GUIDANCE NOTES

GD05-2005

China Classification Society

GUIDELINES FOR DIRECT STRENGTH ANALYSIS OF CONTAINER SHIP

2005

Contents

Chapter 1 General

1.1 General requirements

1.1.1 The Guidelines apply to the direct strength analysis as specified in Chapter 7 “Container Ships”, PART TWO of the Rules for Classification of Sea-Going Steel Ships (hereinafter referred to as the Rules) by China Classification Society, and to the direct calculations of strength of main structural members of hull structure of unconventional and special container ships not covered by the Rules.

1.1.2 The Guidelines provide ways to evaluate strength of the whole ship, of the primary structure of cargo hold and of local structure of deck hatch corner under given loads.

1.1.3 The fatigue strength check of hull structure is to be in accordance with CCS Guidelines for Fatigue Strength of Ship Structure.

1.1.4 Structural model and given loads are to fully reflect the following structural response:

- stress of longitudinal members under local load and overall longitudinal bending moment;
- stress of main transverse members (including transverse bulkheads);
- buckling characteristics of main members.

1.1.5 Technical documents of direct calculations to be submitted for approval are to include:

(1) List of drawings used;

(2) Detailed description of load conditions in still water, including draft and curve of still water bending moment distribution;

(3) Detailed description of wave load conditions, including calculated data of wave load in three directions (if any) for each condition and curves of distribution;

(4) Detailed description of inertial load (or acceleration) for each condition;

(5) Detailed description of finite element model of hull structure;

(6) Details of characteristics of materials used;

(7) Detailed description of boundary conditions;

(8) Details of applied loads;

(9) Figures and results showing structural model response related to load;

(10) Summary, including figures, of global and local deformations;

(11) Summary, including figures, showing Von Mises stress, stresses in x and y directions and shear stress of all members in compliance with strength criteria;

(12) Plate buckling analysis and results;

(13) Tabular output showing results meeting or not meeting strength standard;

(14) If necessary, proposed structure modifications, including stress evaluation and buckling characteristics.

1.1.6 For finite element structural analysis of whole ship, it is recommended that the designer cycle is to discuss the calculation procedure requirements with CCS at the early stage of design.

1.1.7 When the calculation program to be used is other than those listed in the Compass system of CCS, the applicant is to provide relevant supporting documents for that program subject to consent of CCS.

1.2 Definitions

1.2.1 The units adopted for calculations in the Guidelines are:

Mass:	Ton (t);
Length:	Metre (m);
Time:	Second (s);
Force:	Newton (N) or kilonewton (kN);
Stress:	Newton/milimetre^2 (N/mm^2);
Pressure:	Kilonewton/metre^2 (kN/m^2).

1.2.2 Definition of symbols

L	—	Ship's length, in m, as defined in Section 1, Chapter 1, PART TWO of the Rules;
B	—	Ship's breadth, 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 m/s^2;
C_w	—	Wave coefficient;
ρ	—	Density of seawater, ρ = 1.025 t/m^3;
σ_x	—	Stress of element in x direction, in N/mm^2;
σ_y	—	Stress of element in y direction, in N/mm^2;
τ_{xy}	—	Shear stress of element in xy planes, in N/mm^2;
σ_e	—	Von Mises stress, in N/mm^2, = $\sqrt{\sigma_x^2+\sigma_y^2-\sigma_x\sigma_y+3\tau_{xy}^2}$;
σ_1	—	Longitudinal stress of hull girder, in N/mm^2;
σ_w	—	Transverse or vertical stress of hull girder, in N/mm^2;
τ	—	Average shear stress within overall web depth, in N/mm^2;
k	—	Material conversion factor;
E	—	Elastic modulus of material, E = 2.06×10^5 N/mm^2 for steel;
v	—	Poisson's ratio of material, v = 0.3 for steel.

1.3 Scantlings of structural members

1.3.1 The scantlings of structural members for direct calculations in the Guidelines are defined to take the construction sizes (as in the drawing). If "net" scantlings are used, the relevant allowable stress is to be specially considered.

Chapter 2 Direct Calculations of Global Strength of Whole Ship

2.1 General requirements

2.1.1 For container ships of which the structural scantlings and arrangement are as follows, direct calculations are in general to be applied for assessment of global strength of their primary structure:

- The structural arrangement is of non-conventional type, or the structural scantlings are other than those as specified in the Rules;
- The width of strength deck hatch is greater than 0.89 B.

2.1.2 Where direct calculations are intended to be used for assessment of global strength of primary structure of a container ship, the FE model, loading conditions and strength criteria may be in accordance with the Guidelines.

2.1.3 Application of direct calculations of global strength using FE model of entire hull:

(1) to assess the global strength of primary structure of hull under combined bending and torsional moment, with respect to the characteristics of its torsion strength of container ships;

(2) to provide boundary conditions for fine mesh analysis of local structure (if any), e.g.:

- detailed analysis for hatch corner at the connection of container hold area with the engine room structure;
- detailed analysis for hatch corner at the connection of the upper deck including hatch side coaming;

(3) to provide boundary conditions for detailed analysis of non-conventional arrangement.

2.2 Finite element model for calculations

2.2.1 Extent of finite element model

2.2.1.1 The ship's global three-dimensional finite element model covers hull structure within ship's complete length and full breadth, including all effective longitudinal material in main hull, bow and stern structures, engine room and superstructure, etc.: deck plating, side shell, longitudinal bulkhead and double bottom. The model covers also primary transverse structures such as transverse bulkhead, floor frame and transverse deck strip, etc. Local supporting members such as bracket are not considered in the model. Openings in girders and brackets are omitted.

2.2.1.2 When the structure and loads are symmetric either port or starboard, port may be represented for ship's model and symmetrical boundary conditions are to be applied to the longitudinal center plane.

2.2.2 Type of elements

2.2.2.1 All kinds of structures in the model are discretized with the construction thickness into following types based on their structural responses:

- Shell element (four-node and three-node element):
  Deck, side shell and bottom, inner bottom, bottom girder, longitudinal and transverse bulkheads, floor, wing space web, side girder, etc. Warped element is to be avoided for shell plate, in particular bilge plate, and triangular elements are to be used for this kind of simulation;
- Beam element:
  Girder, beam and watertight bulkhead stiffener, etc.;
- Rod element:
  Pillar, etc.

2.2.2.2 Secondary members on plating may be lumped to equivalent beam element and put them on mesh boundary of plate element. The sectional area of this beam element is the sum of members and its sectional properties are to be considered for eccentric setting of connection of equivalent beam with plating.

2.2.2.3 Mesh size of elements:

- Longitudinally: 1 element for each spacing of double bottom floors;
- Transversely: 1 element for each spacing of girders;
- Vertically: 1 element for each spacing of vertical girders or deck.

The aspect ratio of elements in midship range may be set as about 1:3, and that for other ranges at about 1:2.

2.2.3 Coordinate system

Right-handed Cartesian coordinate system is adopted as the global coordinate system of the ship's model, with the original point at the intersection of frame no. 0 at aft perpendicular with baseline in ship's longitudinal center plane:

- x axis: in ship's longitudinal direction, from frame no. 0 at stern to bow as positive;
- y axis: in ship's transverse direction, from centreline to port as positive;
- z axis: in ship's vertical direction, upward from baseline as positive.

Figure 2.2.1 shows the finite element model of a typical container ship

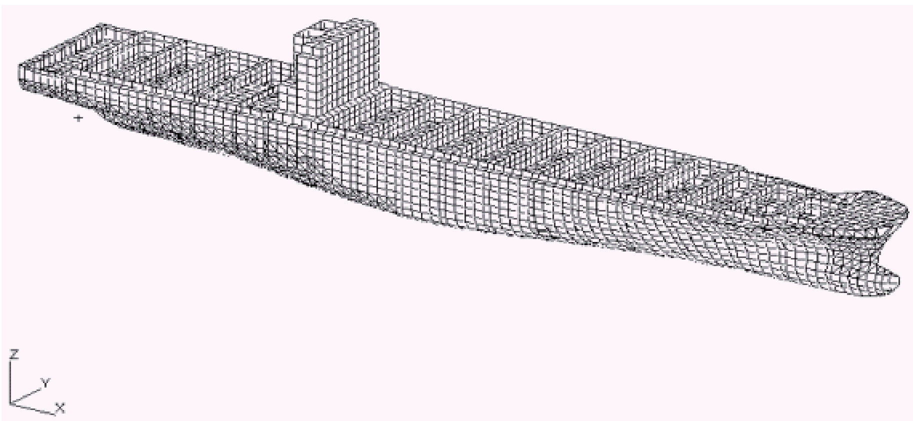


Figure 2.2.1 Structural Finite Element Model of a Typical Complete Container Ship

2.3 Loading conditions

2.3.1 Each calculation condition consists of load condition in still water and wave load condition.

2.3.2 Still water condition

2.3.2.1 The still water condition is to be selected according to loading manual, and generally the full load condition where maximum still water bending moment occurs is to be taken as the still water condition for calculation.

2.3.2.2 The still water condition for calculation is generally to include the following loading cases: Ship is in upright condition, at or near to the scantling draft. One 40'bay in midship range is to be left empty, and the still water bending moment within 0.4 L amidships is maximum.

2.3.3 Wave load condition

2.3.3.1 The load under still water condition as determined according to paragraph 3.2 is taken as the basic loading condition for wave load conditions.

2.3.3.2 Parameters of wave load conditions, such as length, height and phase of waves, are to be determined by the method and procedure used for determining design waves, see Determination of Design Waves in this Appendix.

2.3.3.3 The wave load conditions determined by design waves are to include head sea and oblique sea conditions.

2.3.4 Calculation conditions

2.3.4.1 Each calculation condition is based on different combination of still water condition and wave load condition. For container ships, conditions generally to be calculated are given in Table 2.3.4.1.

Calculation Conditions **Table 2.3.4.1**

Wave condition / Still water condition	No.1: Maximum vertical wave bending moment	No.2: Maximum horizontal wave bending moment	No.3: Maximum torque L/2	No.4 Maximum torque 3L/8	No.5 Maximum torque 5L/8
Full load condition	LC1	LC2	LC3	LC4	LC5

Notes: ① The wave load (bending moment) for each condition in the Table is applied to corresponding nodes of ship's model by simulation through design waves.

② For ships designed for unrestricted service, the prediction of the maximum wave load likely to be experienced during their service life covers mainly sea conditions to be encountered during navigation in sea areas around the world, expressed in the probability of waves occurring in various periods and heights. It is suggested that the wave scatter diagram and two- or three-dimensional wave theory recommended by IACS be adopted for calculation of values for long-term prediction at various probability levels of wave spectrum. The probability level of prediction value order of the maximum vertical wave bending moment approximately corresponding to values obtained by calculations in accordance with the Rules is taken as the probability level of direct calculations.

The hull is placed on the determined regular waves, and the external load acting on the hull due to waves may be simulated by design waves. The load responses due to length, phase and height of such design waves are equivalent to values for long-term prediction.

Figure 2.3.4.1 is a flowchart of procedure in direct calculations for complete ship's three-dimensional finite elements model.

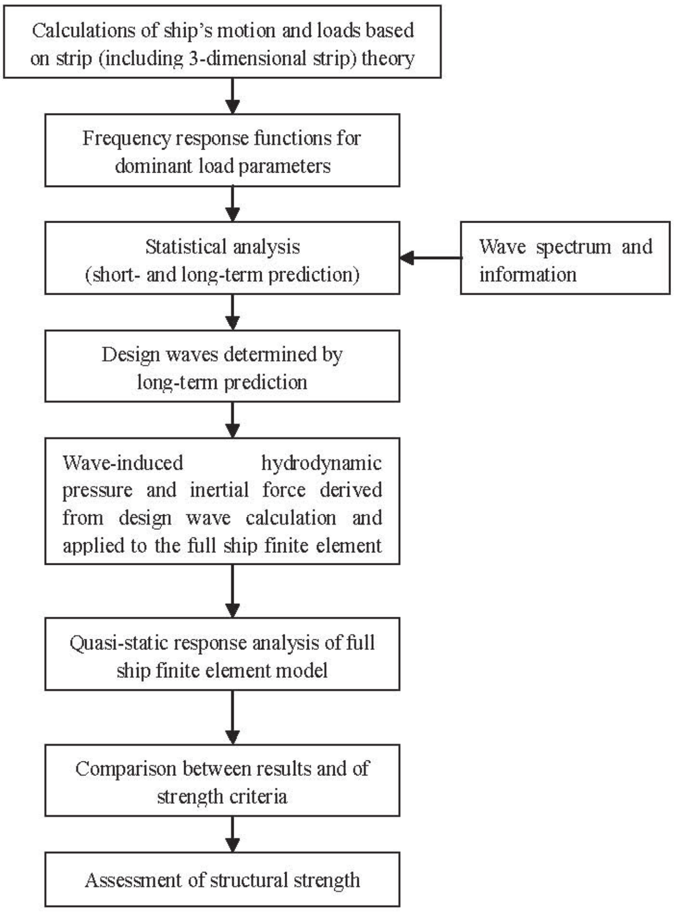


Figure 2.3.4.1 Flow Chart of Direct Calculations

2.3.5 The components of each loads in the above conditions may be sorted into the following types:

2.3.5.1 Light weight. The ship's finite element model may be divided into a series of areas along distribution curve of light weight in longitudinal direction and use the different material density to simulate the light weight by controlling of material density. The weight of machines in their respective areas acts as joint force on corresponding model nodes. Other secondary equipment and machinery are also simulated by material density in their areas.

2.3.5.2 The weight of cargo (containers) in hold and on deck, which acts, according to load distribution areas, on corresponding nodes.

2.3.5.3 External hydrostatic pressure, which acts, according to draft under the calculation condition, on external wet surface of hull.

2.3.5.4 Wave pressure. The hydrodynamic pressure on elements of wet surface is to be obtained by calculation program based on two-dimensional strip theory and applied on shell elements of hull.
2.3.5.5 Inertial force, to be obtained by multiplying mass model consisting of structural mass and cargo mass with acceleration of nodal motion. Application of inertial forces on nodes and dynamic balance of external forces in ship's finite element model may be achieved by CCS/NASLOAD — loading and dynamic balance adjustment program.

2.4 Boundary conditions

2.4.1 After the ship's dynamic balance is adjusted, the calculation model is basically in a free dynamic balance (free body), and in order to prevent rigid body motion, 6 displacement constraints are applied at corresponding nodes of hull as shown in Figure 2.4.1.

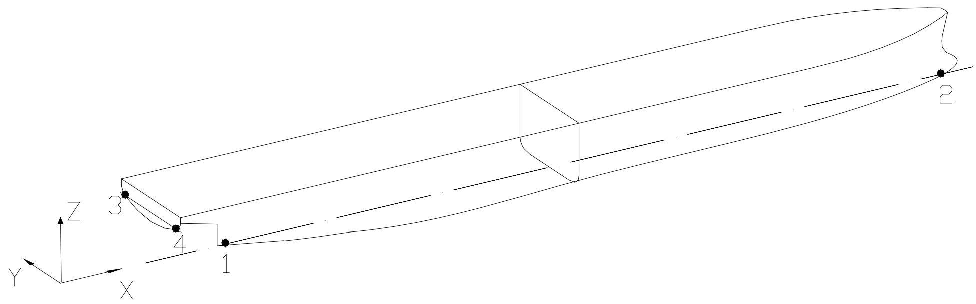


Figure 2.4.1 Diagram of Boundary Condition

2.4.2 Constraint conditions for bottom plate keel in longitudinal centerline plane at aft end (node 1 in Figure 2.4.1) and fore end (node 2 in Figure 2.4.1) are as follows:
Aft end node 1: transverse constraint:

$$\delta_y = 0$$

Fore end node 2: longitudinal, transverse and vertical constraint:

$$\delta_x = \delta_y = \delta_z = 0$$

2.4.3 Constraint conditions for node 3 (left side) and node 4 (right side) which are equally distant from longitudinal center plane on horizontal girder of aft closing plate are as follows:
Node 3 and node 4: vertical constraint:

$$\delta_z = 0$$

2.5 Allowable stress

2.5.1 The plate stress membrane stress at centroid of element.

2.5.2 The allowable stresses of plates including girder web is as follows:

$$[\sigma_e] = 190/k \quad \text{in N/mm}^2$$

$$[\tau] = 100/k \quad \text{in N/mm}^2$$

2.5.3 The allowable stress of beam element:

$$[\sigma_e] = 190/k \quad \text{in N/mm}^2$$

2.5.4 The allowable stress of plating at local stress concentration:

$$[\sigma_e] = 235/k \quad \text{in N/mm}^2$$

Chapter 3 Direct Calculations of Primary Structure of Cargo Hold

3.1 General requirements

3.1.1 The direct calculations of local strength of cargo hold are performed to evaluate (verify) the strength of the following primary structure within cargo area with regard to local-load considerations:

- double bottom structure;
- transverse (transverse bulkhead, transverse web frame) structure;
- side (longitudinal bulkhead) structure.

3.1.2 Direct calculations of hold structure are to be carried out where structural arrangement is as either one of the follows:

- *B* > 32.2 m; or
- width of hatch in strength deck is greater than 0.85 *B*.

where: *B* — Breadth of the ship, in m, as defined in Section 1, Chapter 1 of PART TWO of the Rules.

3.2 Structural modeling

3.2.1 Normally, the extent of model covers “1/2 hold + 1 hold + 1/2 hold” cargo area located at about amidship, i.e. the length of four 40 feet container bays in ship’s length direction, the ship depth in vertical direction and the breadth of the ship (the change of in hull form is to be ignored) in transverse direction.

3.2.2 The finite element model is generally to cover transverse watertight bulkheads and transverse open bulkheads. Within a model of the length of two holds, the transverse open bulkheads are at both ends and the middle. Figure 3.2.2 shows a typical finite element hold model (port half of the model).

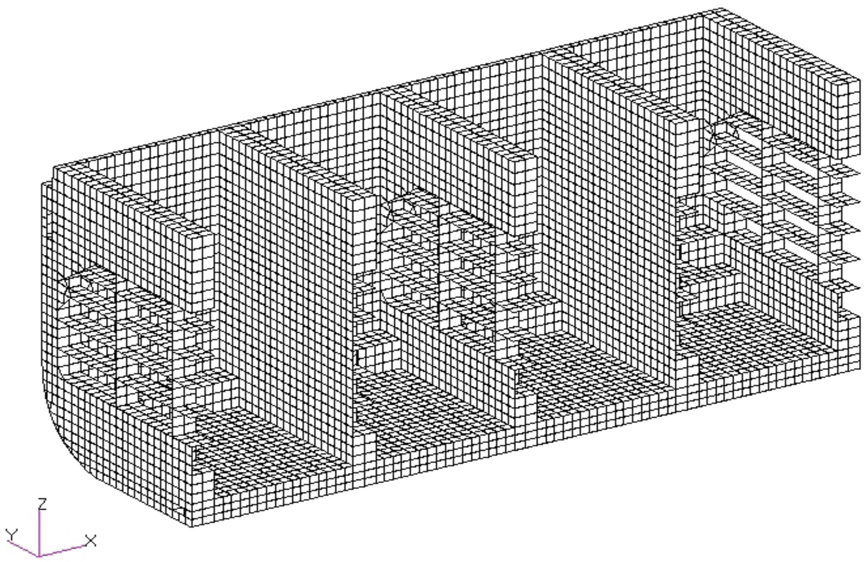


Figure 3.2.2 Typical Finite Element Hold Model

3.2.3 The coordinate of the finite element model is taken as right-handed system, i.e.:

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

3.2.4 Unless specified otherwise, the scantlings indicated on drawings are taken as the value of thickness, length, etc. of members in finite element model.

3.2.5 All primary plating such as shell, inner skin, girders, transverse bulkhead structure including its vertical and horizontal stringer webs are simulated plate elements. Secondary members such as frames on plating are simulated beam elements, with the eccentric section properties for connection of plating.

3.2.6 Faceplate of members is simulated rod element, with the axial area as the faceplates.

3.2.7 Stiffener on web is simulated rod element, with the axial area as the cross-section area of the stiffener.

3.2.8 The meshing of finite elements is to be performed as follows:

(1) 1 element for each spacing of longitudinals in transverse and vertical direction of hull;

(2) 1 element for each spacing of frames in longitudinal direction of hull;

(3) web of primary members(such as longitudinal stringer in double sides, transverse web frame, double bottom girder and floor as well as vertical and transverse girders on transverse bulkhead): 3 elements with depth of web of these members.

3.2.9 In general, all openings in the frame web between double sides or in double bottom floor may be modeled by deleting the appropriate elements in the corresponding position. Figures 3.2.9(1) to 3.2.9(3) show typical finite element transverse member models.

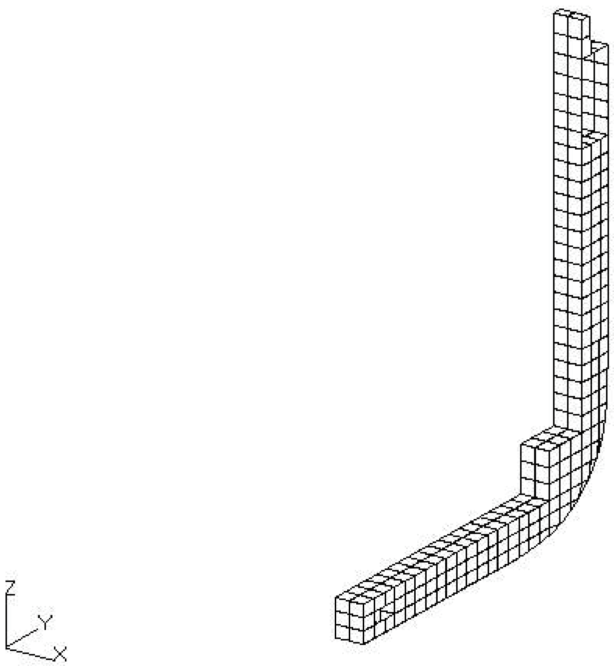


Figure 3.2.9 (1) Typical Finite Element Transverse Model with Cutoff

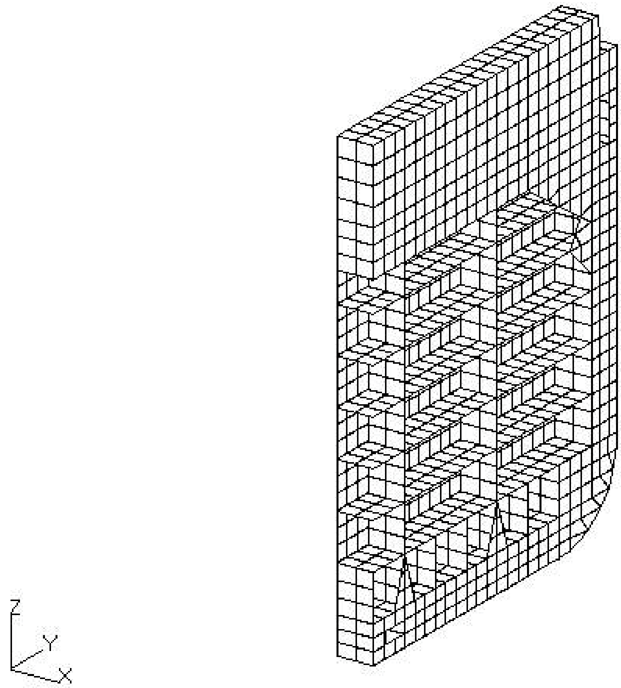


Figure 3.2.9 (2)   Typical Finite Element Model of a Transverse Watertight Bulkhead

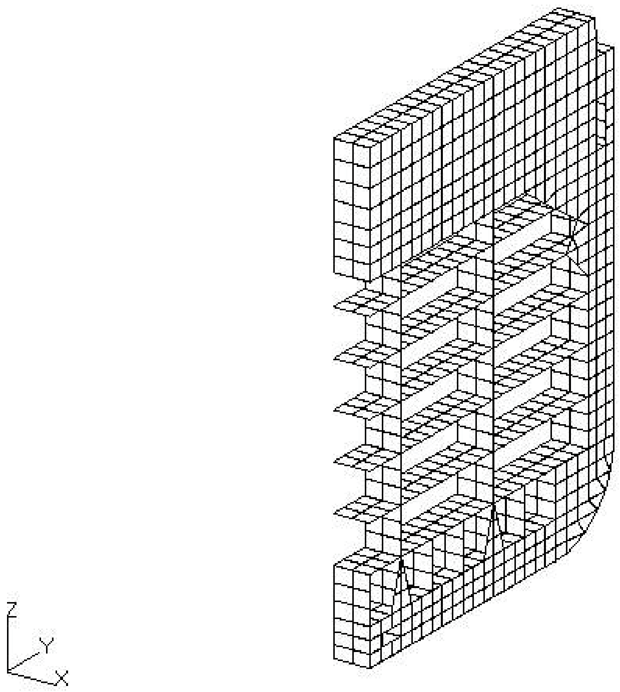


Figure 3.2.9 (3)   Typical FE Model of an Open Bulkhead

3.3 Conditions for calculation

3.3.1 Table 3.3.1 and Figure 3.3.1 show the loading conditions to be considered for direct calculations.

Conditions for Calculation **Table 3.3.1**

Condition description	Condition identification no	External load		Cargo (containers) load				Type of boundary condition
		Load in still water	Wave load	Cargo hold		Over hatch cover		
One empty middle hold with 40 ft container locations	Cond 1 (LC1)	d_s(1)	P_W(2)	Empty bays	-	Empty bays	-	symmetric
	Cond 1G (LC1G)			Other bays	40 ft	Other covers	40 ft	
	Cond 2 (LC2)	d_s(1)	P_W(2)	Empty bays	-	Empty bays	40 ft	symmetric
	Cond 2G (LC2G)			Other bays	40 ft	Other covers	40 ft	
	Cond 3 (LC3)	d_s(1)	P_W(2)	Empty bays	-	Empty bays	20 ft	symmetric
	Cond 3G (LC3G)			Other bays	20 ft	Other covers	20 ft	
1 empty middle hold with 40 ft container locations during heeling	Cond 4 (LC4)	d_s(4)	-	Empty bays	-	Empty bays	-	asymmetric
				Other bays	40 ft	Other covers	40 ft	
Heeling of ship	Cond 5 (LC5)	d_s(4)	-	All bays	20 ft	All covers	20 ft	asymmetric
Surging of ship	Cond 6 (LC6)	-	-	40 ft containers loaded in all holds, with longitudinal load due to longitudinal acceleration		40 ft containers loaded on all hatch covers, with longitudinal load due to longitudinal acceleration		symmetric

(1) d_s — draft of structure, in m;

(2) P_W — local wave pressure due to wave crest, as shown in Figure 3.5;

(3) heeling angle to be taken as equal to 30° or tan-1 (2 (D - d_s) /B), whichever is lesser, under heeling conditions (LC4, LC5);

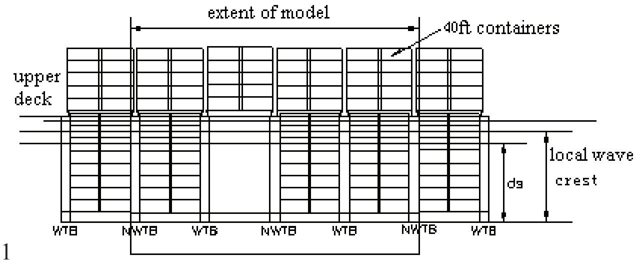
(4) load (20 ft, 40 ft) within hold to be taken as maximum allowable container weight;

(5) load (20 ft, 40 ft) on hatch cover to be taken as maximum stack weight;

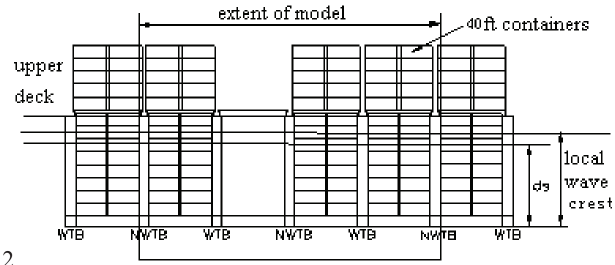
(6) for condition 6, load within hold and on hatch cover to be determined as specified in paragraph 3.3.7;

(7) conditions for load calculations under overall longitudinal bending moment to be considered where conditions 1, 1G, and 3G are corresponding conditions, as detailed in paragraphs 3.3.2 and 3.3.3.

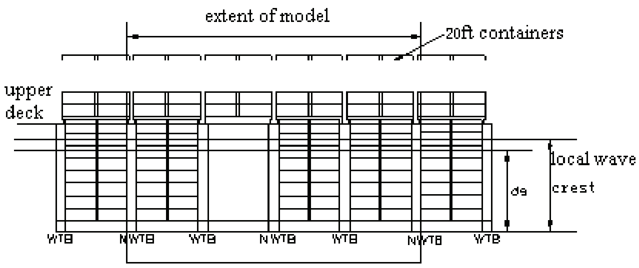
3.3.2 For strength assessment of double bottom girder, inner bottom and shell plating under loading conditions 1, 2 and 3, it is to be considered for the stress composition resulting from the stress due to the overall longitudinal bending moment acting on hull girder and the stress along ship's length due to local loads. The hull girder stress may be calculated by means of the FE method as specified in the Guidelines, and the boundary conditions are given in paragraph 3.4.3 below.



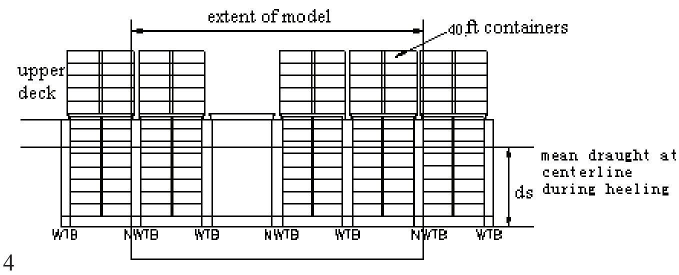
Condition 1



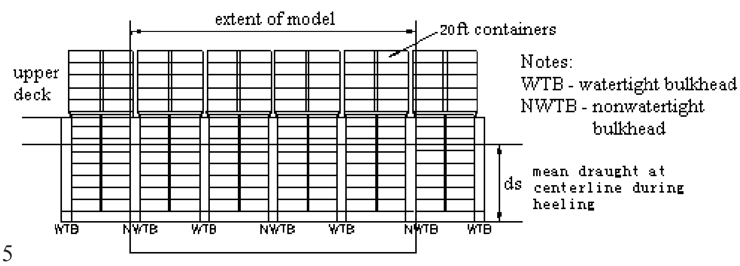
Condition 2



Condition 3



Condition 4



Condition 5

Figure 3.3.1 Illustration of loading conditions

3.3.3 The overall longitudinal bending moment of hull girder consists of still water bending moment and wave bending moment. The still water bending moment is taken as the maximum permissible hogging moment within 0.4 L amidships under all loading conditions as indicated in loading manual, and the wave bending moment (hogging) is calculated according to Chapter 2, PART TWO of the Rules.

3.3.4 The load components to be included are as follows:

- the light weight;
- the container loads;
- the hydrostatic pressure due to draft;
- the additional pressure due to local wave crest, as stated in paragraph 3.3.5;
- the longitudinal loads acting on containers due to longitudinal acceleration of ship, to be calculated according to paragraph 3.3.7.

3.3.5 The additional wave pressure acting on side and bottom is shown in Figure 3.3.5:

at waterline: $P_W = k_W \times 3\ C_W$ kN/m^2

at baseline: $P_B = k_B \times 1.5\ C_W$ kN/m^2

at side top: $P_S = 0$ kN/m^2

$k_W = 1.1$

$K_B = 1.5$

linear interpolation between P_W and P_B

C_W — wave coefficient:

$C_W = 10.75 - ((300 - L) / 100)^{1.5}$ 90 m $\leqslant L \leqslant$ 300 m

$C_W = 10.75$ 300 m $< L \leqslant$ 350 m

$C_W = 10.75 - ((L - 350) / 150)^{1.5}$ 350 m $< L \leqslant$ 500 m

$P_W = 3.3\ C_W$
$P_B = 2.25\ C_W$
d_s — draft of structure
linear interpolation between P_W and P_B

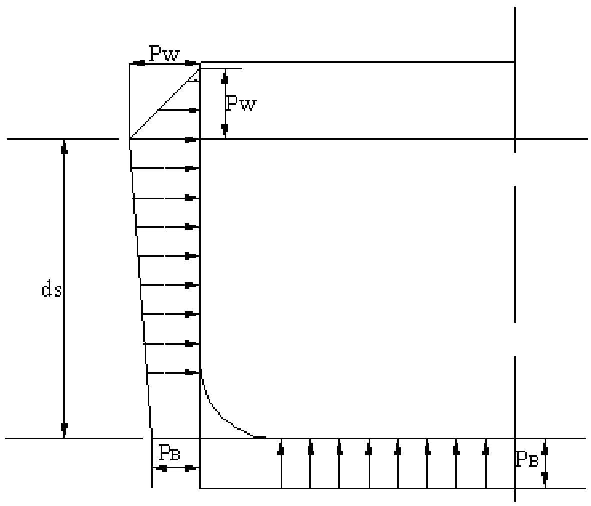


Figure 3.3.5 Distribution of Wave Crest at Side and Bottom of Container Ship

3.3.6 For the heeled cases (4 and 5), the loads are to be calculated assuming that the ship is held at the required static heel angle. The transverse load components of containers in holds are to be distributed to suitable locations on the transverse bulkheads. The loads from containers above deck are to be distributed as sheer loads to the top of the transverse coaming.

3.3.7 Determination of longitudinal load acting on containers induced by acceleration of longitudinal motion of ship

3.3.7.1 Where longitudinal deck girders are fitted and the span of cross deck box is not greater than 13. 0 m, the condition 6 is not needed to be considered.

3.3.7.2 The calculation of acceleration of longitudinal motion of ship under condition 6 is to be in accordance with 3.4 of Chapter 3 of CCS Guidelines for Fatigue Strength of Ship Structure, and as follows:

Longitudinal composite acceleration al is to be calculated as follows:

$$a_l = \sqrt{a_x^2 + \left[a_p(z - z_{rp}) + 10\sin\psi_m\right]^2} \quad \text{in m/s}^2$$

where: (1) z — vertical distance from the point for calculation to baseline, in m;

(2) z_{rp} — vertical distance from rotating axis for rolling and pitching to baseline, taken as the lesser of values obtained per following two formulas:

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

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

where: D — ship depth, in m;

d — draft, in m.

(3) a_x — surging acceleration, to be calculated as follows:

$$a_x = 2a_0\sqrt{C_b}$$

where: C_b — block coefficient;

a_0 — acceleration coefficient, to be calculated as follows:

$$a_0 = 3C_w / L + C_v V / \sqrt{L}$$

where: $C_v = \sqrt{L}/50$, taken as not greater than 0.2;

L — ship's length, in m;

V — speed, in kn;

C_w — coefficient, to be calculated according to paragraph 3.4.3.

(4) a_p — acceleration at pitching angle, to be calculated as follows:

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

where: T_p — pitching period, in s, to be calculated as follows:

$$T_p = 1.80\sqrt{L/10} \quad \text{in s}$$

where: L — ship's length, in m.

(5) ψ_m — maximum pitching angle, in rad, to be calculated as follows, but not to be greater than 0.14:

$\psi_m = 0.25\ a_0 / C_b$ in rad

where: C_b — block coefficient;

a_0 — acceleration coefficient, see 3.3.7.2 (3).

3.3.7.3 The forces arising from acceleration of longitudinal motion of each container within hold is distributed from corresponding corners of the container to the primary members of transverse bulkhead (or transverse open bulkhead) in way of cell guides.

3.3.7.4 Determination of load due to containers on hatch cover

(1) The longitudinal forces from containers on each hatch cover are to be calculated at mid-height of the stack. The moment about stack base caused by longitudinal forces may be ignored;

(2) The weight of containers is to be taken as the largest permitted by the Loading Manual;

(3) The longitudinal forces from containers sited between the ship's side and the longitudinal hatch coaming may be ignored;

(4) 15% of the total longitudinal force acting on hatch cover is to be distributed on nodes at top of longitudinal and transverse hatch coamings to simulate friction force to which the bearing pads at hatch coaming are subjected due to longitudinal motion;

(5) The remaining 85% of the longitudinal forces on hatch cover are to be as acting nodes of the longitudinal stop positions. If the stop positions are unknown, then they are assumed to be located at the mid-breadth of the aft end of the hatch cover. Three covers are to be assumed if the number of hatch covers is unknown.

3.4 Boundary conditions

3.4.1 Centerline plane

3.4.1.1 For symmetrical structural configuration and load cases (e.g. conditions 1, 2, 3 and 6), half breadth FE model (e.g. port) may be taken, with following symmetrical restraint conditions applied to all nodes on longitudinal centerline plane (in Figure 3.4.1):

Restraint of displacement along transverse axis, i.e. $\delta_y = 0$;

Restraint of rotation around longitudinal axis, i.e. $\theta_x = 0$;

Restraint of rotation around vertical axis, i.e. $\theta_z = 0$.

3.4.2 Boundary conditions for local loads

3.4.2.1 The boundary conditions given in this section applied to the finite element model with symmetrical loads are shown in Table 3.3.1. The boundary conditions for fore and aft end planes of the model may be taken symmetrically.

3.4.2.2 All nodes within the fore and aft end planes of the model (see figure 3.4.1) are restrained as follows:

Plane A: Restraint of displacement along ship's longitudinal axis, i.e. $\delta_x = 0$;

	Restraint of rotation around ship's transverse axis,	i.e. $\theta_y = 0$;
	Restraint of rotation around ship's vertical axis.	i.e. $\theta_z = 0$.
Plane B:	Restraint of rotation around ship's transverse axis,	i.e. $\theta_y = 0$;
	Restraint of rotation around ship's vertical axis.	i.e. $\theta_z = 0$.

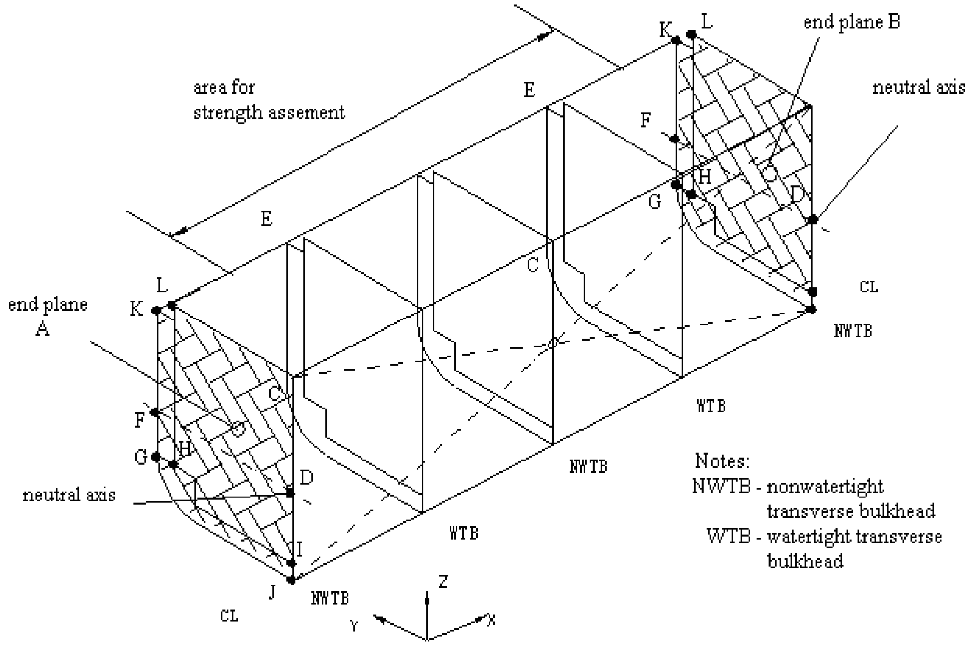


Figure 3.4.1 Symbols for Boundary Conditions for Calculation Conditions

3.4.2.3 K and L respectively within end planes A and B, at top of the intersection of hopper tank with side plating and longitudinal bulkhead plating are restrained against displacement along vertical axis, i.e. $\delta_z = 0$, in order to eliminate rigid displacement. Two groups of vertical forces are applied to other nodes on lines of intersection LH and KG in order to reduce stress concentration at supports due to vertical constraints, i.e.: the sum of vertical forces is to be equal to that of cargo loads acting on the whole model and external water pressure (vector sum) in opposite direction.

3.4.2.4 For condition 6 (force arising from acceleration of longitudinal motion applied on transverse bulkhead), side plating and longitudinal bulkhead at both ends (ends A and B) are respectively restrained against vertical displacement at top K of upper deck and top L of longitudinal hatch coaming, i.e. $\delta_z = 0$.

3.4.3 Boundary conditions for calculation of overall longitudinal bending stress of hull girder

3.4.3.1 The boundary conditions apply only to calculation of hull girder bending stress by means of finite element model.

3.4.3.2 Overall longitudinal bending moment of hull girder is applied to intersection D (set as an independent point or the main node in the model) of neutral axis of transverse hull section and longitudinal center plane within end planes A and B. The half of overall longitudinal bending moment is to be taken for half breadth finite element model.

3.4.3.3 Boundary conditions for end planes A and B: following restraint conditions rigidly with degree of freedom linked to independent point (i.e. the master node) are applied to all nodes on longitudinal material (non-independent or slave-points), within the planes except node D:

displacement along longitudinal axis, i.e. δ_x;

rotation around transverse axis, i.e. θ_y;

rotation around vertical axis, i.e. θ_z.

3.4.3.4 Constraints for independent point (master node) D within end planes A and B are as follows:

restraint of rotation around vertical axis: $\theta_z = 0$;

restraint of displacement along transverse axis and longitudinal axis and of rotation around longitudinal axis: $\delta_y = \delta_z = \theta_x = 0$.

3.4.3.5 Restraint of displacement along longitudinal axis at independent point D within end plane A: $\delta_x = 0$.

3.4.3.6 Intersection F of neutral axis with side shell respectively within ends A and B is restrained against displacement along vertical axis, in order to eliminate rigid displacement, i.e. $\delta_z = 0$.

3.4.4 Boundary conditions for asymmetrical load conditions 4 and 5

3.4.4.1 The boundary conditions apply to heeling conditions with asymmetrical load conditions. The full breadth FE model is to be taken into account.

3.4.4.2 Fore and aft symmetrical conditions are applied respectively to end planes A and B, as specified in paragraph 3.4.2.2.

3.4.4.3 Intersections G an H of hopper tank with side plating and longitudinal bulkhead plating respectively within end planes A and B are restrained against displacement along vertical axis, i.e. $\delta_z = 0$. Two groups of vertical forces are applied to other nodes on lines of intersection LH and KG to reduce stress concentration at supports due to vertical constraints, i.e.: the sum of such vertical forces is to be equal to that of cargo loads acting on the whole model and external water pressure (vector sum) in opposite direction.

3.4.4.4 Nodes I and J of longitudinal center girder at bottom respectively within end planes A and B are restrained against transverse linear displacement, i.e. $\delta_y = 0$.

3.4.5 The calculation results for those elements around the nodes restrained by boundary conditions do not reflect the true forces acting on the structure, because these elements are influenced by the boundary conditions. The calculation results for elements in such areas are not to be checked.

3.5 Allowable stress

3.5.1 The plate element stress is to be taken as the membrane stress of the plate.

3.5.2 The allowable stresses for primary members are given in Table 3.5.2.

Strength Criteria **Table 3.5.2**

Structure item	Condition to be checked	allowable stresses (N/mm^2)				Buckling factor of safety
		σ_L	σ_W	σ_e	τ	λ
Bottom shell, inner bottom plating	LC1G, 2G, 3G	220/k	—	—	—	1.0
	LC1, 2, 3	100/k	140/k	—	—	—
Double bottom girders	LC1G, 2G, 3G	220/k	—	235/k		1.0
	LC1, 2, 3	100/k	—	180/k	90/k	—
Double bottom floors, transverse web frame	LC1, 2, 3, 4, 5	—	—	180/k	90/k	1.1
Side shell plating, longitudinal bulkhead	LC1G, 2G, 3G	—	—	—	—	1.0
	LC1, 2, 3, 4, 5	—	140/k	—	90/k	—
Longitudinal stringer in wing space	LC1G, 2G, 3G	—	—	—	—	1.0
	LC1, 2, 3, 4, 5	100/k	—	180/k	90/k	—
Transverse bulkhead plating	LC1, 2, 3	—	140/k	180/k	90/k	1.1
Transverse bulkhead girder	LC1, 2, 3	—	140/k	180/k	—	1.1
	LC4, 5	—	140/k	180/k	—	—
	LC6	—	—	85/k	—	—
Cross-deck transverse box	LC4, 5	—	140/k	180/k	90/k	1.1
	LC6	—	—	85/k	—	—
Bracket toe end with local stress concentration	LC1, 2, 3, 4, 5, 6	—	—	220/k	—	—
Longitudinal and reinforcing bar	ibid.	—	—	180/k	—	

Notes:

Median stress (also called membrane stress) at center of element is to be taken for plate element and checked according to allowable stress components given in the Table;

σ_L — normal stress along ship's length;

σ_W — normal stress along ship's breadth or depth;

τ — average shear stress within overall height (or overall depth) of web;

$$\lambda = \frac{\text{composite critical buckling stress}}{\text{actual compressive stress to be calculated}}.$$

3.5.3 The element for node at hatch cover bearing pad on top of hatch coaming is directly subjected to the load resulting from hatch cover under loading condition 6, so the allowable equivalent stress is as follows:

$$\sigma_e = 123/k \quad \text{in N/mm}^2$$

where: k —higher tensile steel factor.

3.6 Evaluation of buckling strength

3.6.1 Plate panel buckling strength is to be checked for plating and girder web of primary members complying with the acceptance of buckling safety factor λ given in Table 3.5.2.

3.6.2 The plate panel in the Guidelines means that part of plating other than periphery, with no any frame or stiffening member in its area. Only rectangular plate panel is to be considered in calculation of plate panel buckling.

3.6.3 The "net" thickness obtained by the standard thickness deduction as shown in Table 3.6.3 is to be taken as the plating thickness in calculation of plate panel buckling.

Standard Thickness Deduction for Calculation of Buckling Strength Table 3.6.3

Position	Standard thickness deduction t_c (mm)
Deck, wing space plating (e.g. second deck, etc.)	1.0
Longitudinal bulkhead (inner skin)	1.0
Shell plating (including bottom), inner bottom	1.0
Inner structure (girder, floor) of double bottom	1.0
Transverse bulkhead structure (watertight, non-watertight)	0.0
Cross-deck structure	0.0

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

3.6.5 Stress due to reduction of thickness through standard thickness deduction according to Table 6.1 is to be increased as follows:

$$\sigma' = \sigma \frac{t}{t - t_c}$$

where: σ' — corrected compressive stress for buckling calculation;

σ — working stress obtained by finite element calculation;

t — plate thickness (construction thickness) for finite element calculation;

t_c — standard thickness deduction as given in Table 3.6.3.

3.6.6 The value of λ in Table 3.5.2 may be derived either as indicated in Appendix 2, or by any other accepted method subject to approval of CCS.

Chapter 4 Direct Calculations of Local Fine Mesh Structural Strength for Deck Hatch Corner

4.1 General requirements

4.1.1 This chapter provides ways based on fine mesh model to evaluate fatigue strength, of local structure of deck hatch corner of container ships and the ships with large deck openings (smooth and free edges) under bending and torsional loads (hereinafter referred to as evaluation of fatigue strength of hatch corner). Those not specified in this Chapter are to be in accordance with the relevant requirements of CCS Guidelines for Fatigue Strength of Ship Structure.

4.1.2 The wave load calculation for evaluation of fatigue strength of hatch corner in this Chapter is based upon the design wave method used for structural analysis of the whole ship, i.e. dynamic load is determined by the dominant load parameters obtained from seakeeping analysis reaching maximum (minimum) values, for details, see Section 2.3, Chapter 2 and Appendix 1of the Guidelines.

4.1.3 Fatigue damage calculation in this Chapter is based upon Palmgren-Miner linear cumulative damage model, S-N curve and environmental data of long-term prediction on sea condition (IACS Rec. No.34 Data), etc., for details, see relevant chapters in CCS Guidelines for Fatigue Strength of Ship Structure, and it is also based upon the construction quality in the shipyard approved by surveyors.

4.1.4 Evaluation of fatigue strength of hatch corner in this Chapter adopts allowable stress range approach, alternatively, spectrum analysis method applied in evaluation of fatigue life can also be used.

4.1.5 The positions of local structure of deck hatch corner to be evaluated in accordance with fine mesh model are to include hatch corner at the connection of container hold area with the engine room structure, the deck hatch corner forward of No.1 cargo hold and the hatch corner at the connection of the upper deck including hatch side coaming amidships.

4.1.6 The scantlings of structural members in fine mesh model are defined to take the construction sizes. If "net" scantlings are used, the relevant allowable stress is to be specially considered.

4.2 Finite element model for calculations

4.2.1 The local fine mesh model is to be modeled in accordance with the requirements of the following 4.2.2 to 4.2.10.

4.2.2 The three-dimensional fine mesh model of local structure of deck hatch corner can be separated, and the displacement results obtained from global three-dimensional rough mesh finite element analysis are applied to the corresponding boundary nodes as compulsory displacement condition to be analyzed individually. Alternatively, the fine mesh model can be inserted directly to the whole ship model for analysis. The boundary of fine mesh model, under the requirements of satisfying following model extents, is preferable to be taken on the structure of primary supporting and web frames.

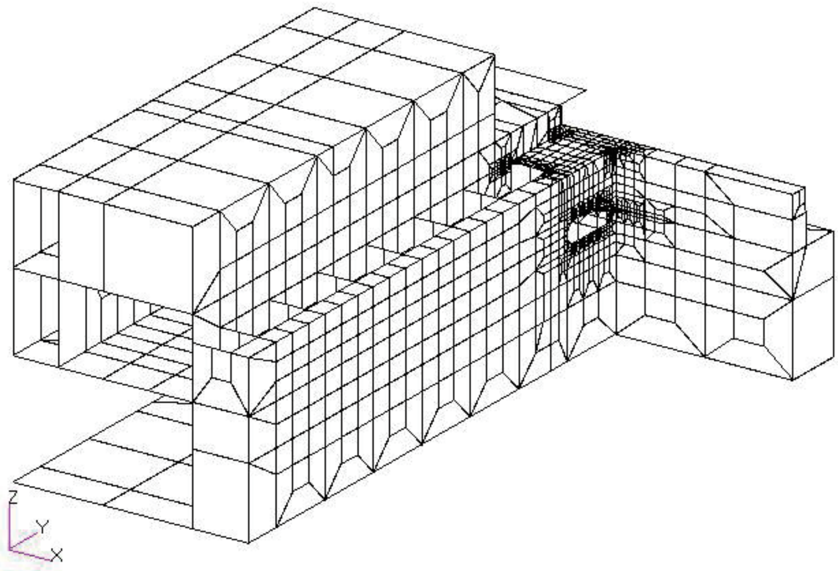


Figure 4.2.2(1)   Finite element model of hatch corner in way of engine room front bulkhead

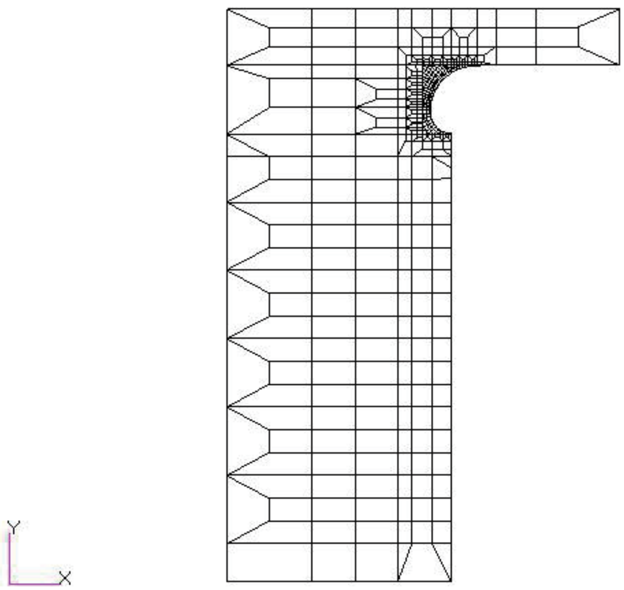


Figure 4.2.2(2)   Finite element model of hatch corner in way of engine room front bulkhead (upper deck hatch corner)

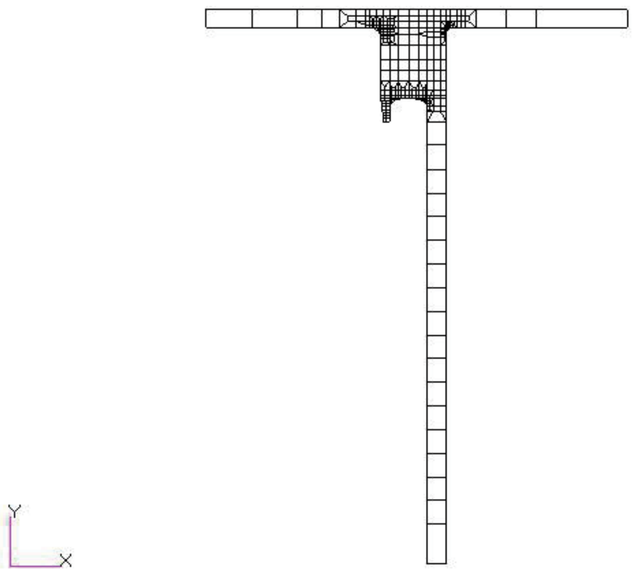


Figure 4.2.2(3) Finite element model of hatch corner in way of engine room front bulkhead (top plate of hatch coaming)

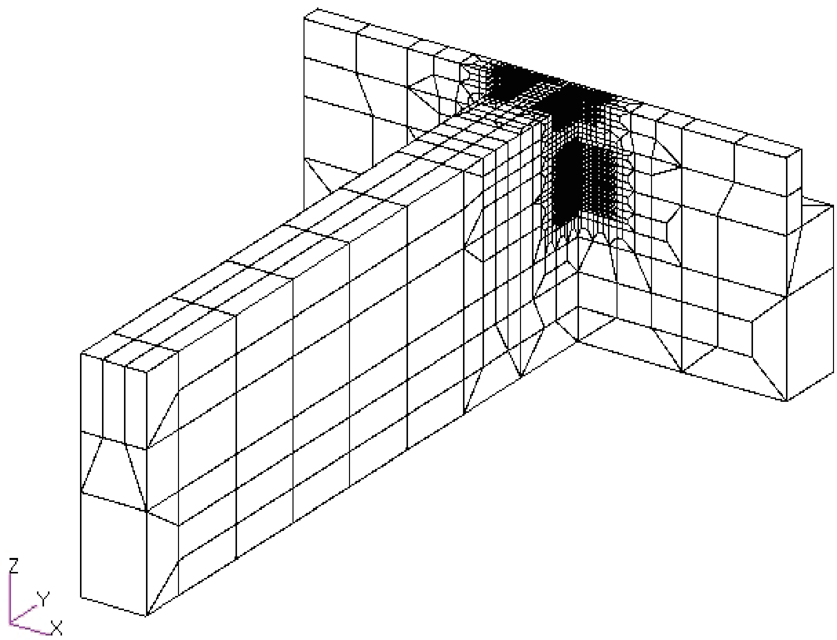


Figure 4.2.2(4) Finite element model of hatch corner in way of cargo hold area

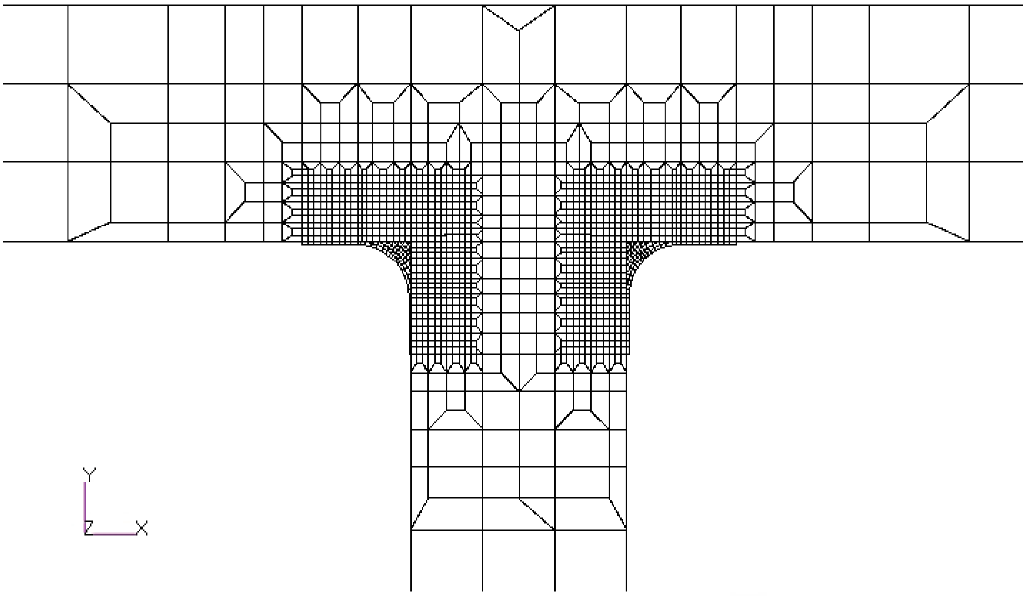


Figure 4.2.2(5) Finite element model of hatch corner in way of cargo hold area (zooming upper deck hatch corner)

4.2.3 Finite element fine mesh model of local structure of hatch corner at the midship region

4.2.3.1 The three-dimensional local fine mesh model at the midship region is generally selected from the position of deck opening where the maximum stress or maximum warping displacement at transverse deck strip occurs, and the corresponding extent of model is as follows:

(1) For longitudinal extent, transverse deck strip corner extending half length of a 40 feet container bay forward and afterward each (i.e. longitudinally from midpoint of one 40 feet container bay to midpoint of next 40 feet container bay);

(2) For vertical extent, from No.2 deck below main deck (or called No.2 platform below main deck) to the coaming top plate;

(3) For transverse extent, from the centerline to ship side , model covers hatch corner in way of main deck and the transitional structure of corner in way of coaming top plate, please refer to Figure 4.2.2(4) and Figure 4.2.2(5).

4.2.4 Finite element fine mesh model of local structure of hatch corner at forward end of engine room

4.2.4.1 The three-dimensional local fine mesh model at forward end of engine room is selected from the position of hatch corner in way of bulkhead at forward end of portside engine room, and the corresponding extent of model is as follows:

- For longitudinal extent, transverse bulkhead at forward end of engine room extending forward half length of a 40 feet container bay (i.e. to midpoint of a 40 feet container bay) and extending afterward similar distance to transverse web frame (in general, at the position in way of transverse web frame of the global model);

- For vertical extent, from No.2 deck to hatch coaming (in general, within superstructure to B deck);
- For transverse extent, from the centerline to ship side.

4.2.4.2 All the models are to include fine mesh in way of hatch corners as well as at the scarping and at the end terminations of longitudinal hatch coamings where relevant. The coaming stays are also to be represented in the model. For details, see Figures 4.2.2(1) to 4.2.2(3).

4.2.5 The stipulations of three-dimensional local fine mesh model of hatch corner at the aft end of engine room and hatch corner at the forward end of No.1 cargo hold are the same as those in 4.2.3.1.

4.2.6 If the stress level obtained from whole ship analysis is low at the hatch corner at the aft end of engine room in each load case , it is unnecessary to take further fine mesh analysis.

4.2.7 Plate elements are used to simulate primary structural members such as upper deck, shell plate, longitudinal bulkhead and transverse plates in the model, and beam elements are used to simulate longitudinals and stiffeners.

4.2.8 Arc of corner, arc of top plate of hatch coaming and other geometries in upper deck area in the model are to be represented precisely in the fine mesh model, and all the openings (ventilation systems, access openings) are to be represented precisely in the model.

4.2.9 The method of providing virtual rod elements at the position of hatch corner edge to obtain element normal stress is to be used to get tangential stress where tangential stress of hatch corner edge can not be obtained from the finite element analysis programs , and virtual rod elements can be applied to the following positions:

(1) along the edge of hatch corner radius at the top level of upper deck and hatch coaming;

(2) along the upper edge of the superstructure to longitudinal hatch coaming scarphing bracket (if any).

4.2.10 The element meshes of the local fine mesh model at the node in way of model boundary are to be consistent with the rough mesh model of the whole ship so as to make that displacement of the rough mesh model can directly and correspondingly transmit to the boundary of fine mesh model.

4.2.11 In the fine mesh model, plate element at the positions of hot-spot stress evaluation is divided in accordance with the mesh size of plate thickness × plate thickness ($t \times t$). The division density is maintained within the fine mesh zone, extending at least 10t distance in all directions from the center of hot spot stress, and then transiting smoothly to the model boundary, to meet the stipulations in 4.2.10.

4.3 Loads

4.3.1 The loads of fine mesh model consists of imposed displacements at the node of model boundary and local loads, and the imposed displacements of the boundary are selected from the corresponding conditions and obtained from analysis of the whole ship.

4.3.2 Design load conditions

4.3.2.1 In case that the fatigue strength is checked in accordance with allowable stress method, the probability level of exceedance corresponding to wave load is taken as 10^{-8} . The loading condition is taken as the full load condition in loading manual where maximum still water bending moment occurs, and the design wave determined by the method of dominant load parameter is selected as the calculation condition of wave load. For the calculation of design waves, please refer to Section 2.3 of Chapter 2 and Appendix 1 "Determination of Design Waves" of the Guidelines.

4.3.2.2 In general, load cases of design wave applied in fatigue assessment of hatch corner are to be as follows:

Table 4.3.2.2

LC1: Maximum vertical wave bending moment in way of 1/2*L* from AP（hogging）
LC2: Minimum vertical wave bending moment in way of 1/2*L* from AP（sagging）
LC3: Maximum horizontal wave bending moment in way of 1/2*L* from AP
LC4: Minimum horizontal wave bending moment in way of 1/2*L* from AP
LC5: Maximum wave torque in way of 3/8L from AP
LC6: Minimum wave torque in way of 3/8L from AP
LC7: Maximum wave torque in way of 1/2L from AP
LC8: Minimum wave torque in way of 1/2L from AP
LC9: Maximum wave torque in way of 5/8L from AP
LC10: Minimum wave torque in way of 5/8L from AP

4.3.2.3 The design wave load and still water condition determined by design waves listed in 4.3.2.2 are applied to whole ship finite element model, after balance adjustment of dynamic loads, displacement and stress of the global structure are obtained by calculation. Diagram of deformation displacement of the whole ship model under design load is shown in Figure 4.3.2.2.

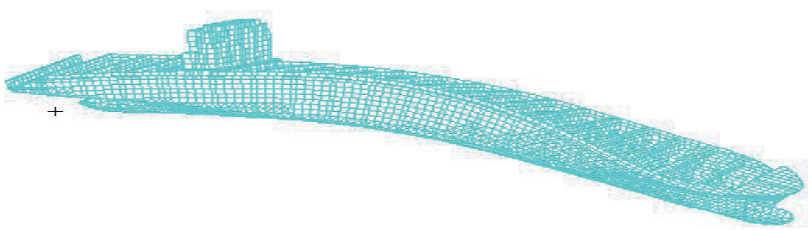


Figure 4.3.2.2 Diagram of displacement of the whole ship in design wave load case

4.3.2.4 During fatigue check of hatch corner by allowable stress method, the range of dynamic stress at the edge of hatch corner based on the calculation result of each load case stipulated in 4.3.2.1 is synthesized in accordance with the following:

$\Delta\sigma_{12} = \sigma_{LC1} - \sigma_{LC2}$
$\Delta\sigma_{34} = \sigma_{LC3} - \sigma_{LC4}$
$\Delta\sigma_{56} = \sigma_{LC5} - \sigma_{LC6}$
$\Delta\sigma_{78} = \sigma_{LC7} - \sigma_{LC8}$
$\Delta\sigma_{910} = \sigma_{LC9} - \sigma_{LC10}$

where: σ_{ij}——dynamic stress range of corner edge along tangent direction under the combined load cases i, j, in N/mm^2;

σ_{LCi}——stress value of corner edge along tangent direction under the load case i, in N/mm^2.

4.4 Boundary conditions

4.4.1 The boundary conditions applied to the whole ship rough mesh finite element model balanced by dynamic load are in accordance with the stipulations in Section 2.4 of Chapter 2.

4.4.2 Where the fine mesh model of hatch corner is not incorporated in the global model and analyzed separately, the nodal displacements in way of boundary of hatch corner fine mesh model of the global model obtained from calculation of above-mentioned load cases are to be transmitted to the corresponding nodes of fine mesh model as the imposed displacement boundary condition of fine mesh model.

4.5 Allowable stress range

4.5.1 Weibull distribution of stress range of hull structure

4.5.1.1 Assuming that the long-term distribution of stress range of hull structure is two-parameter Weibull distribution, shape parameter ξ of Weibull distribution is to be calculated as follows:

$$\xi = 1.45 - 0.036 f \sqrt{L}$$

where: L— ship's length，in m;

$f = 1 - 0.08z/d$ when $z \le d_1$;

$f = 0.92 + 0.08(z - d_1)(D - d_1)$ when $z > d_1$;

when calculation point is on transverse bulkhead， $f=0.92$;

D——moulded depth, in m;

d_1——draft in load cases, in m;

z——vertical distance from calculation point to baseline, in m.

4.5.2 Selection of designed S-N curve

4.5.2.1 Selection of S-N curve is to be in accordance with relevant requirements of CCS Guidelines for Fatigue Strength of Ship Structure. S-N curve is selected based on the corresponding check position. C curve in S-N curve is to be selected for check of fatigue strength in way of smooth and free edge of deck hatch corner of container ship.

4.5.3 Allowable stress range

4.5.3.1 Where fatigue strength of hatch corner of hull structure is checked in accordance with allowable stress range, shape parameter ξ of Weibull distribution is to be calculated in accordance with the stipulations in 4.5.1.1.

4.5.3.2 According to the stipulations in 4.5.3.1 and the corresponding ξ value, allowable stress range is given in Table 4.5.3.3.

4.5.3.3 The fatigue strength of deck hatch corner of container ship is to meet the following requirements:

$$\Delta\sigma \leqslant f_t [S_L]$$

where: $f_t = 0.9$;

$\Delta\sigma$— dynamic stress range under design condition， in N/mm^2， to be calculated according to the stipulations in 4.3.2.3;

$[S_L]$— allowable stress range， in N/mm^2, as to the evaluation of fatigue strength of the deck hatch corner, C curve in S-N curve is selected, and given in Table 4.5.3.3 according to the calculated value of shape parameter ξ.

Allowable stress range [S_L] N/mm² **Table 4.5.3.3**

ξ	S − N curve							
	B	C	D	E	F	F2	G	W
.60	1253.57	1055.68	802.21	703.69	598.72	527.84	438.42	315.86
.61	1214.51	1022.78	777.21	681.77	580.06	511.40	424.76	306.02
.62	1177.47	991.59	753.51	660.97	562.37	495.80	411.80	296.69
.63	1142.30	961.97	731.00	641.23	545.57	480.99	399.50	287.83
.64	1108.89	933.83	709.62	622.48	529.61	466.92	387.82	279.41
.65	1077.13	907.08	689.29	604.64	514.44	453.55	376.71	271.40
.66	1046.90	881.62	669.95	587.67	500.00	440.82	366.13	263.79
.67	1018.11	857.38	651.53	571.51	486.25	428.70	356.07	256.53
.68	990.67	834.27	633.97	556.11	473.15	417.14	346.47	249.62
.69	964.50	812.24	617.22	541.42	460.65	406.13	337.32	243.02
.70	939.52	791.20	601.24	527.40	448.72	395.61	328.58	236.73
.71	915.67	771.11	585.97	514.01	437.33	385.56	320.24	230.72
.72	892.87	751.91	571.38	501.21	426.44	375.96	312.27	224.97
.73	871.06	733.54	557.42	488.96	416.02	366.78	304.64	219.48
.74	850.18	715.97	544.06	477.25	406.05	357.99	297.34	214.22
.75	830.19	699.13	531.27	466.03	396.51	349.57	290.35	209.18
.76	811.04	683.00	519.01	455.27	387.36	341.51	283.65	204.35
.77	792.67	667.53	507.26	444.96	378.58	333.77	277.22	199.73
.78	775.05	652.69	495.98	435.07	370.17	326.35	271.06	195.29
.79	758.13	638.44	485.15	425.57	362.09	319.23	265.14	191.02
.80	741.88	624.76	474.75	416.45	354.32	312.38	259.46	186.93
.81	726.26	611.60	464.76	407.68	346.86	305.81	254.00	182.99
.82	711.23	598.95	455.15	399.25	339.69	299.48	248.74	179.21
.83	696.78	586.78	445.90	391.13	332.79	293.40	243.69	175.57
.84	682.87	575.06	436.99	383.32	326.14	287.54	238.82	172.06
.85	669.47	563.78	428.42	375.80	319.74	281.90	234.14	168.68
.86	656.56	552.90	420.15	368.55	313.57	276.46	229.62	165.43
.87	644.11	542.42	412.19	361.56	307.63	271.22	225.27	162.29
.88	632.10	532.31	404.50	354.82	301.89	266.16	221.07	159.27
.89	620.51	522.55	397.09	348.32	296.36	261.28	217.01	156.35
.90	609.32	513.13	389.93	342.04	291.01	256.57	213.10	153.53
.91	598.51	504.03	383.01	335.97	285.85	252.02	209.32	150.80
.92	588.07	495.23	376.33	330.11	280.86	247.62	205.67	148.17
.93	577.98	486.73	369.87	324.44	276.04	243.37	202.14	145.63
.94	568.21	478.51	363.62	318.96	271.38	239.26	198.72	143.17
.95	558.76	470.55	357.57	313.66	266.87	235.28	195.42	140.79
.96	549.62	462.85	351.72	308.52	262.50	231.43	192.22	138.48
.97	540.77	455.39	346.06	303.55	258.27	227.70	189.13	136.25
.98	532.19	448.17	340.57	298.74	254.18	224.09	186.13	134.09
.99	523.88	441.17	335.25	294.07	250.21	220.59	183.22	132.00
1.00	515.82	434.39	330.09	289.55	246.36	217.20	180.40	129.97
1.01	508.01	427.80	325.09	285.16	242.62	213.91	177.67	128.00
1.02	500.42	421.42	320.24	280.91	239.00	210.72	175.02	126.09
1.03	493.07	415.23	315.53	276.78	235.49	207.62	172.44	124.23
1.04	485.93	409.21	310.96	272.77	232.08	204.61	169.95	122.44
1.05	478.99	403.37	306.52	268.88	228.77	201.69	167.52	120.69
1.06	472.25	397.70	302.21	265.09	225.55	198.86	165.16	118.99
1.07	465.71	392.18	298.02	261.42	222.42	196.10	162.87	117.34
1.08	459.34	386.82	293.95	257.85	219.38	193.42	160.65	115.74
1.09	453.15	381.61	289.99	254.37	216.43	190.81	158.48	114.18
1.10	447.14	376.54	286.14	250.99	213.55	188.28	156.38	112.66
1.11	441.28	371.61	282.39	247.71	210.76	185.81	154.33	111.19
1.12	435.58	366.81	278.74	244.51	208.03	183.41	152.34	109.75
1.13	430.03	362.14	275.19	241.39	205.38	181.08	150.40	108.35
1.14	424.63	357.59	271.74	238.36	202.80	178.80	148.51	106.99
1.15	419.37	353.16	268.37	235.40	200.29	176.59	146.67	105.66
1.16	414.24	348.84	265.09	232.53	197.84	174.43	144.87	104.37
1.17	409.24	344.63	261.89	229.72	195.45	172.32	143.13	103.11
1.18	404.37	340.53	258.77	226.99	193.13	170.27	141.42	101.89
1.19	399.62	336.53	255.73	224.32	190.86	168.27	139.76	100.69
1.20	394.99	332.63	252.77	221.72	188.65	166.32	138.14	99.52

Appendix 1

Determination of Design Waves

1. Calculation of wave load

1.1 Ship motion and wave load are calculated by the CCS006SR-96 program based on two-dimensional linear strip theory or by the three-dimensional linear program.

1.2 The full load condition and ballast condition are taken for calculation, and other conditions may be taken as necessary.

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

(1) the number of wave frequency (or wave length) is to be taken as 20 ~ 30 cases, range of wave frequency taken as 0.2 ~3 according to the ratio of wave length to ship's length (λ/L), and the increments taken as 0.1;

(2) not less than 7 wave heading angles are to be taken, including 0º (head sea), 30º, 60º, 90º, 120º, 150º, 180º (following sea);

(3) ship speed is taken as 0.

2. Statistical analysis

2.1 P-M wave spectrum is used for calculation of ship's motion on irregular waves, wave load response and its short- and long-term prediction:

$$S(\varpi, H_{\frac{1}{3}}, T_2, \theta) = \begin{cases} \dfrac{2}{\pi} 124 H_{1/3} T_2^{-4} \varpi^{-5} \exp(-\dfrac{496}{T_2^4 \varpi^4}) \cos^2\theta, |\theta| \le \dfrac{\pi}{2} \\ 0, \theta \text{ as other values} \end{cases}$$

where: ω — circular frequency of waves, in rad/s;

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

T_2 — zero-crossing wave period, in s;

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

θ — included angle between complex wave and main sea direction, in rad.

2.2 The wave scatter diagram used in the calculations uses the wave data recommended by IACS (IACS Rec. No. 34).

3. Calculation of design waves

3.1 Design wave parameters

The design wave parameters are defined as shown in Figure 3.1:

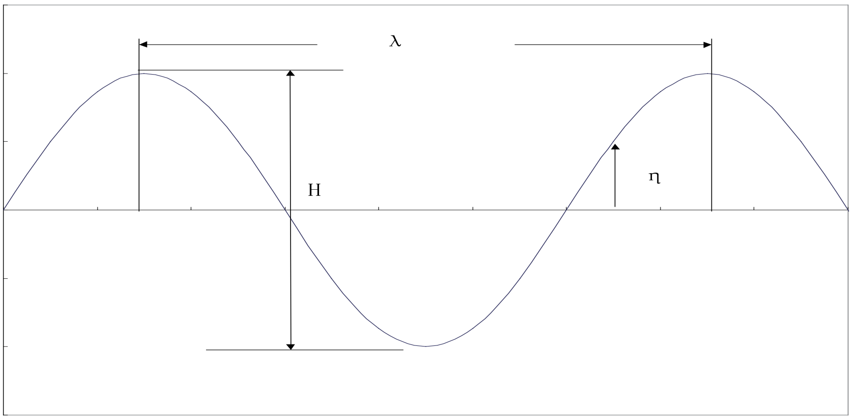


Figure 3.1 Design Wave Parameters

where: λ — wave length, minimum distance between two adjacent wave crests, in m;

H — wave height, minimum distance from wave crest to wave trough, in m;

η — wave surface, as sine equation.

3.2 Determination of design waves

3.2.1 Selection of dominant load parameters:

(1) For assessment of container ship structure, the dominant load parameters are to be taken as follows:

- vertical wave bending moment
- horizontal wave bending moment
- torsional moment

(2) The probability level corresponding to vertical wave bending moment specified in Section 2, Chapter 2 of PART TWO of CCS Rules and Regulations for the Construction and Classification of Sea-going Steel Ships, 2001 is taken as that of long-term prediction of dominant load parameters.

3.2.2 Calculation of frequency response functions of dominant load parameters

The curve of frequency response functions of dominant load parameters under different heading angles of regular waves is calculated using the calculation program. Figure 3.2.2 shows frequency response functions.

3.2.3 The wave frequency ω_a where dominant load parameters are at the maximum amplitude are determined according to frequency response functions.

3.2.4 Calculation of wave length

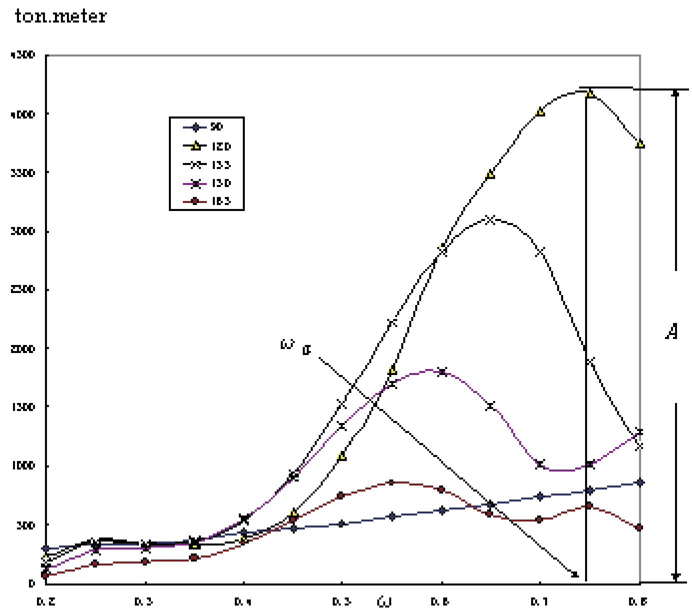


Figure 3.2.2 Frequency Response Functions

(1) Design wave length is to be calculated as follows:

$$\lambda = (2\pi g)/\omega_a^2$$

where: λ — design wave length, in m;

g — gravitational acceleration;

ω_a — wave frequency corresponding to dominant load parameters exceeding the maximum amplitude, to be determined per paragraph 3.2.3, in rad/s.

3.2.5 Calculation of wave amplitude

(1) Amplitude of design waves is to be calculated as follows:

$$a_w = \frac{L_j}{A_j}$$

where: a_w — amplitude of design waves;

A_j — maximum amplitude of dominant load parameters;

L_j — long-term extreme value of dominant load parameter at the probability level according to paragraph 3.2.1(2);

j — dominant load parameter no., $j = 1$ for vertical wave bending moment, $j = 2$ for horizontal wave bending moment, $j = 3$ for torsional moment.

3.2.6 Time instant where dominant load parameter reaches maximum

(1) The time t_j instant where dominant load parameter reaches maximum is to be determined as follows:

$$t_j = (n\pi + \pi/2 - \varepsilon_j)/\omega_a$$

where: ω_a — to be determined per paragraph 3.2.3, in rad/s;

ε_j — phase angle of the load component FRF;

j — as in paragraph 3.2.5;

n — 0 or 1, according to either hogging or sagging of vertical wave bending moment.

3.2.7 Distribution of wave pressure and other load components

(1) Wave pressure and other load components under design waves are to be calculated as follows:

$$P_i = (A_i)\,(a_w)\,\sin\,(\omega_a t_j + \varepsilon_i)$$

where: P_i — wave pressure or other load components at arbitrary calculation position of hull;

A_i — amplitude of frequency response function of wave pressure or other load component P_i;

ε_i — phase corresponding to wave pressure or other load component P_i;

t_j — to be determined according to paragraph 3.2.6.

Appendix 2

Buckling Strength of Plate Panel

1. Any of the following two methods may be used for calculation of buckling strength of plate panel.
2. Method 1: to obtain plate panel buckling strength by means of eigenvalue from finite elements.

2.1 Modeling

2.1.1 The thickness of the panel selected for buckling strength check is deducted as specified in Table 3.6.3. The principle for meshing: not less than 8 meshes at each side, preferably in square shape.

2.2 Load and boundary conditions

2.2.1 Load: the results σ_x, σ_y, τ_{xy} (i.e. applied stress) for median plane stress of the panel, as calculated by means of finite element hold model, are taken according to the selected condition and multiplied respectively by the thickness before deduction to obtain corresponding pressure and to be applied on corresponding boundaries, as follows:

$$N_x = \sigma_x \times t_o,$$
$$N_y = \sigma_y \times t_o,$$
$$N_{xy} = \tau_{xy} \times t_o$$

where: t_o is construction thickness.

2.2.2 Where compressive stress varies between plate panels to a large extent, it may be applied as linearly distributed load, and mean value of shear stress is to be taken.

2.2.3 Boundary condition: The midpoints of four boundaries of the panel are selected for the purpose of restraining rigid displacement. The midpoints of longitudinal boundaries constrain displacement in direction x, the midpoints of transverse boundaries constrain displacement in direction y, and 4 sides constrain displacement in direction z, as shown in Figures 2.2.2 (a) and 2.2.2 (b).

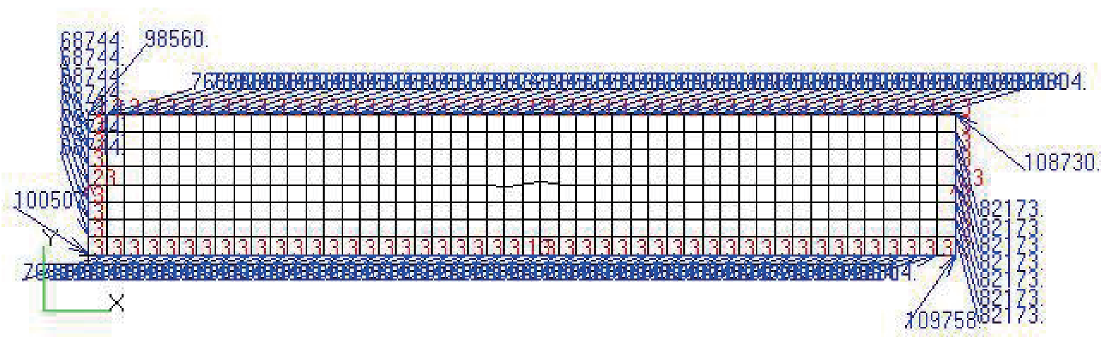


Figure 2.2.2(a) Model where biaxial pressure and shear force are applied

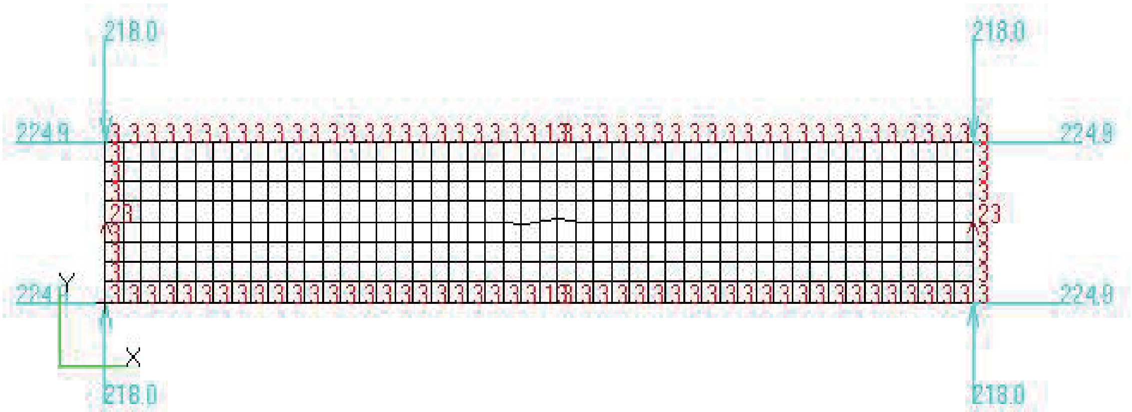


Figure 2.2.2(b) Model where biaxial pressure is applied

Notes: 1. Boundary constraint as shown in both Figure 2.2.2(a) and Figure 2.2.2(b) are applicable.
2. The boundary load shown in Figure 2.2.2(a) is of nodal pressure type, and that in Figure 2.2.2(b) is of boundary pressure type.

2.3 Check of buckling strength

2.3.1 In calculation of buckling safety factor, consideration is to be given to boundary constraint coefficient "C" as defined in paragraph 2.2.7, PART TWO of the Rules and Regulations for the Construction and Classification of Sea-going Steel Ships (2001) of China Classification Society.

2.3.2 The factor shown in MSC-PATRAN post-processing is critical buckling factor λ. And according to boundary constraint condition, it may be multiplied by the boundary constraint coefficient as defined in paragraph 2.3.1 of this Appendix and is not to be less than the values of safety factor in Table 3.5.2 of the Guidelines.

3. Method 2: Simplified equations

3.1 Critical buckling stress and plastically correction

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

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

where: k_x — buckling coefficient for shorter side subjected to compression and bending, to be calculated according to 3.1.1(a) of this Appendix, where: see 3.2.2 for σ_{x1} and σ_{x2};

C_1 — boundary constraint coefficient, see Table 3.1.1(b);

E — Yung's modulus. For steel, $E = 2.06 \times 10^5$ N/mm^2;

ν — Poisson's ratio, may be taken as 0.3 for steel;

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.

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

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

where: K_y — buckling coefficient for longer side subjected to compression and bending, to be calculated according to 3.1.1(a) of this Appendix, where: see 3.2.2 for σ_{y1} and σ_{y2};

C_2 — boundary restraint coefficient, see Table 3.1.1(b) of this Appendix;

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

other symbols are the same as in 3.1.1.

3.1.3 The elastic critical buckling stress τ_{cr_e} of plate panel subject to shear force is defined as follows:

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

where: k_t — shear buckling coefficient, to be calculated according to 3.1.1(a) of this Appendix, where: see 3.2.2 for τ_{xy};

other symbols are the same as in 3.1.1 and 3.1.2.

Buckling Coefficient of Plate Panel **Table 3.1.1(a)**

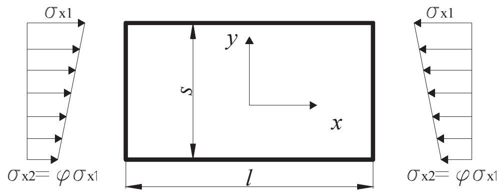
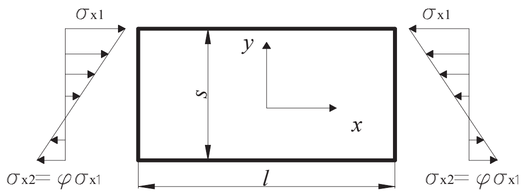
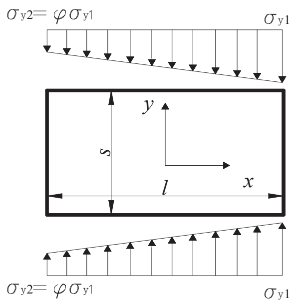
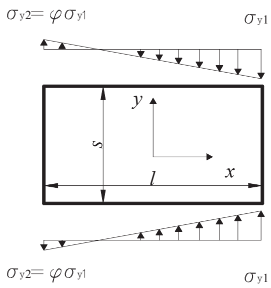
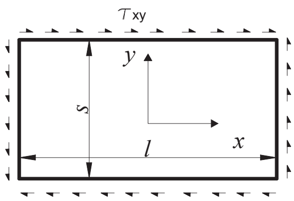
	Mechanical model of plate panel subject to pressure, bending and shear forces	Buckling coefficient
Shorter side subject to stress	 where: 0≤ φ≤1	$k_x = \dfrac{8.4}{\varphi + 1.1}$
	 where: −1≤ φ<0	$k_x = 7.6 - 6.4\varphi + 10\varphi^2$
Longer side subject to stress	 where: 0≤ φ≤1	$k_y = \left[1 + \left(\dfrac{S}{l}\right)^2\right]^2 \dfrac{2.1}{\varphi + 1.1}$
	 where: −1≤ φ<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: $k_p = \begin{cases} 24(\dfrac{s}{l})^2 & \dfrac{l}{s} \le \dfrac{3}{2} \\ 2 + 16(\dfrac{s}{l})^2 + 8(\dfrac{s}{l})^4 & \dfrac{l}{s} > \dfrac{3}{2} \end{cases}$
Edges subject to shear stress		$k_t = 5.34 + 4(\dfrac{s}{l})^2$

Plate Panel Boundary Restraint Coefficients C1 and C2 Table 3.1.1(b)

Boundary	C_1	C_2	
		In double bottom or double sides	Elsewhere
Angle steel or T-stiffeners	1.1	1.3	1.2
Flat bars or bulb	1.0	1.2	1.1

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

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

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

where: σ_{xcr}, σ_{ycr}, τ_{cr} — respectively as corrected critical buckling compressive stress along axes X and Y under uniaxial stress and critical buckling shear stress of plate panel;

σ_{xcr_e}, σ_{ycr_e}, τ_{cr_e} — respectively as elastic critical buckling compressive stress along axes X and Y under uniaxial stress and critical buckling shear stress of plate panel, see 3.1.1, 3.1.2 and 3.1.3;

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

τ_S — $\sigma_S/\sqrt{3}$.

3.2 Criteria for buckling strength

3.2.1 The buckling strength of plate panel under component stresses is to be corrected as follows:

$$\lambda \geqslant [\lambda]$$

where: λ — ratio of the critical buckling stress under component stress of plates panel to actual compressive stress, to be calculated according to Table 3.2.1 of this Appendix,

where:$[\lambda]$ — plate panel buckling safety factor, see Table 3.5.2 of the Guidelines. When the model is fine meshed, the requirement for λ value may be relaxed as appropriate subject to consent of CCS.

σ_{x1}, σ_{y1} and τ_{xy} — see 3.2.2;
σ_{xcr}, σ_{ycr} and τ_{cr} — see 3.1.4;
l and s are the same as in 3.1.2 and 3.1.1.

3.2.2 σ_{x1} and σ_{y1} in tables of this Appendix are bigger values of working stress acting on sides of plate panel along axes X and Y, σ_{x2} and σ_{y2} are the lesser values of such stress, and these values are to be taken as average of membrane stress of plate panel sides (average value for two opposite nodes) in calculation; τxy is average shear stress. σ_{x1}, σ_{x2}, σ_{y1}, σ_{y2} and τxy are as indicated in Figure 3.1.1(a).

3.2.3 The working stress σ_{x1}, σ_{y1} and τxy along axes X and Y, obtained in accordance with 3.2.2, are considered in their absolute values in calculation. Where σ_{x1} and σ_{y1} are considered as tension stress, such stress component is to be taken as zero.

Calculation of λ **Table 3.2.1**

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

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