorter sides	 where：$0 \le \varphi \le 1$	$k_x = \dfrac{8.4}{\varphi + 1.1}$
	 where：$-1 \le \varphi < 0$	$k_x = 7.6 - 6.4\varphi + 10\varphi^2$
Compression on longer sides	 where：$0 \le \varphi \le 1$	$k_y = \left[1 + (\dfrac{s}{l})^2\right]^2 \dfrac{2.1}{\varphi + 1.1}$
	 where：$-1 \le \varphi < 0$	$k_y = 1.909(1+\varphi)\left[1 + (\dfrac{s}{l})^2\right]^2 - k_p \varphi + 10\varphi(1+\varphi)(\dfrac{s}{l})^2$ where: $k_p = \begin{cases} 24(\dfrac{s}{l})^2 & \dfrac{l}{s} \le \dfrac{3}{2} \\ 2 + 16(\dfrac{s}{l})^2 + 8(\dfrac{s}{l})^4 & \dfrac{l}{s} > \dfrac{3}{2} \end{cases}$
Shearing on sides		$k_t = 5.34 + 4(\dfrac{s}{l})^2$

Boundary Constraint Coefficients C_1 and C_2 of Plate Panel Table 8.2.2

Boundary	C_1	C_2	
		Within double bottom or double hull	Other locations
Angel or T-bar	1.1	1.3	1.2
Flat plate or bulb bar	1.0	1.2	1.1

② The elastic critical buckling stress σ_{ycr_e} of the plate panel, of which the longer side is subjected to compression, is defined as follows:

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

where: K_y — buckling coefficient for longer side subjected to compression and bending specified in Table 8.2.1;

C_2 — boundary restraint coefficient specified in Table 8.2.2;

y — defined as axial direction of shorter side of plate panel;

Others are the same as those in ① .

③ The elastic critical buckling stress τ_{cr_e} of the plate panel, which is subjected to shearing, is defined as follows:

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

where: k_t — shear buckling coefficient specified in Table 8.2.1;

Others are the same as those in ① and ② .

④ The elastic critical buckling stress of plate panel is to be corrected as follows:

$$\sigma_{\substack{xcr\\(ycr)}} = \begin{cases} \sigma_{\substack{xcr\_e\\(ycr\_e)}} & \text{when } \sigma_{\substack{xcr\_e\\(ycr\_e)}} \le \dfrac{\sigma_S}{2} \\ \sigma_S\left(1-\dfrac{\sigma_S}{4\sigma_{\substack{xcr\_e\\(ycr\_e)}}}\right) & \text{when } \sigma_{\substack{xcr\_e\\(ycr\_e)}} > \dfrac{\sigma_S}{2} \end{cases}$$

$$\tau_{cr} = \begin{cases} \tau_{cr\_e} & \text{when } \tau_{cr\_e} \le \dfrac{\tau_S}{2} \\ \tau_S\left(1-\dfrac{\tau_S}{4\tau_{cr\_e}}\right) & \text{when } \tau_{cr\_e} > \dfrac{\tau_S}{2} \end{cases}$$

where: σ_{xcr_e}, σ_{ycr_e}, τ_{cr_e} — elastic critical buckling compressive stress and critical buckling shear stress of plate panel along axes X and Y respectively, with referred to ① , ② and ③ ;

σ_S — Yield strength of material, in N/mm^2;

τ_S — $\frac{\sigma_S}{\sqrt{3}}$

(3) Buckling strength evaluation

① The ratio λ of the critical buckling stress of plate panel with composite stress to the actual compressive stress, determined by Table 8.2.3, is not to be less than the safety factor specified in Table 8.1.2.

② The absolute values of σ_x, σ_y and τ_{xy} are applied for the evaluation and they are taken as zero when the working stress along axis x or y is tensile.

λ Calculation **Table 8.2.3**

Stress status \ Ratio of plate panel	$1 \le \frac{l}{s} \le \sqrt{2}$	$\sqrt{2} < \frac{l}{s} \le 8$
Bi-directional compression	$\frac{1}{(1+k_1)}\frac{\sigma_{xcr}}{\sigma_x}$	$\frac{1}{\sqrt{(1+k_1^2)}}\frac{\sigma_{xcr}}{\sigma_x}$
Compression along axis X + shear	$\frac{1}{\sqrt{(1+k_2^2)}}\frac{\sigma_{xcr}}{\sigma_x}$	
Compression along axis Y + shear	$\frac{1}{\sqrt{(1+k_3^2)}}\frac{\sigma_{ycr}}{\sigma_y}$	
Bi-directional compression + shear	$\frac{1}{\sqrt{(1+k_1^2+k_2^2)}}\frac{\sigma_{xcr}}{\sigma_x}$	

Where:

$$k_1 = \frac{\sigma_y/\sigma_{ycr}}{\sigma_x/\sigma_{xcr}}, \quad k_2 = \frac{\tau_{xy}/\tau_{cr}}{\sigma_x/\sigma_{xcr}}, \quad k_3 = \frac{\tau_{xy}/\tau_{cr}}{\sigma_y/\sigma_{ycr}}$$

Notes: ① σ_{x1} and σ_{y1} are the greater values of working stresses acting on sides of plate panel along axes X and Y; σ_{x2} and σ_{y2} are the smaller values of such stresses, and σ_x and σ_y are to be taken as the average values of σ_{x1}, σ_{x2} and σ_{y1}, σ_{y2} and σ_{y2} respectively; τ_{xy} is the average shear stress. σ_{x1}, σ_{x2}, σ_{y1}, σ_{y2} and τ_{xy}, as shown in Table 8.2.1.

② σ_{xcr}, σ_{ycr} and τ_{cr} are the elastically corrected critical buckling compressive stresses and critical buckling shear stress of plate panel along axes *X* an *Y* respectively.