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GUIDELINES FOR COMPLETE SHIP MODEL CALCULATION OF CRUISE SHIPS

2021

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Beijing

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CHAPTER 1   GENERAL

1.1   General provisions

1.1.1   The Guidelines are applicable to cruise ships the length of which is 150 m and over.

1.1.2   Chapter 2 of the Guidelines is the direct calculation of the complete ship. The envelope value method is adopted for the direct calculation of the complete ship and assessment of the strength of the primary members of the hull structure. The deformations or stresses obtained from the direct calculation of the complete ship will also be used for refined analysis.

1.1.3   Chapter 3 of this Guidelines, the refined analysis, provides a method for the refined analysis of stress concentration areas such as side bulkhead openings and tapering brackets to assess their yield and fatigue strength.

1.2   Symbols and definitions

1.2.1   Unless expressly provided otherwise, the definitions of the symbols in the Guidelines are same as those in PART TWO of CCS Rules for Classification of Sea-going Steel Ships (hereinafter referred to as the Rules).

1.2.2   Since cruise ships generally do not have still water sagging condition, the Guidelines use maximum and minimum to describe the two ultimate conditions of the hull girder load. Among them, the maximum still water bending moment corresponds to the maximum hogging condition when loaded, and the minimum still water bending moment corresponds to the minimum hogging condition when loaded. The Guidelines assume a 10^{-8} probability level of exceedance for the dynamic load.

1.2.3   The fore end (FE) of the rule length L is the perpendicular to the summer load waterline at the forward side of the stem. The aft end (AE) of the rule length is the perpendicular to the waterline at a distance L aft of the fore end.

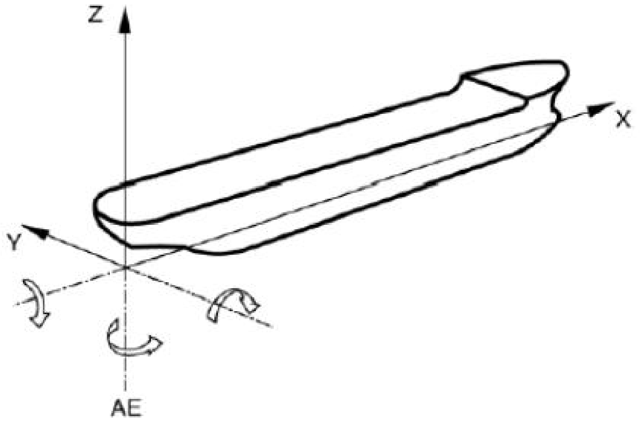

Figure 1.2.3   Definitions of the coordinate system

1.2.4   Unless expressly provided otherwise, the following right-handed Cartesian coordinate system is used in the Guidelines:

Origin: the intersection of the longitudinal section of the ship, the aft end of the ship length L and the baseline;

- X-axis: longitudinal axis, positive forward;
- Y-axis: transverse axis, positive to port;
- Z-axis: vertical axis, positive upwards.

1.3 Method and process

1.3.1 The complete ship analysis method used in the Guidelines is the "rule load method", also known as the "envelope value method". The method requires that the bending moment and shear force at each section of the length of the ship reach their maximum or minimum values.

1.3.2 Figure 1.3.2 shows the flow of the complete ship analysis. The process on the left is the strength assessment process and the main line of analysis. Each step in the flowchart is completed in turn. If the strength does not meet the requirements, return to the previous step, modify the design and re-assess. On the right, the stress transfer function required for stress correction is obtained by structural analysis and calculation. The refined analysis of the embedding method is the same as the complete ship analysis process.

1.3.3 The refined analysis flow chart of the sub-model method is shown in Figure 1.3.3. The sub-model is loaded with the displacement results of the complete ship analysis, and then the strength assessment process is completed. The sub-model is also to be loaded and analyzed for the transfer function load case on the right to obtain the stress transfer function of each element.

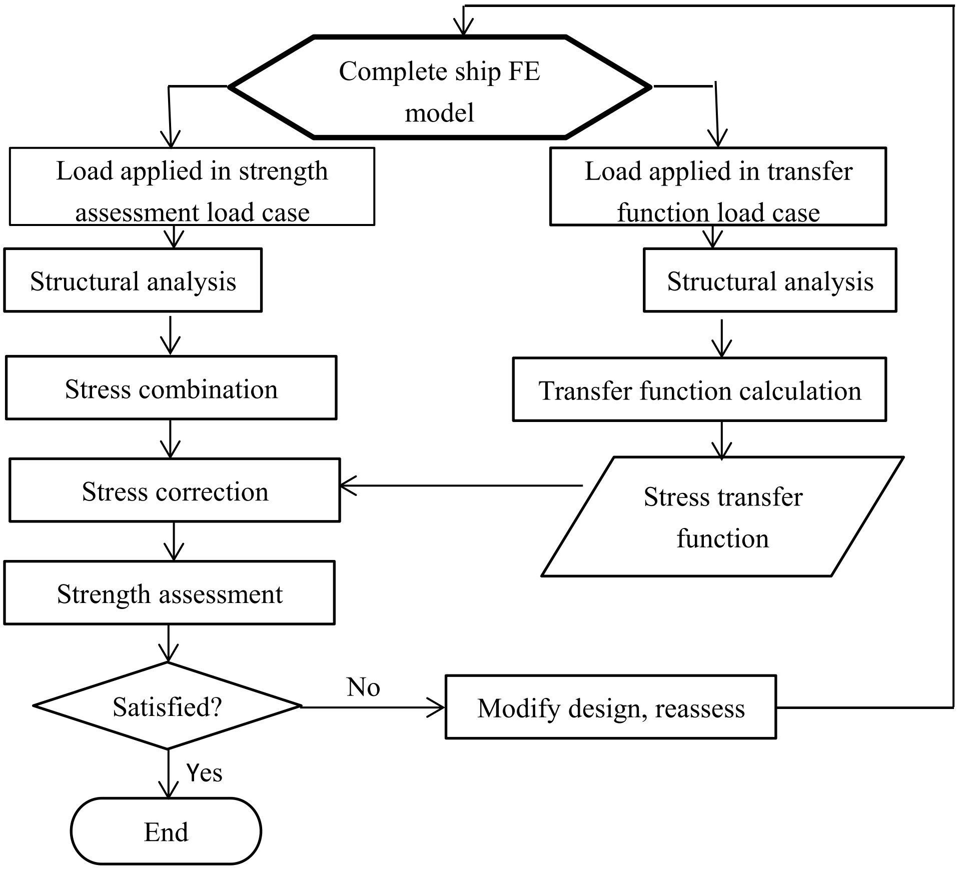

Figure 1.3.2 Process of complete ship analysis

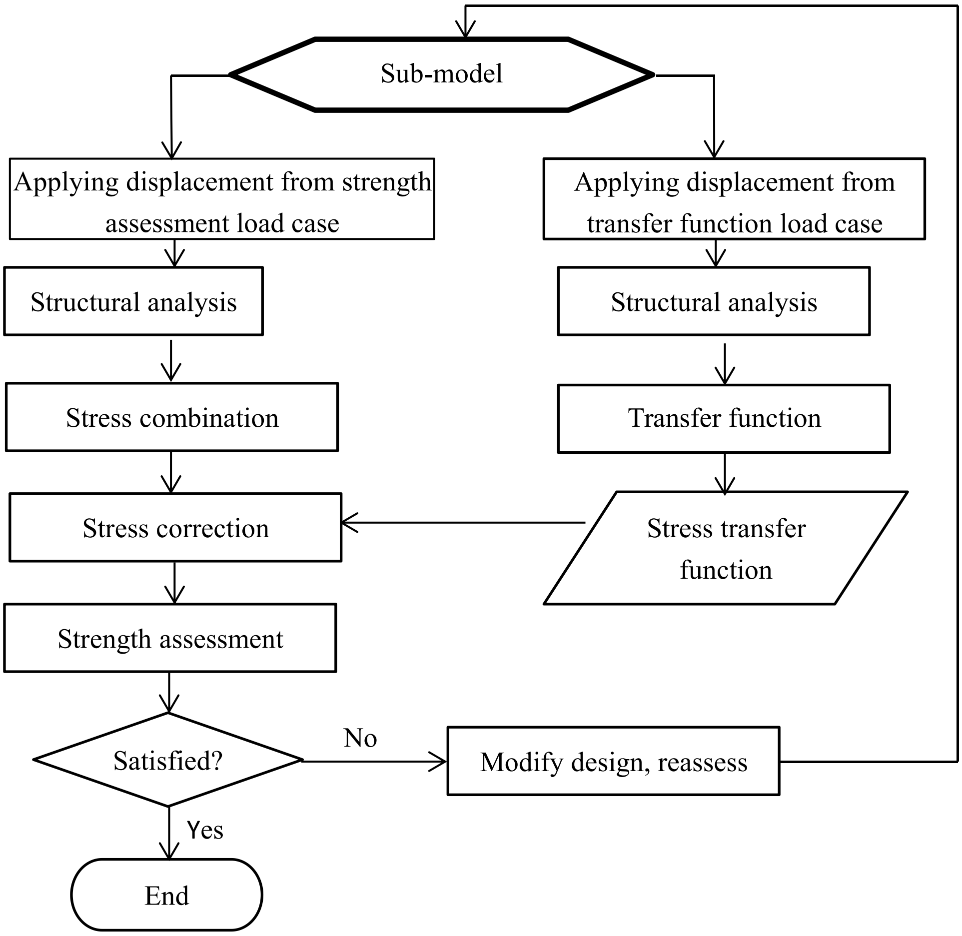

Figure 1.3.3 Process of sub-model analysis

CHAPTER 2 COMPLETE SHIP MODEL CALCULATION

2.1 Complete ship FE mode

2.1.1 Extent of the model

2.1.1.1 A three-dimensional FE model is to be used to simulate the hull structure of the complete ship, including the main hull structure, superstructure and deckhouse structure. Local support and reinforcement structure, such as bracket, the reinforcement structure under anchor and mooring equipment may be omitted in the simulation. See figure 2.1.1.1.

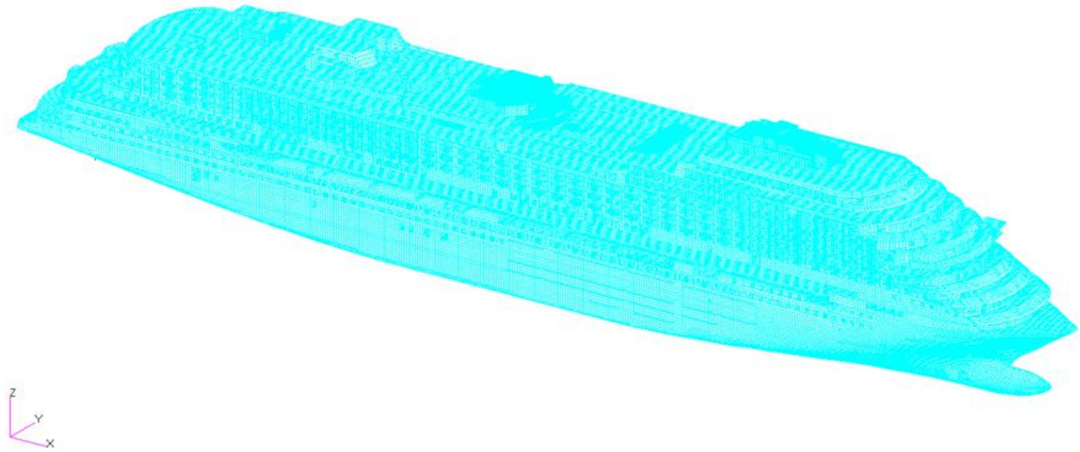

Figure 2.1.1.1 FE model of complete ship

2.1.2 Elements and meshes

2.1.2.1 Hull plates and webs of primary supporting members are simulated by shell elements while secondary stiffeners and face plates of primary supporting members are simulated by beam elements. Triangular elements are to be minimized in high stress area. For plate elements, meshes are divided for each spacing of longitudinals in the transverse and vertical direction, and the shell elements between transverses are divided into several units in the longitudinal direction such that the aspect ratio of shell elements is to be close to 1 as far as possible. See Figures 2.1.2.1(1) and 2.1.2.1(2).

2.1.2.2 The plate floor is to be modelled at least three shell elements on its height. The web of the primary supporting members of the deck may be modelled with one element on its height.

2.1.2.3 Large openings as well as windows and doors are to be modeled in the model to accurately simulate the bending and shear strength as well as stress distribution of the hull girder. Figure 2.1.2.3 gives FE mesh arrangement of the ship side. In order to accurately simulate the size of the openings and ensure reasonable aspect ratios of the elements, finer meshes are used for the door and window opening area than those used for the main hull area.

2.1.2.4 The FE model scantlings is based on the as-built thicknesses excluding the owner’s extras.

2.1.2.5 Pillars are normally simulated by beam elements. When shell elements are used to simulate pillars, the stress at the edge of the pillars needs to be obtained by virtual beam elements.

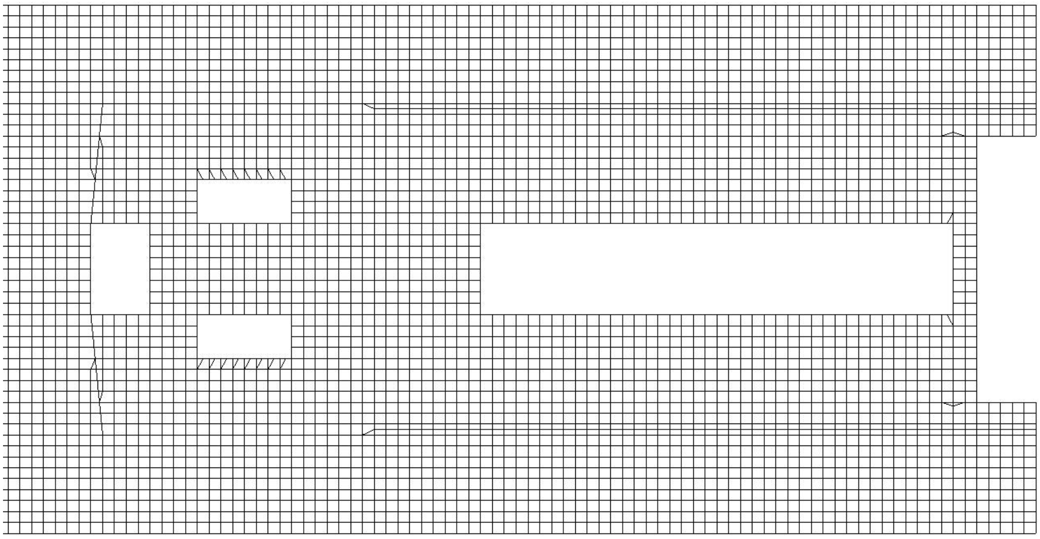

Figure 2.1.2.1(1) FE meshes of deck level

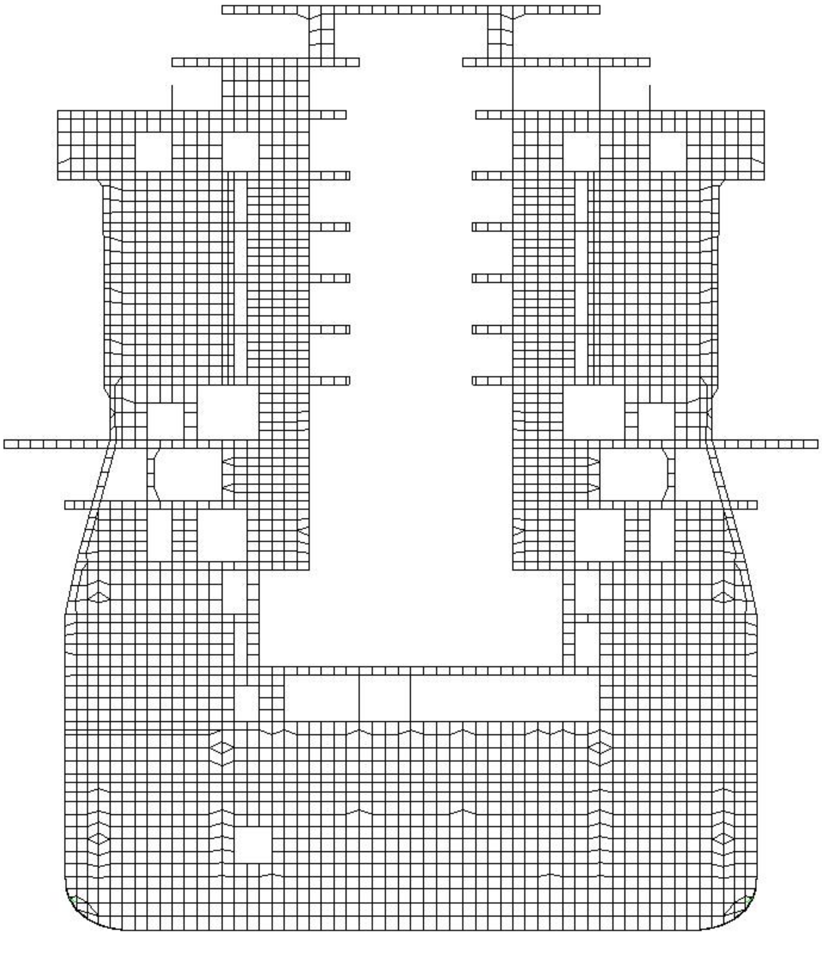

Figure 2.1.2.1(2) FE meshes of transverse bulkhead

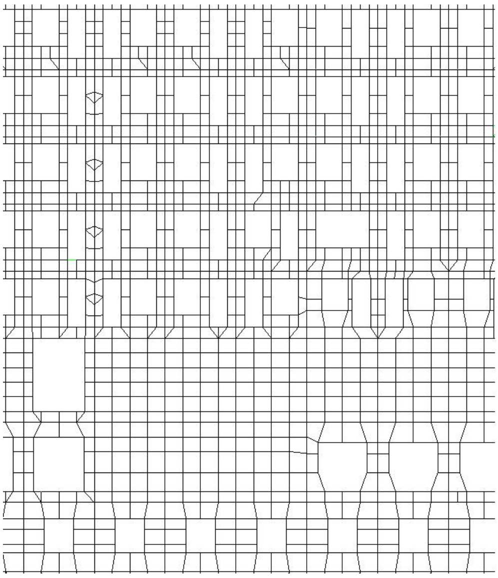

Figure 2.1.2.3 Meshes of door and window openings

2.1.3 Mass properties

2.1.3.1 In order to apply the gravity load, it is necessary to adjust the material density of the FE model by region, or set the mass element, so that the mass distribution of the model is consistent with the design load. Section bending moment and shear force under STA(+) and SAT(-) sub-load cases are to be consistent with the corresponding loading calculation results.

2.1.3.2 The mass of the liquid in the deep tank can be simulated by setting mass points on the perimeter, which are to be built at the junction of the plate elements to eliminate stress concentration. The mass of heavy equipment is simulated by elements that reflect its mass properties and are connected to the hull in a reasonable manner.

2.2 Assessment load cases and sub-load cases

2.2.1 Assessment load cases

2.2.1.1 The complete ship analysis includes six assessment load cases, LC1~LC6. See Table 2.2.1.1. Each assessment load case is composed of several sub-load cases. The stress results of the assessment load case are composed of the stress results of sub-load cases. The load, boundary conditions and adjustment of floating condition are detailed in 2.3.

2.2.1.2 LC1 and LC2 check the hull structural strength in the hogging and sagging conditions respectively. The loads include the hull girder load and the local load.

2.2.1.3 LC3 and LC4 check the hull structural strength under maximum and minimum shear force amidships. The loads include the still water shear force and the wave shear force.

2.2.1.4 LC5 and LC6 check the hull structural strength in the rolling condition. The main loads are gravity, external sea pressure and rolling force of inertia.

Complete ship assessment load cases Table 2.2.1.1

Assessment load case	Sub-load case	Load component	Boundary condition	Adjustment of floating condition
LC1 Hogging	STA(+) Still water	Lightship, maximum hogging deadweight,	BC1	✔

	hogging	hydrostatic pressure		
	WB(+) Wave hogging	Wave shear force(hogging) Wave bending moment(hogging)	BC1	-
	PRE(+) Wave crest pressure	Wave dynamic pressure (wave crest)	BC2	-
LC2 Sagging	STA(-) Still water sagging	Lightship, minimum hogging deadweight, hydrostatic pressure	BC1	✔
	WB(-) Wave sagging	Wave shear force(sagging) Wave bending moment(sagging)	BC1	-
	PRE(-) Wave trough pressure	Wave dynamic pressure (wave trough)	BC2	-
LC3 Shear force amidships(+)	STA(+) Still water hogging	Lightship, maximum hogging deadweight, hydrostatic pressure	BC1	✔
	SHEAR(+) Positive shear force amidships	Wave shear force (positive)	BC1	-
LC4 Shear force amidships(-)	STA(-) Still water sagging	Lightship, minimum hogging deadweight, hydrostatic pressure	BC1	✔
	SHEAR(-) Negative shear force amidships	Wave shear force (negative)	BC1	-
LC5 Rolling-port	ROLL(P) Rolling to port	External sea pressure in rolling condition gravity and rolling force of inertia	BC3	-
LC6 Rolling-starboard	ROLL(S) Rolling to starboard	External sea pressure in rolling condition gravity and rolling force of inertia	BC3	-

2.2.2 Sub-load cases

2.2.2.1 A sub-load case includes a certain set of loads (such as wave bending moment) in the assessment load case. Sub-load cases have corresponding boundary conditions and can be independently analyzed for structure to obtain element stress.

2.2.2.2 STA(+) is the maximum hogging still water sub-load case, and its load is determined by the load with the maximum still water bending moment in the Load Manual. The load components include the hydrostatic pressure, lightship and gravity of the load as well as hull girder still water bending moment and still water shear force generated by the above-mentioned local loads.

2.2.2.3 STA(-) is the minimum hogging still water sub-load case, and its load is determined by the load with the minimum still water bending moment in the Load Manual. The load components are same as those in STA(+).

2.2.2.4 WB(+) is the hogging wave sub-load case. The loads are hogging wave bending moment and hogging wave shear force. WB(-) is the sagging wave sub-load case. The loads are sagging wave bending moment and sagging wave shear force. See 2.3.3.2 and 2.3.3.3 for the target values of the two sub-load cases respectively. See 2.3.4.2 for the actual values.

2.2.2.5 PRE(+) and PRE(-) are the local wave pressure sub-load cases, representing wave crest and wave trough respectively. See 2.3.1.2 for the loads.

2.2.2.6 SHEAR(+) and SHEAR(-) are wave shear force amidships sub-load cases. The wave shear force reaches its maximum and minimum values respectively in the region between 0.4L-0.6L amidships. See 2.3.3.4 and 2.3.4.3 for its target value and actual value respectively.

2.3 Loads and boundary conditions

2.3.1 Local loads

2.3.1.1 External pressure in still water is calculated as follows:

$$p_{hs} = \rho_w g(d_1 - z) \qquad \text{kN/m}^2,\ z \le d_1$$

$$= 0 \qquad \text{kN/m}^2,\ z > d_1$$

where: ρ_w ——density of sea water, to be taken as 1.025t/m^3;

d_1 ——draught in the assessment load case, in m;

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

2.3.1.2 See Table 2.3.1.2 for the dynamic wave pressure of load cases LC1 and LC2, where the positive value indicates wave crest, acting inward, used for LC1 and superimposed with the static pressure of 2.3.1.1; the negative value indicates wave trough, acting outward, used for LC2 and offsetting the static pressure of 2.3.1.1. See 2.3.3.2 for the definition of C in the Table. Refer to Figure 2.3.1.2 for the dynamic wave pressure.

Dynamic wave pressure Table 2.3.1.2

Range of z (m)	Wave crest (kN/m^2)	Wave trough (kN/m^2)
$d_1 < z \le d_1 + 0.33C$	$3.3C-10(z-d_1)$	0
$0 \le z \le d_1$	$2.25C+1.05zC/d_1$	$\mathrm{Max}(-2.25C-1.05zC/d_1,\ \rho g(z-d_1))$

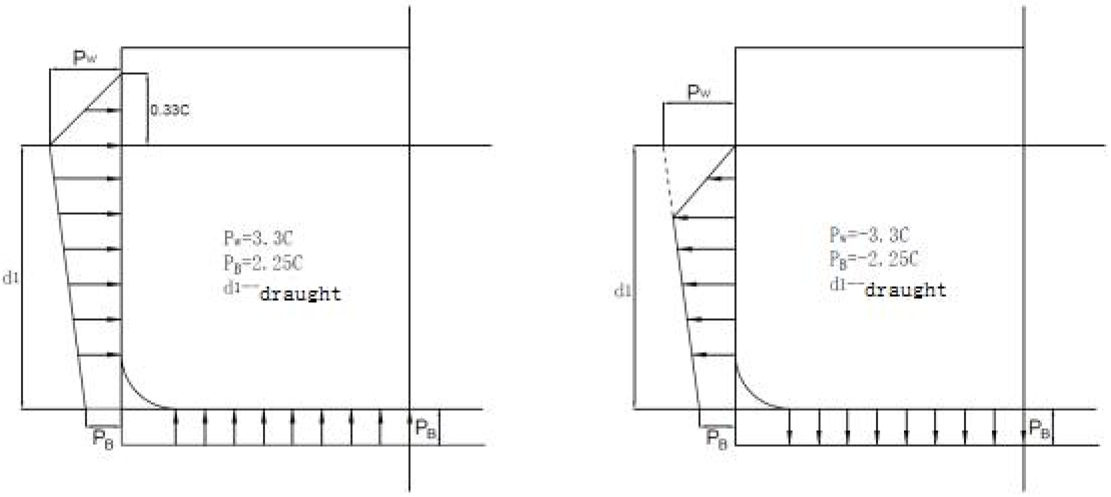

Figure 2.3.1.2 Dynamic wave pressure

2.3.1.3 The external sea pressure in rolling load cases LC5 and LC6 is calculated according to the formula in 2.3.1.1. Changes in floating condition due to rolling is to be taken into account in the calculation. See 1.5.2, Chapter 1, PART TWO of the Rules for the calculation method of the heel angle.

2.3.1.4 The gravity load depends on the load. The FE model of the complete ship is to accurately simulate the mass distribution of the lightship and deadweight, and gravity is applied through the acceleration field.

2.3.1.5 The horizontal inertia force in heeling condition is loaded by acceleration field. See 1.5.2, Chapter 1, PART TWO of the Rules for the calculation method of the horizontal acceleration.

2.3.2 Hull girder load

2.3.2.1 The hull girder load is the main load of the complete ship analysis, and it reaches its maximum/minimum value at each section along the ship length. For hydrostatic bending moment and shear force, the permissible value is taken. For wave bending moment and shear force, the rule value is taken. These bending moments and shear forces, as well as those combined with still water and waves, are referred to as the "target value" of the hull girder load. Structural strength is assessed using stress results based on the target value of hull girder load. See 2.3.3 for the detailed specifications for the target value.

2.3.2.2 The target value of the hull girder load is the envelope value, and it is difficult to achieve the target bending moment and shear force in all sections at the same time in the direct calculation of the complete ship. In the analysis, the bending moment and shear force close to the target value of the hull girder load are applied with the method of 2.3.4. At this time, the bending moment and shear force applied on the model are called the "actual value".

2.3.2.3 Because the actual value of the load is not completely consistent with the target value, the stress generated by the difference is to be calculated by the stress transfer function, and the stress result of the actual value is to be corrected accordingly to obtain the stress result of the target value for strength assessment. See 2.4.1 for the stress correction method.

2.3.3 Target value of the hull girder load

2.3.3.1 The target values of hydrostatic bending moment and shear force are permissible values, which are provided by the designer. The hydrostatic bending moment target value curves of LC1 and LC2 are the maximum and minimum permissible bending moment curves respectively. Of the permissible hydrostatic shear force curves provided by the designer as shown in Figure 2.3.3.1, curve A1-A4 is the maximum permissible shear force curve, and curve B1-B4 is the minimum permissible shear force curve. The target values of hydrostatic shear force under various load cases are shown in Table 2.3.3.1.

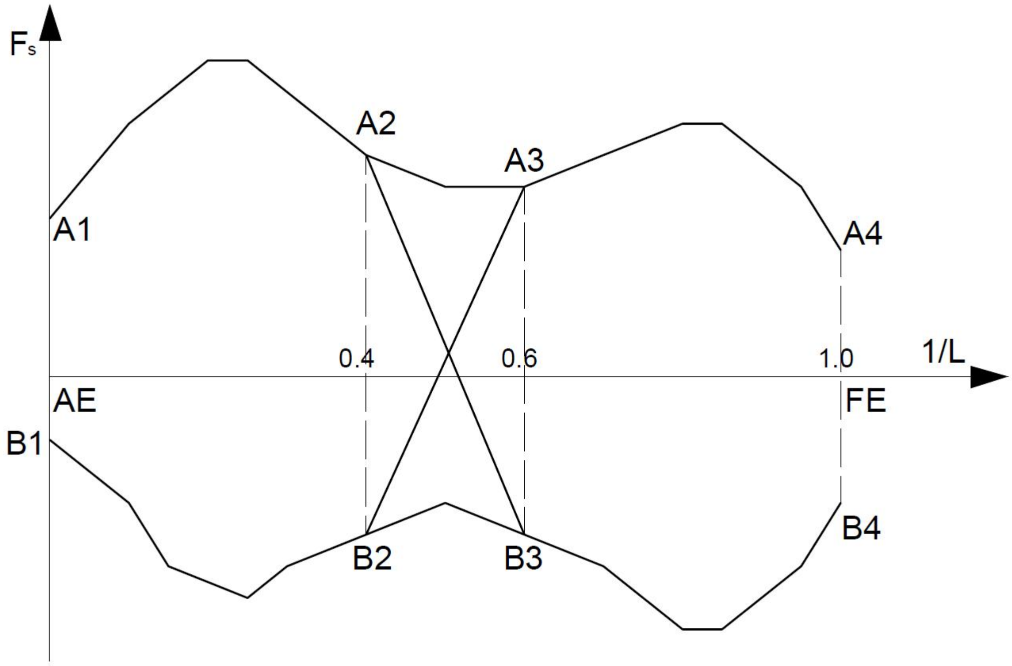

Figure 2.3.3.1 Permissible hydrostatic shear force curves

Hydrostatic shear force target value curves under various load cases Table 2.3.3.1

Load case	LC1	LC2	LC3	LC4
Target shear force curve	A1-A2-B3-B4	B1-B2-A3-A4	A2-A3	B2-B3

2.3.3.2 The hogging wave bending moment $\mathrm{M_W}(+)$ in LC1 and the sagging wave bending moment $\mathrm{M_W}(-)$ in LC2 are calculated as follows respectively:

$$M_W(+) = 0.19\mathrm{M}CL^2BC_b \quad kN.m$$

$$M_W(-) =- 0.11\mathrm{M}CL^2B(C_b + 0.7) \quad kN.m$$

where: M ——bending moment distribution factor, see Figure 2.3.3.2;

L ——length of ship , in m;

B ——breadth of ship, in m；

C_b——block coefficient, to be taken not less than 0.60;

C ——wave coefficient, to be calculated as follows:

$$C = 10.75 - \left(\frac{300-L}{100}\right)^{3/2} \quad \text{when } 90 \le \mathrm{L} \le 300\mathrm{m};$$

$$C = 10.75 \quad \text{when } 300\mathrm{m} < \mathrm{L} < 350\mathrm{m};$$

$$C = 10.75 - \left(\frac{L-350}{150}\right)^{3/2} \quad \text{when } 350\mathrm{m} \le \mathrm{L} \le 500\mathrm{m}.$$

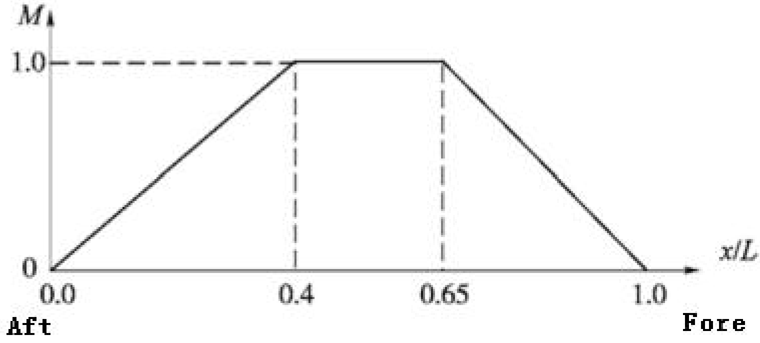

Figure 2.3.3.2 Distribution of wave bending moment along the length of the ship

2.3.3.3 The hogging wave shear force $F_W(+)$ in LC1 and the sagging wave shear force $F_W(-)$ in LC2 are calculated as follows respectively:

$$F_W(+) = 0.3F_1CLB(C_b + 0.7) \quad kN$$

$$F_W(-) = 0.3F_2CLB(C_b + 0.7) \quad kN$$

where: F_1, F_2——shear force distribution factors, see Figures 2.3.3.3(1) and 2.3.3.3(2).

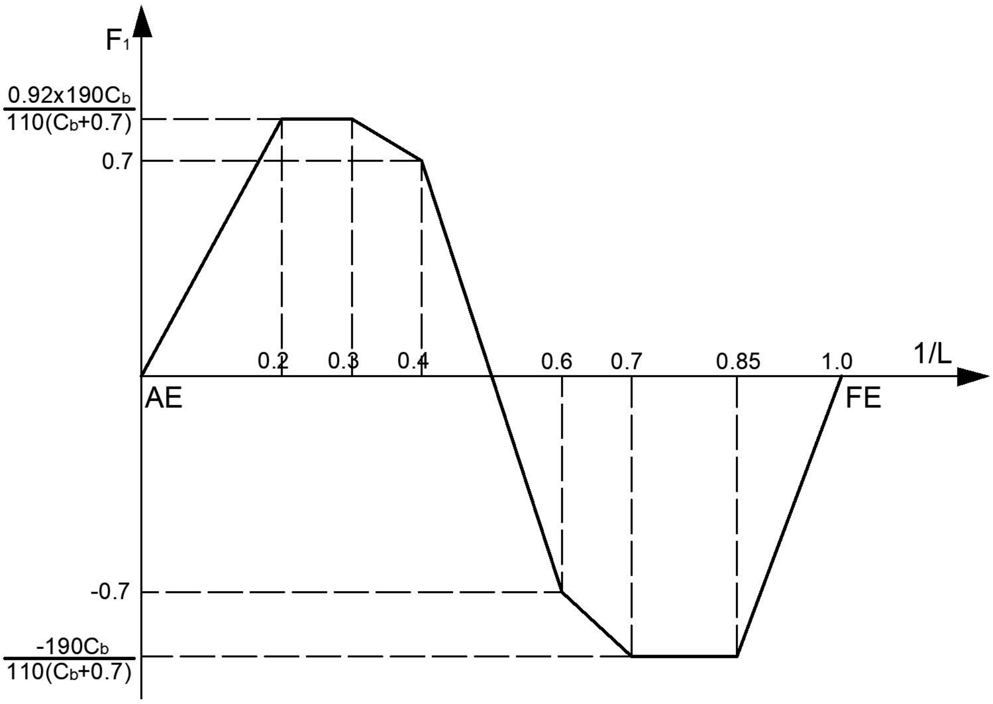

Figure 2.3.3.3(1) Hogging wave shear force distribution factor F_1

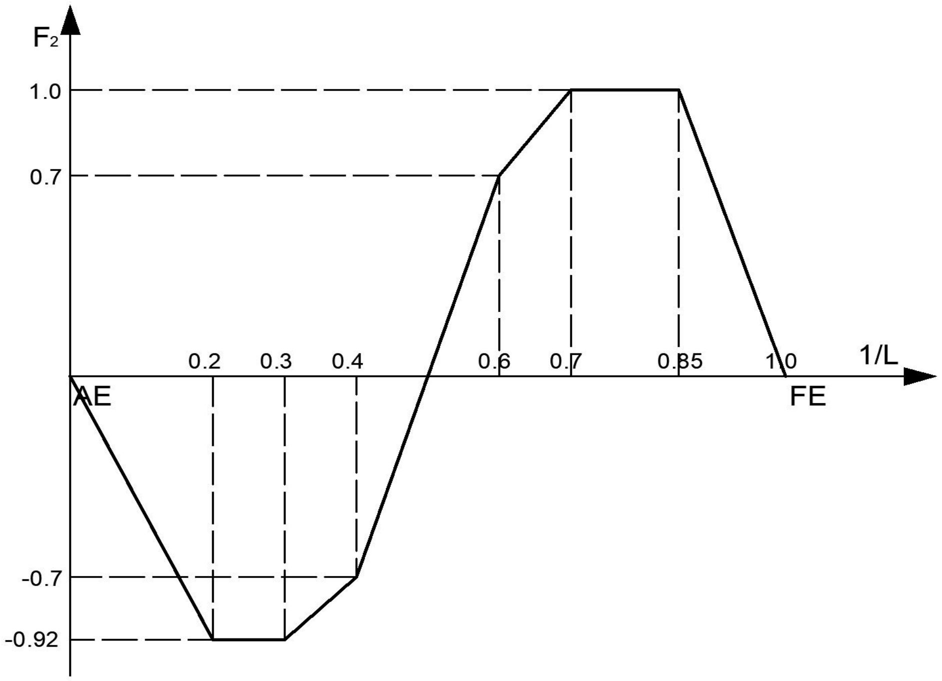

Figure 2.3.3.3(2) Sagging wave shear force distribution factor F_2

2.3.3.4 The maximum shear force $F_W(M+)$ at 0.4L-0.6L amidships in LC3 and the minimum shear force $F_W(M-)$ at 0.4L-0.6L amidships in LC4 are calculated as follows:

$$F_W(M+) = 0.21CLB(C_b + 0.7) \quad kN \qquad \text{(LC3)}$$

$$F_W(M-) = -0.21CLB(C_b + 0.7) \quad kN \qquad \text{(LC4)}$$

2.3.4 Actual value of the hull girder load

2.3.4.1 The hydrostatic bending moment and shear force are obtained by integrating the gravity and buoyancy loads in the model along the length of the ship, and the calculated results are to be in good agreement with those given by the loading calculation.

2.3.4.2 The wave bending moment and shear force are to be loaded by distributed force along the length of the ship. For LC1 and LC2, the distribution of the wave bending moment along the length of the ship is as follows:

$$BM_1(\mathrm{x}) = M_W\left(a_1x^5 + a_2x^4 + a_3x^3 + a_4x^2\right) \quad kN.m$$

The distribution of wave shear force along the length of the ship is obtained by derivation of the above equation as follows:

$$SF_1(\mathrm{x}) = \frac{M_W}{L_O}(5a_1x^4 + 4a_2x^3 + 3a_3x^2 + 2a_4x) \quad kN$$

The corresponding distributed force is obtained by further derivation:

$$P_1(\mathrm{x}) = \frac{M_W}{L_O^2}(20a_1x^3 + 12a_2x^2 + 6a_3x + 2a_4) \quad kN/m$$

where: M_W——wave bending moment amidships, in $kN.m$, see 2.3.3.2;

L_O——overall length of the complete ship model, in m;

x——relative coordinate of the point considered in the complete ship model, to be taken as 0 and 1 for the stern and bow ends of the model respectively;

$$a_1 = \frac{z_{22} - z_{12}}{z_{11}z_{22} - z_{21}z_{12}}$$

$$a_2 = \frac{z_{11} - z_{21}}{z_{11}z_{22} - z_{21}z_{12}}$$

$$a_3 = -3a_1 - 2a_2$$

$$a_4 = 2a_1 + a_2$$

where: $z_{11} = \gamma_1^5 - 3\gamma_1^3 + 2\gamma_1^2$

$z_{12} = \gamma_1^4 - 2\gamma_1^3 + \gamma_1^2$

$z_{21} = \gamma_2^5 - 3\gamma_2^3 + 2\gamma_2^2$

$z_{22} = \gamma_2^4 - 2\gamma_2^3 + \gamma_2^2$

where: γ_1——relative coordinate at 0.4L in the complete ship model, calculated as follows:

$$\gamma_1 = \frac{\alpha + 0.4}{\alpha + \beta + 1}$$

γ_2——relative coordinate at 0.65L in the complete ship model, calculated as follows:

$$\gamma_2 = \frac{\alpha + 0.65}{\alpha + \beta + 1}$$

where: α——ratio of the model length after the aft end (AE) of the ship to the length of the ship;

β——ratio of the model length before the fore end (FE) of the ship to the length of the ship.

2.3.4.3 The wave shear forces in amidships shear force load cases LC3 and LC4 are given in the following formulae. See Table 2.3.4.3 for the shear force distribution factors F_3 and F_4.

$$F_W(\mathrm{LC3}) = 0.3F_3CLB(C_b + 0.7) \quad kN$$

$$F_W(LC4) = 0.3F_4CLB(C_b + 0.7) \quad kN$$

Shear force distribution factors Table 2.3.4.3

x	F_3	F_4
0	0	0
0.1L	-0.56	0.56
0.2 L	-0.56	0.56
0.4 L	0.7	-0.7
0.6 L	0.7	-0.7
0.8 L	-0.56	0.56
0.9 L	-0.56	0.56
1.0 L	0	0

2.3.4.4 In order to apply the wave bending moment and shear force of 2.3.4.2, the distributed force P_1 is integrated in the range of each transverse along the length of the ship, and the force in this range is obtained, which is applied dispersedly on each node of the intersection line between the transverse and the shell plating. Figure 2.3.4.4 shows an example of loading (local). Wave shear force of 2.3.4.3 is applied in the same way.

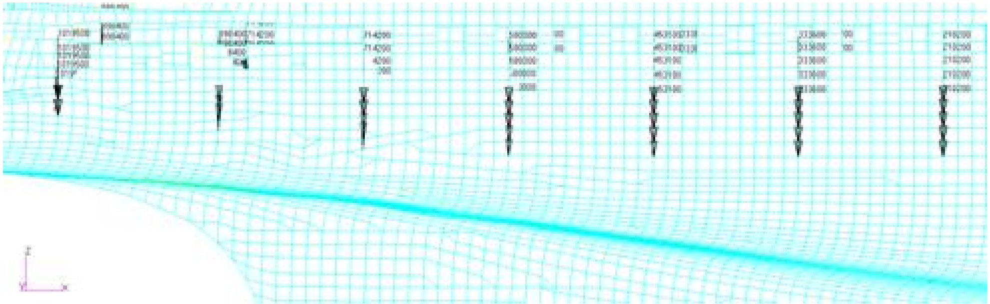

Figure 2.3.4.4 Means of loading for hull girder loads

2.3.4.5 Other means of loading can be used to load the wave bending moment and shear force on the complete ship FE model. For this purpose, a detailed description of the means used is to be provided subject to CCS agreement.

2.3.5 Boundary conditions and equilibrium

2.3.5.1 The complete ship analysis includes three boundary conditions of displacement, namely BC1, BC2 and BC3, which are used for different sub-load cases. See Table 2.2.1.1 for their corresponding relationship.

2.3.5.2 BC1 boundary condition constrains the rigid displacement of the model; see Figure 2.3.5.2: the y-direction displacement of the bottom plate keel at the stern (point 1) is zero; at the bow (point 2), the displacement in x, y and z directions is zero; the displacement in the z direction of the two end nodes (point 3, point 4) of the intersecting line between the bulkhead deck and the transom plating is zero.

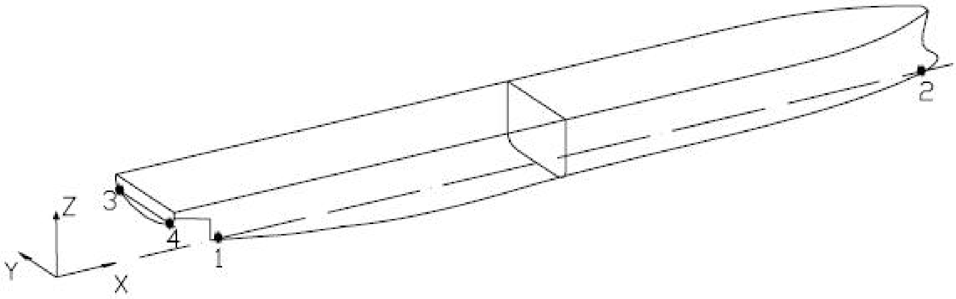

Figure 2.3.5.2 Illustration of boundary conditions

2.3.5.3 The displacement constraints of BC2 boundary condition are shown in Table 2.3.5.3. It is also required to apply a reaction force equal to the local load on the opposite direction at the node of the intersecting line between the transverse and the shell plating, so as to avoid bending of hull girder caused by local load.

BC2 boundary condition Table 2.3.5.3

Constraint	$\delta_x = 0$	$\delta_y = 0$	$\delta_z = 0$
Acting on	Point 2	Points 1, 2	All nodes on the bulkhead deck sideline

2.3.5.4 In the rolling condition, boundary condition BC3 is applied as follows:

(1) constrain displacement in z direction of all nodes on the intersecting line between the

transverse and side shell;

(2) constrain displacement in y direction of all nodes on the intersecting line between the central longitudinal section and the flat keel;

(3) constrain displacement of point 2 in x direction.

2.3.5.5 For loading conditions STA(+) and STA(-), equilibrium of gravity and buoyancy are to be checked, and floating condition is to be adjusted where necessary to achieve equilibrium of total forces. See 1.5.7.6, Section 1, PART TWO of the Rules for the requirements for equilibrium.

2.4 Stress correction

2.4.1 Stress correction method

2.4.1.1 According to the difference between the actual bending moment/shear force value at the section position of the target element and the target value, the load-stress transfer function is used to correct the stress, and the stress under the target value is obtained:

$$\sigma_x = \sigma_{x-FEM} + f_{mx}\Delta M + f_{qx}\Delta Q$$

$$\sigma_y = \sigma_{y-FEM} + f_{my}\Delta M + f_{qy}\Delta Q$$

$$\tau_{xy} = \tau_{xy-FEM} + f_{mxy}\Delta M + f_{qxy}\Delta Q$$

$$\sigma_a = \sigma_{a-FEM} + f_{ma}\Delta M + f_{qa}\Delta Q$$

where:

$\sigma_x, \sigma_y, \tau_{xy}, \sigma_a$——stresses under the load target value, namely x direction stress, y direction stress, shear stress and axial stress in girder element;

$\sigma_{x-FEM}, \sigma_{y-FEM}, \tau_{xy-FEM}, \sigma_{a-FEM}$——stress obtained by analyzing the actual value of hull girder load;

f_{mx}, f_{my}, f_{mxy}, f_{ma}——load-stress transfer function, i.e. the stress generated in the unit hull girder bending moment of the section where the target element is located. The calculation method is shown in 2.4.3.

$f_{qx}, f_{qy}, f_{qxy}, f_{qa}$——shear-stress transfer function, i.e. the stress generated in the unit hull girder shear force of the section where the target element is located. The calculation method is shown in 2.4.3.

$\Delta M, \Delta Q$—— the difference between the target values and the actual values of bending moment and shear force of the section where the target element is located.

2.4.1.2 The equivalent stress, longitudinal stress and maximum shear stress of the plate element used in the strength assessment are to be calculated based on the stress corrected in accordance with 2.4.1.1.

2.4.1.3 Where the actual values of bending moment and shear force of the model reach or exceed the target values, stress correction may not be required.

2.4.2 Transfer function load cases and loads

2.4.2.1 The load-stress transfer function is to be calculated based on the stress results of bending condition and shear condition. The two conditions only include the hull girder load, as shown in

Figure 2.4.2.1.

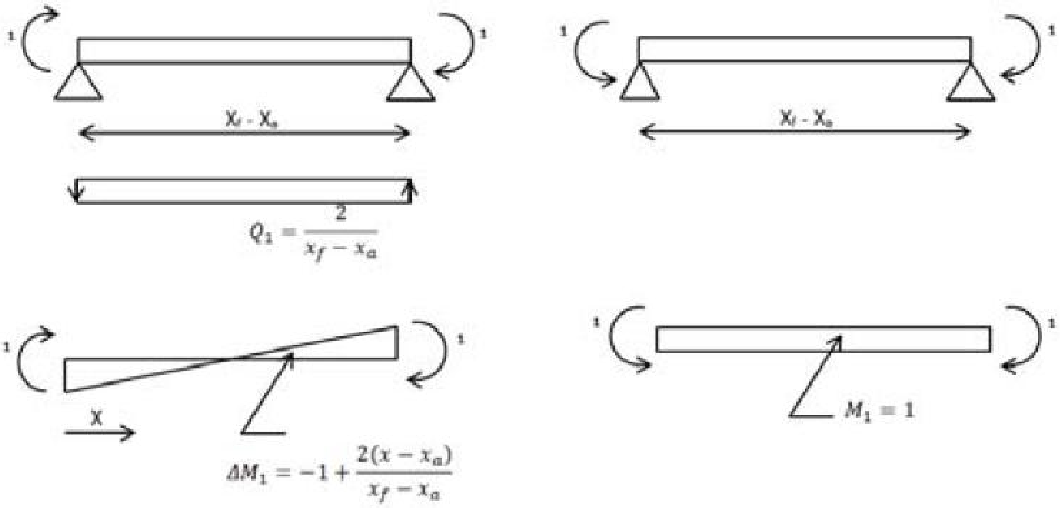

Figure 2.4.2.1 Calculation of shear condition (left) and bending condition (right) of transfer function

2.4.2.2 Shear condition load: unit bending moment is applied at both ends of hull girder, and the bending moments at both ends are in the same direction. Under such conditions, the shear force generated in the hull is:

$$Q_1(x) = \frac{2}{x_f - x_a}$$

Bending moment distributions along the ship's length are:

$$M_1(x) = -1 + \frac{2(x - x_a)}{x_f - x_a}$$

where: x_f, x_a—— coordinates of the bending moments applied fore and aft;

x—— coordinate of the section where the element is located.

2.4.2.3 Bending condition load: bending moment of unit size is applied at both ends of the hull girder, and 1 and -1 are taken for the bow and the stern respectively. Under such conditions, the shear force generated in the hull is:

$$Q_2(x) = 0$$

Bending moment distribution along the ship's length is:

$$M_2(x) = 1$$

2.4.2.4 The boundary conditions of the above two conditions are as follows: two independent nodes are created at both ends of the model, and the nodes of longitudinal members below the main deck on the sections at both ends of the model Rule length are connected to the independent points by MPC, and the displacement in three directions are same. The independent node on aft end of the model is fixed for linear displacements in x, y and z directions and rotation around x axis. The independent node on fore end of model is fixed for linear displacements in y and z directions. The bending moment in each condition is also applied through the above two independent points.

2.4.3 Calculation of transfer function

2.4.3.1 The stress in the element is generated by the bending moment and shear force of the hull girder. Based on the linear theory, for the shear condition:

$$\sigma_{1x} = f_{mx}M_1 + f_{qx}Q_1$$
$$\sigma_{1y} = f_{my}M_1 + f_{qy}Q_1$$
$$\tau_{1xy} = f_{mxy}M_1 + f_{qxy}Q_1$$

for the bending condition:

$$\sigma_{2x} = f_{mx}M_2 + f_{qx}Q_2$$
$$\sigma_{2y} = f_{my}M_2 + f_{qy}Q_2$$
$$\tau_{2xy} = f_{mxy}M_2 + f_{qxy}Q_2$$

where: σ_{1x}, σ_{1y}, τ_{1xy} —— three stress components of the target element in shear condition, namely x direction stress, y direction stress and shear stress;

σ_{2x}, σ_{2y}, τ_{2xy} —— three stress components of the target element in bending condition, namely x direction stress, y direction stress and shear stress;

f_{qx}, f_{qy}, f_{qxy}—— shear force-stress transfer function;

f_{mx}, f_{my}, f_{mxy}—— bending moment-stress transfer function.

The formula of each stress component is separately and simultaneously formulated. According to the above six equations, six transfer functions can be obtained as follows:

$$f_{mx} = \frac{Q_2\sigma_{1x} - Q_1\sigma_{2x}}{Q_2M_1 - Q_1M_2}$$

$$f_{qx} = \frac{M_2\sigma_{1x} - M_1\sigma_{2x}}{Q_1M_2 - Q_2M_1}$$

$$f_{my} = \frac{Q_2\sigma_{1y} - Q_1\sigma_{2y}}{Q_2M_1 - Q_1M_2}$$

$$f_{qy} = \frac{M_2\sigma_{1y} - M_1\sigma_{2y}}{Q_1M_2 - Q_2M_1}$$

$$f_{mxy} = \frac{Q_2\tau_{1xy} - Q_1\tau_{2xy}}{Q_2M_1 - Q_1M_2}$$

$$f_{qxy} = \frac{M_2\tau_{1xy} - M_1\tau_{2xy}}{Q_1M_2 - Q_2M_1}$$

2.4.3.2 Using the same method, the transfer function of axial stress of girder element can be obtained as follows:

$$f_{ma} = \frac{Q_2\sigma_{1a} - Q_1\sigma_{2a}}{Q_2M_1 - Q_1M_2}$$

$$f_{qa} = \frac{M_2\sigma_{1a} - M_1\sigma_{2a}}{Q_1M_2 - Q_2M_1}$$

where: σ_{1a}, σ_{2a} —— axial stress of target element in shear condition and bending condition respectively;

f_{qa}—— shear force-stress transfer function;

f_{ma}—— bending moment-stress transfer function.

2.5 Strength assessment

2.5.1 Extent of strength assessment

2.5.1.1 The stress is to be obtained according to load case assessment in Table 2.2.1.1, and the hull structure strength is to be assessed after correction according to the method in 2.4.1.

2.5.1.2 Strength assessment is to be carried out for shell plating, inner bottom plating, deck plating and bulkhead plating of hull structure, side bulkheads of superstructures and decks, and primary supporting members.

2.5.2 Yield strength

2.5.2.1 Yield strength criteria of hull structure are shown in Table 2.5.2.1. The middle plane stress at the center of the element is to be taken as the stress of the plate element.

Yield strength criteria of hull structure Table 2.5.2.1

Hull structure	Load case	Permissible stress		
		Longitudinal stress	Shear stress	Equivalent stress
Bottom plating, inner bottom plating	LC1, LC2, LC3, LC4	210/K	——	220/K
Bottom girders		210/K	——	220/K
Plate floors		——	110/K	220/K
Other longitudinal members		175/K	110/K	220/K
Transverse members	LC5, LC6	——	$0.35R_{eH}$	$0.75R_{eH}$
Note 1. Only the hull structure between 0.4L-0.6L is checked for LC3 and LC4 load cases,. Note 2. K is material factor.				

2.5.3 Pillar strength

2.5.3.1 Pillar strength criteria are shown in Table 2.5.3.1.

Pillar strength criteria Table 2.5.3.1

Pillar	Criteria
In tension	$\sigma_{axial} \le 0.6R_{eH}$ $\sigma_{axial} + \sigma_{bending} \le 0.84R_{eH}$ $\tau \le 0.47R_{eH}$
Under pressure	$\sigma_{axial} \le 0.8\sigma_{crit}$ $\sigma_{axial}/\sigma_{crit} + \sigma_{bending}/R_{eH} \le 0.84$ $\tau \le 0.47R_{eH}$

Note 1. σ_{crit} is critical buckling stress of pillar, calculated according to the following formula:

$$\sigma_{crit} = \frac{R_{eH}}{1 + \frac{R_{eH}}{E}\left(\frac{L_E}{\pi r}\right)^2}$$

where: L_E —— effective length of the pillar, to be taken as 0.8 times the pillar length;

r —— minimum bending inertia radius of the pillar.

Note 2. $\sigma_{bending}$ is the maximum bending stress in the pillar, calculated according to the following formula:

$$\sigma_{bending} = |\sigma_{extreme} - \sigma_{axial}|$$

where: $\sigma_{extreme}$—— maximum/minimum stress on the pillar section, to be obtained at the edge of the section;

σ_{axial}—— axial stress of the pillar, to be obtained at the centroid of the section.

2.5.4 Buckling strength

2.5.4.1 Unless otherwise specified in this Section, buckling assessment is to be carried out in accordance with the relevant requirements of Chapter 8, PART 9-1 of the Rules. The buckling strength is to comply with the following criteria:

$$\eta \le \eta_{all}$$

where: η—— maximum buckling utilization factor;

η_{all}——permissible buckling utilization factor, see Table 2.5.4.4.

2.5.4.2 The capacity of a structural item is to be assessed with a standard thickness deduction. The standard thickness deduction of each part is shown in Table 2.5.4.2.

Standard thickness deduction Table 2.5.4.2

Member	Thickness deduction (mm)
Tank boundary and shell plating	1.0
Weather deck	0.5
Other structures	0.0

2.5.4.3 Considering the effect of corrosion, the working stress is to be corrected according to the following formula:

$$\sigma_A = \frac{\sigma t}{t - 0.5 t_r} \qquad N/mm^2$$

where: σ_A—— corrected working stress;

σ—— working stress obtained by calculation

t—— plate thickness in the model;

t_r—— standard thickness deduction, see Table 2.5.4.2.

2.5.4.4 The permissible buckling utilization factors for the buckling assessment are shown in Table 2.5.4.4.

Permissible buckling utilization factor Table 2.5.4.4

Member	Load case	Buckling utilization factor
Longitudinal structure	LC1, LC2, LC3, LC4	1.0
Transverse structure		0.9
Transverse structure	LC5, LC6	1.0

2.5.4.5 Buckling assessment methods for stiffened/unstiffened plate panels of cruise ship hull structures are shown in Table 2.5.4.5.

Types of panels and assessment methods of hull structure Table 2.5.4.5

No.	Structure	Assessment method
1	Shell plating Inner bottom Longitudinal bulkheads including bottom girders beneath deck	SP-A

2	Bottom girders	SP-B
3	Superstructure side bulkheads and longitudinal bulkheads Superstructure decks	SP-A
4	Deck girders, horizontal girder webs of longitudinal bulkheads	UP-B
5	Irregular plate panels around opening	UP-B
6	Plate floors beneath transverse bulkheads	SP-A
7	Plate floors	SP-B
8	deck transverses, girder web of transverse bulkheads	UP-B
9	Irregular plate panels at bulkheads, plate floors, etc.	UP-B
Note: generally speaking, the length of plate panel is to be taken as the span of longitudinals or stiffeners, and the width of plate panel is to be taken as the spacing of longitudinals or stiffeners.		

Chapter 3 Refined Analysis

3.1 General provisions

3.1.1 Objectives

3.1.1.1 On the basis of the complete ship model calculation in Chapter 2, refined analysis is to be carried out for the stress concentration area of the ship structure in accordance with the requirements of this Chapter.

3.1.2 Assessment areas

3.1.2.1 Refined analysis is to be carried out for the following areas:

(1) superstructure end brackets;
(2) opening of side doors and windows
(3) large side openings, such as the entrance to the embarkation platform;
(4) other high stress concentration areas.

3.1.2.2 The yield strength assessment is to be carried out for the above refined areas, and the fatigue strength assessment is to be carried out for the opening corners.

3.1.3 Analysis methods

3.1.3.1 The independent refined model is generally used to assess the assessment areas specified in 3.1.2.1. The displacement obtained from the complete ship is applied to the independent model as a boundary condition, and other loads are mapped to the independent model, namely the "sub-modeling method". The refined analysis can also be carried out for local structure in the complete ship model, namely the "embedding method".

3.2 Refined model

3.2.1 Extent and boundary of the sub-model

3.2.1.1 The extent of the sub-model is to be sufficient so as to avoid stress distortion in the assessment areas due to boundary conditions. Model boundaries are generally to be provided at transverses, girders and decks.

3.2.1.2 The meshes of the sub-model are to match the complete ship model at the boundaries to accurately transfer the displacement results of the complete ship analysis.

3.2.2 Requirements for elements and meshes

3.2.2.1 For the refined model, hull plates and web plates of primary members are to be simulated by shell elements, and face plates of secondary members and primary members are to be simulated by beam elements. Secondary members within 500 mm of the target refined area are to be simulated by plate elements.

3.2.2.2 The mesh size in the refined area is to comply with the following requirements:

(1) The element scale is to simulate the local geometry of the hull structure, so as to reflect the local stress concentration and give an accurate stress. Generally, the mesh of 50mm x 50mm can be used.

(2) Along the edge of the opening corner, the number of elements in every 90 degrees central angle is not to be less than 8.

(3) In order to obtain the edge stress of the opening corner, a virtual beam element is to be

established along the edge of the plate thickness. The height of the element is equal to the thickness of the plate, and its cross-sectional area is 1mm^2.

Figure 3.2.2.2(1) shows a model example of the window and door opening area. Figure 3.2.2.2(2) shows an example of dummy elements at the opening corner.

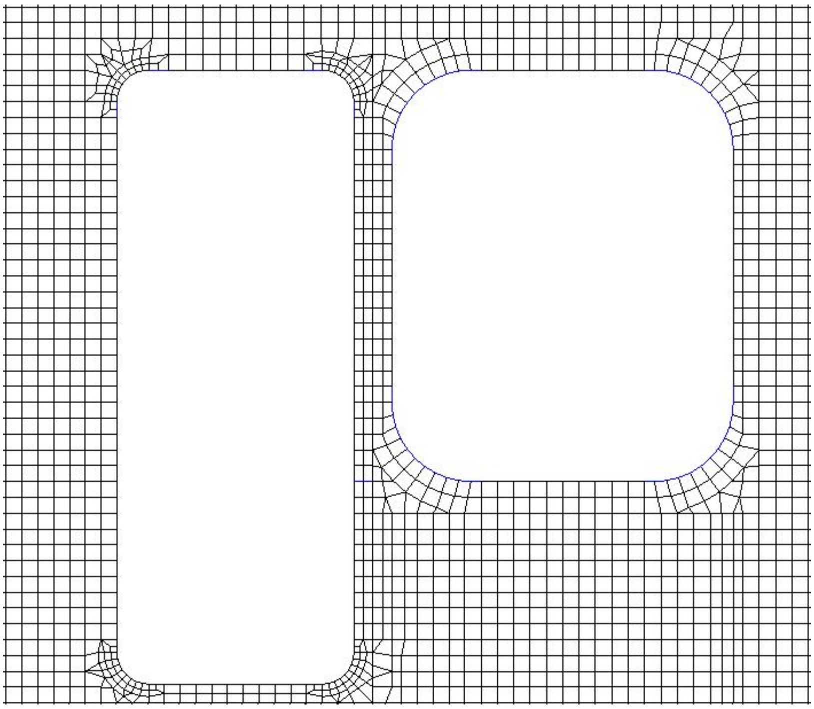

Figure 3.2.2.2(1) Refined mesh of door and window openings

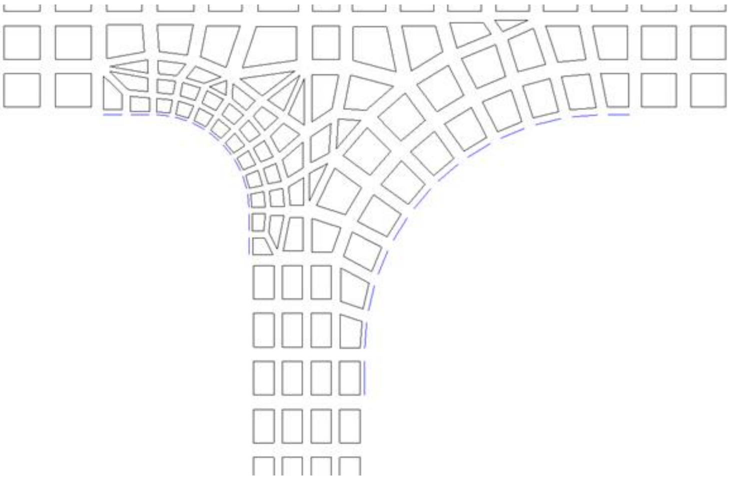

Figure 3.2.2.2(2) Virtual beam elements at the opening corner

3.3 Load cases and loads

3.3.1 Load cases

3.3.1.1 The refined assessment load case is to be the same as the complete ship assessment load case and is to include the stress transfer function load case and is to be corrected according to the method in 2.4.1 before strength assessment.

3.3.2 Loads

3.3.2.1 Where the sub-model method is used, the displacement results of the complete ship assessment are to be applied to the sub-model boundary to transfer the global load, and local loads within the extent of the sub-model, such as pressure, gravity and inertia forces, are to be applied.

3.4 Strength criteria

3.4.1 Yield strength

3.4.1.1 The stress criteria of the refined area are shown in Table 3.4.1.1.

Permissible stress Table 3.4.1.1

Location	Stress component	Permissible stress
Refined area	Equivalent stress of plate element	$1.35R_{eH}$
Note: where the element is less than 50mmx50mm, the mean stress of the elements included within the equivalent range is to be used.		

3.4.2 Fatigue strength

3.4.2.1 Where the axial stress of the virtual beam element is used for the opening corner, the stress range S_D is to be calculated according to the following formula:

$$S_D = MAX\left\{\left|\sigma_{LC1} - \sigma_{LC2}\right|, \left|\sigma_{LC3} - \sigma_{LC4}\right|, \left|\sigma_{LC5} - \sigma_{LC6}\right|\right\}$$

where: σ_{LC1}~ σ_{LC6}—— axial stress of the target element under various load cases.

3.4.2.2 The stress range is to be corrected as follows:

$$S_D^{'} = f_m f_t f_c S_D$$

where: $f_m = \dfrac{1200}{965 + R_{eH}}$;

f_t—— plating thickness correction factor, to be calculated in accordance with 3.3.3 in Chapter 3 of the Guidelines for Fatigue Strength of Ship Structure;

f_c—— corrosion correction factor, taken as 1.05.

3.4.2.3 The fatigue damage is to be calculated according to the following formula:

$$D_{TOTAL} = \frac{N_D \alpha}{K} \frac{S_D^{'\,m}}{\left(\ln N_L\right)^{m/\xi}} \mu_k \Gamma\left(1 + \frac{m}{\xi}\right)$$

where: N_D—— total cycles of loads within 20 years' service life of ships, to be taken as 0.65×10^8;

α—— in-service coefficient of ship, taken as 0.85;

N_L—— cycles of load spectrum response circle, to be taken as 10^8;

K—— *S-N* curve parameter, see Table 3.4.2.3;

S_D' —— corrected design stress ranges, in N/mm^2, calculated according to 3.4.2.2:

ξ ——Weibull distribution shape parameters, calculated as follows:

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

where: L ——length of ship, in m;

$f = 1 - 0.08\, z/d_1$ for $z \le d_1$;

$f = 0.92 + 0.08(z - d_1)/(D - d_1)$ for $d_1 < z \le D$;

$f = 1$ for $D < z$;

$f = 0.92$ for the calculated point on transverse bulkhead;

D—— moulded depth, in m;

d_1—— draught in the considered load case, in m;

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

$$\mu_k = 1.0 - \frac{\gamma\left(1 + \frac{m}{\xi_k}, \nu_k\right) - \nu_k^{-\frac{\nabla m}{\xi_k}} \gamma\left(1 + \frac{m + \nabla m}{\xi_k}, \nu_k\right)}{\Gamma\left(1 + \frac{m}{\xi_k}\right)}$$

$$\nu_k = \left(\frac{S_q}{S_{D(k)}}\right)^{\xi_k} \ln N_L$$

m —— inverse slope of the S-N curve, see Table 3.4.2.3;

∇m —— difference of inverse slope of two-slope S-N curves, see Table 3.4.2.3;

$\gamma(x, \nu)$—— incomplete GAMMA function values, to be calculated as follows:

$$\gamma(x, v) = \int_0^v u^{x-1} e^{-u} du$$

Γ —— complete GAMMA function values, to be calculated as follows:

$$\Gamma(x) = \int_0^\infty u^{x-1} e^{-u} du$$

S_q —— stress amplitude values at intersection point of two-slope S-N curves, see Table 3.4.2.3;

S-N curve parameter Table 3.4.2.3

S-N curve	K	S_q	m	∇m

C	3.464×10^{12}	70.2305	3	2
D	1.520×10^{12}	53.3680	3	2

3.4.2.4 The fatigue strength is to comply with:

$$D_{TOTAL} \le 1$$

Where the design fatigue life exceeds 20 years, the fatigue strength is to comply with:

$$D_{TOTAL} \le 20/\mathrm{FL}$$

where: FL —— design fatigue life, in year, to be taken as 25, 30, 35 and 40.