GUIDANCE NOTES
GD09－2018

CHINA CLASSIFICATION SOCIETY

GUIDELINES FOR SPECTRUM-BASED FATIGUE ASSESSMENT OF HULL STRUCTURE

2018

Effective from 1st July 2018

Contents

Section 1 GENERAL PROVISIONS

1.1 Scope of application

1.1.1 The Guidelines applies to fatigue strength assessment of large membrane tank LNG carriers, container ships and ore carriers based on spectrum analysis. Class notation SFA (XX, YY) may be assigned to the above-mentioned ship types after assessment in accordance with the Guidelines and requirements are met. XX refers to environmental condition (e.g.: NA refers to North Atlantic Ocean, see IACS Rec.34 for scatter diagram), YY refers to design life (year), may be taken as 20, 25, 30, 35 or 40.

1.1.2 Unless otherwise specified, the contents of the Guidelines are not to be taken as the mandatory requirements.

1.2 Analysis process

1.2.1 The assessment of fatigue strength is based on Palmgren-Miner linear accumulative damage theory.

1.2.2 Spectrum-based fatigue analysis process consists of the following three parts:

1) Hydrodynamic analysis: to calculate the wave load on regular wave by three-dimensional hydrodynamic analysis.

2) Structural analysis: to obtain the stress transfer function by structural analysis according to wave load.

3) Spectrum analysis and damage calculation: to calculate the structural stress spectrum under various sea conditions, calculate the fatigue damage and obtain the structural damage of the given loading after summation of damage under various sea conditions, to obtain the total damage of the structure in its design life after summation of damage of various loadings.

1.2.3 Spectrum-based fatigue analysis process is shown in Figure 1.2.3.

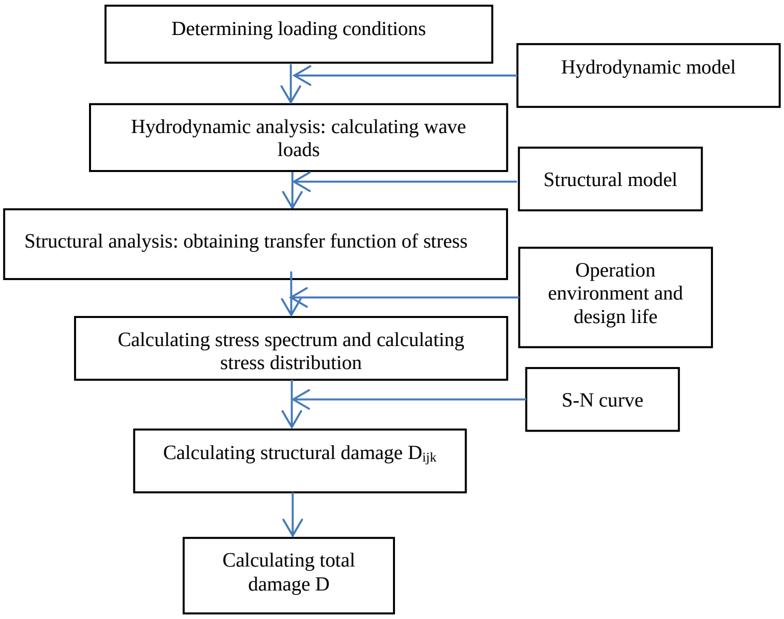

Figure 1.2.3 Flow Chart of Spectrum-based Fatigue Analysis

1.3 Fatigue strength check joint

1.3.1 The minimum scope to be considered for fatigue assessment is given in 1.3.2 to 1.3.4. In addition to the above joints, fatigue assessment joints may be added according to fine mesh analysis and fatigue hot spot assessment, where necessary.

1.3.2 The following joints are to be considered for membrane tank LNG carriers (part of the schematic plan is shown in Figure 1.3.2(1) and Figure 1.3.2(2)):

1) transverse frame in way of knuckle in the middle of tank;

2) at the intersection of bottom girder, deck girder, side girder and transverse bulkhead;

3) transitional bracket toes at aft ends of trunk deck;

4) corners of openings in the door on the side of deckhouse contributing to longitudinal strength.

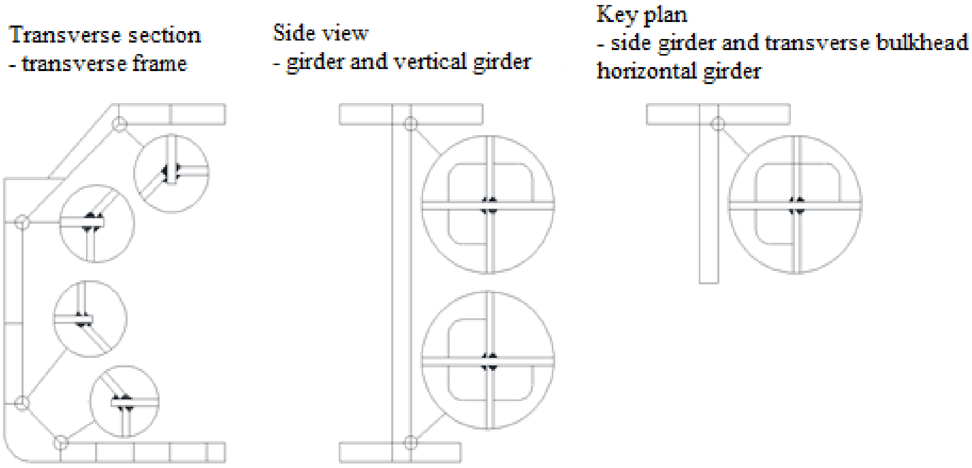

Figure 1.3.2(1) Fatigue Check Zone of Cargo Tank Structure

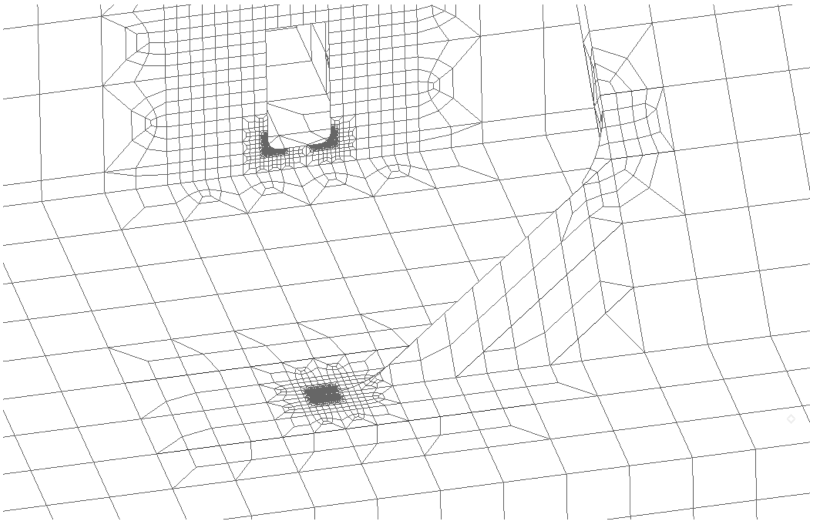

Figure 1.3.2(2) Aft End Bracket of Trunk Deck and Deckhouse Opening

1.3.3 The following areas are to be considered for container ships (part of the schematic plan is shown in Figure 1.3.3(1) to Figure 1.3.3(4)):

1) corners of upper deck hatch on fore and aft ends of engine room (including corners of hatch coaming top plating);

2) corners of upper deck hatch of No.1 cargo hold;

3) corners of upper deck hatch in mid-ship area (including corners of hatch coaming top plating);

4) toe end of bracket at the end of hatch side coaming;

5) corners of cargo hold hatch at aft end of the front deckhouse.

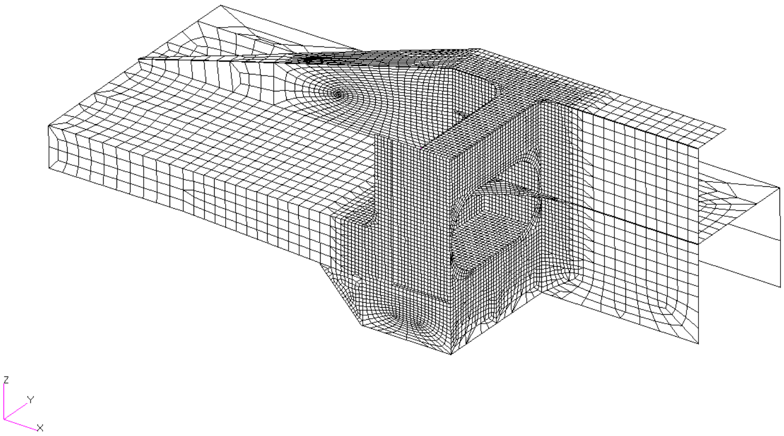

Figure 1.3.3(1) Corners of Hatch at Fore End of Engine Room

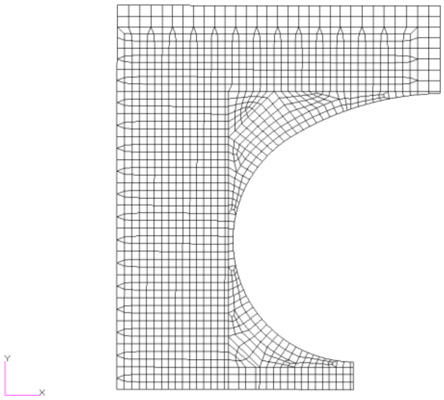

Figure 1.3.3(2) Corners of Hatch at Fore End of Engine Room (zooming up in way of upper deck corner)

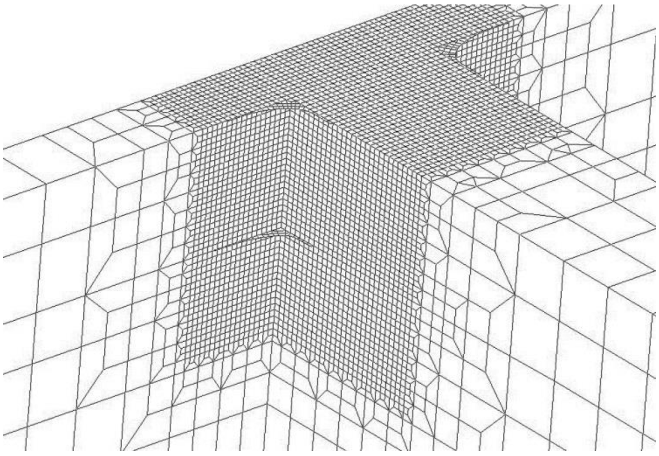

Figure 1.3.3(3) Corners of Cargo Hold Hatch in Mid-ship Area

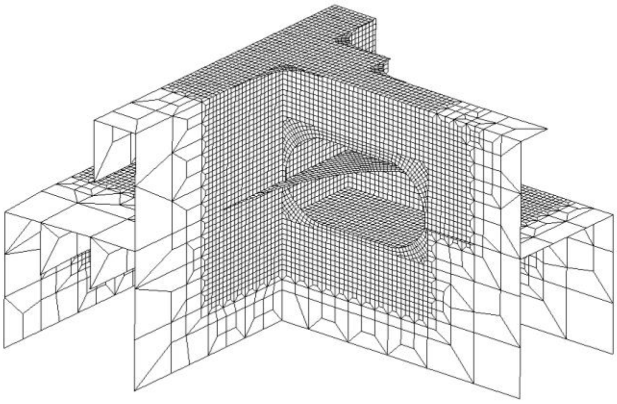

Figure 1.3.3(4) Corners of Cargo Hold Hatch at Aft End of the Front Deckhouse

1.3.4 For ore carriers, the following areas are to be considered (part of the schematic plan is shown in Figure 1.3.4(1) and Figure 1.3.4(2)):

1) connections of mid-ship cargo hold longitudinal bulkheads to inner bottom plating;
2) connections of inner bottom plating of aftermost cargo hold to lower stools;
3) hatch corners of aftermost cargo hold;
4) longitudinal toe of bracket of hatch coaming at the aft end of aftermost cargo hold.

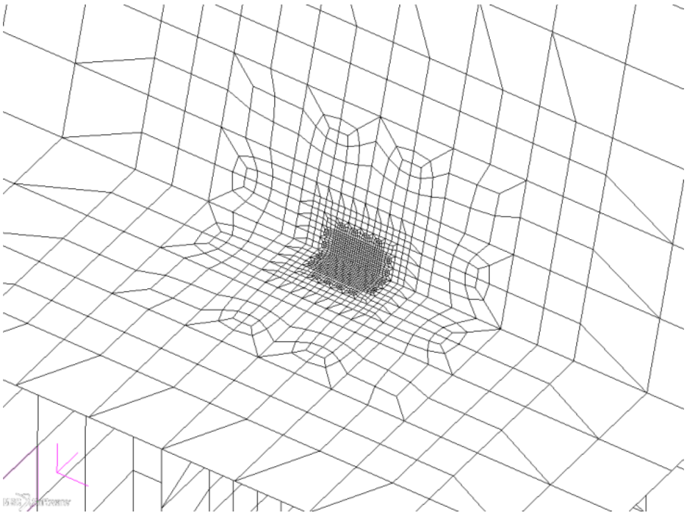

Figure 1.3.4(1) Connection of Longitudinal Bulkheads to Inner Bottom Plating (middle of length of cargo holds)

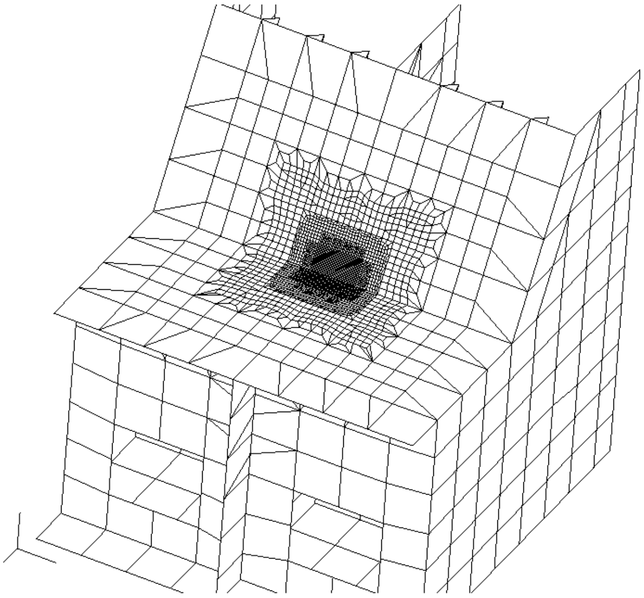

Figure 1.3.4(2) Connection of Inner Bottom Plating to Lower Stools (middle of breadth of cargo holds)

1.4 Definitions

1.4.1 Length of ship, L (in m), is the distance on the summer load waterline from the forward side of the stem to the after side of the rudder post, or to the center of the rudder stock if there is no rudder post. L is not to be less than 96%, and need not be greater than 97%, of the extreme length on the summer load waterline.

For ships without rudder stocks (such as ships provided with azimuth thrusters), L is 97% of the extreme length on the summer load waterline.

1.4.2 Breadth of ship, B (in m), is the horizontal distance measured over the main frames at the widest part of the ship.

1.4.3 Moulded depth D (in m) is the vertical distance measured at the middle of the length L from top of keel to top of the deck beam at side on the uppermost continuous deck. When a rounded gunwale is arranged, the moulded depth is to be measured to the point of intersection of the continued moulded lines of the deck and side shell plating.

1.4.4 Draught d_{LC} (in m) is the vertical distance measured at the middle of the length L from top of keel to the summer load waterline.

1.4.5 Draught d (in m) is the vertical distance measured at the middle of the length L from top of keel to waterline under relevant loading conditions.

1.4.6 Block coefficient C_b is to be determined by the following formula:

$$C_b = \frac{\nabla}{LBd}$$

where: ∇ — moulded volume, in m^3; at draught corresponding to the assigned summer load line;

L — length of the ship, in m;

B — breadth of the ship, in m;

D — draught, in m.

1.4.7 Maximum service speed V is the maximum speed maintained under the deepest navigational draught, maximum RPM of propeller and maximum continuous rating (MCR) of main engine.

1.4.8 Coordinate system

(1) Unless otherwise specified, a right-hand coordinate system (see Figure 1.4.8) is used in the Guidelines:

Origin: Longitudinal centerline section, intersection of the aft end of the ship length and baseline;

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

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

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

(2) Wave heading angle in this Chapter means the angle between wave spreading direction and *X*-axis positive direction under coordinate system mentioned in (1). Under such provisions, 0 °is following sea, 90 °is beam sea (spreading from starboard to port) and 180 °is heading wave.

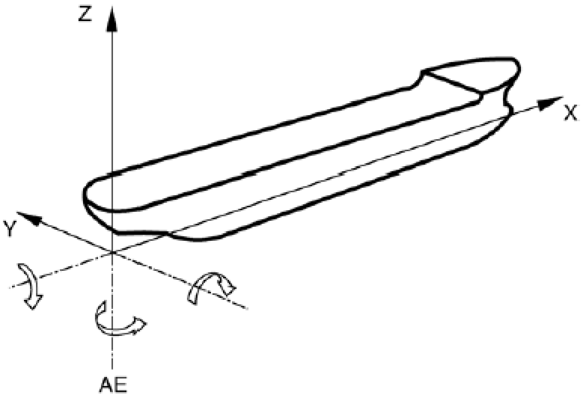

Figure 1.4.8 Reference Coordinate System

Section 2 LOADING CONDITIONS AND LOADS

2.1 Loading conditions

2.1.1 Structural fatigue damage is a process of long-term accumulation and the most common loading condition is to be considered. For membrane tank LNG carriers, container ships and ore carriers, the loading condition and time distribution factor to be considered are shown in Table 2.1.1. For all the ship types, navigation coefficient of 0.85 is considered.

Loading condition and time distribution factor of different ship types Table 2.1.1

Ship type	Full load	Ballast
Membrane tank LNG carrier	0.45	0.40
Container ship	0.65	0.20
Ore carrier	0.5	0.35*

* The time distribution factor is 0.175 as the same as that for normal ballast, if storm ballast exists.

2.2 Calculation conditions

2.2.1 Calculation conditions of spectrum-based fatigue analysis include static conditions and dynamic conditions.

2.2.2 The static condition is taken to calculate the structural stress generated by static loads under the selected loading condition. The stress is used for mean stress correction in the process of fatigue assessment. The static loads acting on the FE model include external hydrostatic pressure and tank static pressure, gravity of hull and stores.

2.2.3 The dynamic condition only includes the dynamic loads due to wave. The load is obtained through hydrodynamic analysis of the given loading and each dynamic load condition corresponds to a regular wave determined by wave heading angle and wave frequency.

2.3 Hydrodynamic analysis

2.3.1 Three-dimensional potential flow procedure is to be used for hydrodynamic analysis so as to calculate hull response on wave.

2.3.2 Each mass model for hydrodynamic analysis is to reflect mass characteristics under the corresponding loading conditions, and hydrodynamic mesh is to reflect actual hull configuration and floating condition (draught, trim and heel).

2.3.3 In order to apply gravity and inertia force on the FE model accurately, mass property of FE model is to be checked so as to reflect mass distribution of corresponding loading condition. The mass model in hydrodynamic analysis may be based on the above-mentioned global FE model. When a simplified model is adopted, it is to simulate mass property of full-scale ship accurately (amount of mass, mass centroid and mass distribution).

2.3.4 Sufficient wave heading angle and frequency range are to be considered in hydrodynamic analysis. The wave heading angles are to be set within the range of 0° to 360°, at a maximum interval of 30°. The frequency is to consider the range from 0.2 rad/s to 1.8 rad/s, at a maximum interval of 0.1 rad/s.

2.3.5 75% of the maximum service speed is to be taken as the navigation speed in the calculation.

2.3.6 If hydrodynamic analysis is carried out by time domain method, time history is to be converted to transfer function by proper means, i.e. time history after reaching stable condition is to be selected for conversion.

2.3.7 Results of hydrodynamic analysis include wave dynamic pressure and motion (acceleration). Wave dynamic pressure is to be applied on shell in the form of pressure, and inertial force (including the horizontal component of acceleration of gravity due to roll and pitch) is to be applied on FE model by means of acceleration field and mass distribution (for hull structure, equipment, and container) or applied on tank boundaries in the form of pressure (for liquid, ore).

2.4 Loads of liquid inside tank

2.4.1 The combined acceleration vector $\left(a_x^2+a_y^2+a_z^2\right)^{1/2}$ of the centroid of tanks is calculated according to the results of hydrodynamic analysis, while positions of reference points for tank pressure calculation are determined according to the vector. When the distance from calculation point to the reference point is h on the direction of the vector, the pressure p applied on the tank boundaries is obtained (see Figure 2.4.1):

$$p=\rho_L h\left(a_x^2+a_y^2+a_z^2\right)^{1/2}, \quad kN/m^2$$

where: ρ_L — liquid density, in t/m^3;

h — distance from pressure calculation point to reference point for tank pressure calculation in the direction of combined acceleration vector, in m;

$\left(a_x^2 + a_y^2 + a_z^2\right)^{1/2}$ — combined acceleration vector, in m/s^2 ;

a_x — longitudinal acceleration at the center of tank considered, in m/s^2 ;

a_y — transverse acceleration at the center of tank considered, in m/s^2 ;

a_z — vertical acceleration at the center of tank considered, in m/s^2 ;

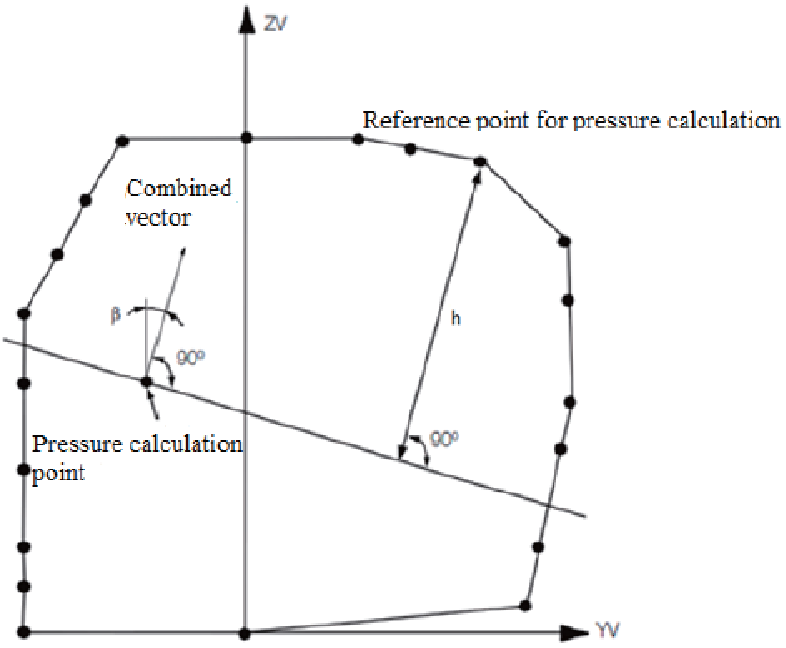

Figure 2.4.1 Tank Pressure Calculation Method

2.5 Container loads

2.5.1 The mass property of container is to be simulated accurately (amount of mass, mass centroid and mass distribution) in calculation. In order to transfer the gravity and inertia force effectively on the main hull structure, solid elements, plate elements or mass points may be arranged in the actual location of container and connected to the relevant positions of hull through effective means of connection.

2.6 Ore loads

2.6.1 Ore static pressure

The static pressure P_{bs} due to ore is to be taken as:

$$P_{bs} = \rho_C g K_C \left(z_C - z\right), \quad kN/m^2, \quad \text{but not less than 0}$$

where: ρ_C — ore density, in t/m^3;

K_C — coefficient, taken as:

For inner bottom, transverse bulkhead and longitudinal bulkhead, lower stool, vertical upper stool

$$K_C = \cos^2\alpha + (1-\sin\psi)\sin^2\alpha \text{ ;}$$

For upper deck, sloping upper stool and horizontal plate of upper stool $K_C = 0$;

α — angle between the considered plate and horizontal plane, in degree;
ψ — angle of repose of ore, in degree, taken as 35 °;
z — height of calculation point, in m;

z_C — the height from baseline to the upper surface of ore corresponding to load calculation point, in m, taken as :

$$z_C = h_{DB} + h_C$$

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

h_C — effective height of the upper surface of ore, in m.

2.6.2 Ore dynamic pressure

Dynamic pressure P_{bd} due to ore in dynamic load condition is to be taken as:

For $z \le z_C$

$$P_{bd} = \rho_C\left[0.25a_X\left(x_G - x\right) + 0.25a_Y\left(y_G - y\right) + K_C a_Z\left(z_C - z\right)\right], \quad kN/m^2$$

For $z > z_C$

$$P_{bd} = 0$$

where: x, y, z — coordinate of calculation point;

x_G , y_G — coordinate in X and Y direction at the centroid of cargo hold;

a_X , a_Y , a_Z — acceleration at the center of gravity of cargo; for full loaded cargohold, (namely V_{Full}), centroid of hold is to be taken as the center of gravity of cargo; for cargo hold not full loaded, the vertical height z_G is to be calculated by the following formula:

$$z_G = h_{DB} + h_{C-cl}/2$$

h_{C-cl} — effective height of the upper surface of ore in the middle position in the direction of ship breadth, in m;

2.6.3 Shear loads of ore

(1) for the cargo hold loaded with ore, when $z \le z_C$ at load calculation point, the following

shear loads are to be considered in addition to the ore pressure defined in 2.6.1 and 2.6.2:
For setting of static loads: static shear loads on longitudinal bulkhead sloping plating and lower stool sloping plating due to gravity, as defined in 2.6.3(2);
For setting of dynamic loads: the following dynamic shear loads pressure:

P_{bs-d} for longitudinal bulkhead sloping plating and lower stool sloping plating, as defined in 2.6.3(3);

P_{bs-dx} for longitudinal direction of inner bottom plating, as defined in 2.6.3(4);

P_{bs-dy} for transverse direction of inner bottom plating, as defined in 2.6.3(4);

P_{bs-x}, P_{bs-y} for shear loads due to acceleration in X and Y direction on longitudinal bulkhead sloping plating and lower stool, as defined in 2.6.3(5).

(2) Static shear loads on sloping longitudinal bulkhead and lower stool sloping plating

The static shear load P_{bs-s} on longitudinal bulkhead sloping plating and lower stool sloping plating due to gravity of ore (positive plating down) is to be taken as:

$$P_{bs-s} = \rho_C g \frac{(1-K_C)(z_C - z)}{\tan\alpha}, \quad kN/m^2$$

(3) Dynamic shear loads on longitudinal bulkhead sloping plating and lower stool sloping plating:

The dynamic shear load P_{bs-d} on longitudinal bulkhead sloping plating and lower stool sloping plating due to vertical acceleration (positive plating down) is to be taken as:

$$P_{bs-d} = \rho_C a_Z \frac{(1-K_C)(z_C - z)}{\tan\alpha}, \quad kN/m^2$$

(4) Dynamic shear loads along the inner bottom plating

The dynamic shear load P_{bs-dx} in longitudinal direction (positive forward) generated on inner bottom plating due to longitudinal acceleration is to be taken as:

$$P_{bs-dx} = -0.75\rho_C a_x (z_C - z) \quad , \quad kN/m^2$$

The dynamic shear load P_{bs-dy} in longitudinal direction (positive to port) generated on inner bottom plating due to longitudinal acceleration is to be taken as:

$$P_{bs-dy} = -0.75\rho_C a_y (z_C - z) \quad , \quad kN/m^2$$

(5) For global FE model assessment, friction force due to acceleration in X and Y direction is to be considered on longitudinal bulkhead sloping plating and lower stool sloping plating, considering the requirements for load equilibrium. Friction force on any sloping plating is to be calculated according to the following requirements:
1) horizontal direction of plating:

$$P_{bs-x} = -0.75\rho_C a_x \left(z_C - z\right)\cos\alpha \cdot \cos\alpha_x - 0.75\rho_C a_y \left(z_C - z\right)\cos\alpha \cdot \cos\alpha_y \,, \quad kN/m^2$$

where: α_x — angle between horizontal direction and X direction of sloping plating;

α_y — angle between horizontal direction and Y direction of sloping plating.

2) Vertical inner bottom direction of plating

$$P_{bs-y} = -0.75\rho_C a_x \left(z_C - z\right)\sin\alpha_x - 0.75\rho_C a_y \left(z_C - z\right)\sin\alpha_y \,, \quad kN/m^2$$

where: α_x — angle between horizontal direction and X direction of sloping plating;

α_y — angle between horizontal direction and Y direction of sloping plating.

2.7 Boundary conditions

2.7.1 By the action of all loads, the global FE model is to be in a dynamic balance state. Unbalanced forces on three directions of model are to be checked. In the case of a head sea condition, the unbalanced force is not to exceed 1% displacement, while in the case of a beam sea condition or an oblique sea condition, it is not to exceed 2% displacement.

2.7.2 Only the boundary conditions restraining rigid body need to be set, as shown in Figure 2.7.2:

1) Node 1 at the aft end: restraining the displacement in transverse direction;

2) Node 2 at the fore end: restraining the displacement in three directions;

3) Nodes 3 and 4 at left and right sides of stern transom plate: restraining the displacement in vertical direction.

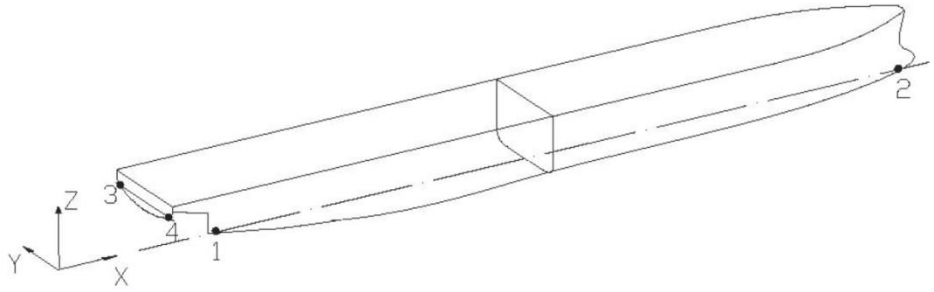

Figure 2.7.2 Diagram of Boundary Condition

Section 3 STRUCTURAL ANALYSIS AND STRESS TRANSFER FUNCTION

3.1 Calculation purposes

3.1.1 Structural analysis is to be carried out for the purpose of hot spot stress calculation according to the loads mentioned in Section 2 and obtain stress transfer function by interpolation.

3.1.2 The structural analysis is to be carried out by three-dimensional FE method, combined coarse mesh global model with local refined model to calculate the hot spot stress within refined area.

3.2 Global FE model

3.2.1 The global FE model is to include all main hull structure, superstructure and deckhouse structure. For membrane tank LNG carrier, trunk deck structure is to be included.

3.2.2 Generally, the model applies longitudinal spacing mesh. Plates of hull structure and webs of primary structural members are to be simulated by plate elements. Stiffeners and face plates of primary supporting members are to be simulated by beam elements.

3.2.3 The size of FE model is to be based on as-built scantlings of hull structures. In order to consider the influence of corrosion, the corrosion correction factor is taken as 1.07.

3.2.4 In order to apply inertial force accurately, mass property of FE model is to be checked so as to reflect mass distribution of hull structures and equipment of full-scale ship. The mass of equipment and container may be simulated by mass concentration elements, but these mass elements are to be effectively connected with hull structures so as to reasonably transfer relevant loads and the rigidity of hull structures is not to be changed.

3.3 Refined model

3.3.1 For areas where the fatigue assessment is required, a refined model is to be used at an area with stress concentration. For details, see Section 6 of Chapter 5 in the Guidelines for Fatigue Strength of Ship Structure.

3.3.2 Refining analysis may be carried out by inserting the refined model into global FE model. Independent local refined model may also be applied and the boundary conditions of its displacement are obtained from the global FE model.

3.3.3 In order to obtain stress of free edge structure (such as hatch corner), a beam element with sectional area of 1 mm^2 is to be set up along the free edge so as to read the stress on the free edge.

3.4 Stress transfer function

3.4.1 The transfer function of direct stress ($\sigma_x, \sigma_y, \tau_{xy}$) for each element is to be obtained through structural analysis and the transfer function of direct stress at hot spot is obtained by interpolation with the above stresses. For welding type joint and cross welding type joint, Section 5 of Chapter 5 in the Guidelines for Fatigue Strength of Ship Structure may be referred for the method of interpolation of hot spot stress.

3.4.2 The principal stress is to be calculated according to the direct stress at hot spot. For static load condition, the formula for calculation of principal stress is specified in Section 2 of Chapter 1 in the Guidelines for Fatigue Strength of Ship Structure. For dynamic load condition, the half amplitude of principal stress is determined by searching within the whole wave circle and the value is stress transfer function.

$$H_\sigma = \max\left(\frac{\sigma_x\left(\omega t+\theta_x\right)+\sigma_y\left(\omega t+\theta_y\right)}{2} + \sqrt{\left(\frac{\sigma_x\left(\omega t+\theta_x\right)-\sigma_y\left(\omega t+\theta_y\right)}{2}\right)^2 + \tau_{xy}^2\left(\omega t+\theta_{xy}\right)} \right)$$

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

t — time, to search within the whole wave circle in calculation, i.e.: $\omega t = 0 \sim 2\pi$;

$\theta_x, \theta_y, \theta_z --\sigma_x, \sigma_y, \pi_{xy}$ phase angles of the corresponding stresses, in rad.

Since the results of stress components are related with loading condition, wave heading angle and wave frequency, the stress transfer function is also the function of these three variables.

3.4.3 For free edge area, axial stress of beam element (see 3.3.3) is taken as stress transfer function.

Section 4 FATIGUE STRENGTH ASSESSMENT

4.1 Stress spectrum and stress range distribution

4.1.1 To determine the wave scatter diagram for fatigue analysis and duration of various sea conditions according to the environmental conditions and design life selected in 1.1.2.

4.1.2 For hot spots intended to carry out spectrum-based fatigue analysis, the corresponding stress transfer function (see 3.4.2) is to be used for spectrum analysis for each sea condition in wave scatter diagram so as to obtain stress spectrum S_σ as follows:

$$S_\sigma\left(\omega_e \left|H_S, T_Z, \theta, L_o\right.\right) = \left|H_\sigma\left(\omega \mid \theta, L_o\right)\right|^2 \bullet S_\eta\left(\omega \mid H_S, T_Z\right)\left|1 - \frac{2\omega V\cos\theta}{g}\right|^{-1}$$

where: H_σ — stress transfer function, see 3.4.2;

S_η — wave spectrum;

ω_e — encounter frequency, to be calculated by:

$$\omega_e = \left|\omega - \left(\frac{\omega^2 V}{g}\right) cos\theta\right|$$

ω — wave frequency;

V — calculated speed, see 2.3.5;

H_S — significant wave height of sea condition;

T_Z — average period of sea condition;

θ — wave heading angle;

L_o — loading condition, to consider various loading conditions defined in Table 2.1.1.

4.1.3 In the process of stress spectrum analysis, considering short-crest wave effects, the square of cosine is to be taken for energy spreading function and each order moment of stress spectrum, in m_n, is to be calculated by the following formula:

$$m_n = \int_0^\infty \sum_{-\pi/2}^{\pi/2} f_s\left(\alpha\right) \bullet \omega_e^n S_\sigma\left(\omega_e \middle| H_S, T_Z, \theta + \alpha, L_o\right) d\omega_e$$

where: θ — main sea direction considered;

α — angle related to sea direction;

$f_s(\alpha)$ — energy spreading function, $\sum_{-\pi/2}^{\pi/2} f_s(\alpha) = 1$. When the wave direction is taken with the same spacing, $f_s(\alpha) = k cos^2(\alpha)$;

S_σ — stress range spectrum;

ω_e — encounter frequency;

H_S — significant wave height of sea condition;

T_Z — average period of sea condition;

L_o — loading condition.

4.1.4 Root variance σ and average period of stress spectrum T_a are to be obtained according to the following formulae:

$$\sigma = 2\sqrt{m_0}$$

$$T_a = 2\pi\sqrt{\frac{m_0}{m_2}}$$

where: m_0 — 0th order moment of stress spectrum;

m_2 — 2nd order moment of stress spectrum.

The stress range S is assumed to be distributed in compliance with Rayleigh distribution, and the probability density function g is:

$$g(S) = \frac{S}{\sigma^2}\exp\left(-\frac{S^2}{2\sigma^2}\right)$$

where: S — stress range;

σ — root variance of stress spectrum.

4.1.5 The time of duration for stress distribution T is calculated according to the time proportion of each stress distribution (considering loading condition, sea condition, wave heading angle), and the design life of ship. Cycle number of stress range is to be determined according to average period. For the ith loading condition, the jth sea condition and kth wave heading angle, the cycle number of stress is to be calculated by the following formula:

$$N_{Tijk} = \frac{T_{ijk}}{T_{aijk}}$$

where: T_{ijk} — period of stress distribution, in *s*;

$T_{ijk} = 31.557x10^6 Lp_i p_j p_k$;

L — design life, in year;

p_i — the proportion of the ith loading in the whole design life, see Table 2.1.1;

p_j — the proportion of the jth sea condition in the whole scatter diagram;

p_k — the proportion of the kth wave heading angle in all wave heading, see 2.3.4;

T_{aijk} — the average period of stress under the combination of considered loading, sea condition and wave heading, in *s*.

4.2 Stress correction factor

4.2.1 The mean stress correction factor is calculated by the following methods:

1) for welding type joint:

$$f_{mean} = \begin{cases} \min\left(1.0, 0.85 + 0.3\sigma_{mean}/S\right), & \sigma_{mean} \geq 0 \\ \max(0.7, 0.85 + 0.3\sigma_{mean}/S), & \sigma_{mean} < 0 \end{cases}$$

2) for free edge of base metal:

$$f_{mean} = \begin{cases} \min\left(1.0, 0.8 + 0.4\sigma_{mean}/S\right), & \sigma_{mean} \geq 0 \\ \max(0.6, 0.8 + 0.4\sigma_{mean}/S), & \sigma_{mean} < 0 \end{cases}$$

where: σ_{mean} — mean stress of considered loading;

S — range of corrected stress, see 4.1.4.

4.2.2 Correction of thickness of plating is carried out within the stress range by the means specified in the Guidelines for Fatigue Strength of Ship Structure.

4.3 S-N curve

4.3.1 The S-N curve used for calculating structural fatigue damage is to be determined according to Section 4 of Chapter 3 in the Guidelines for Fatigue Strength of Ship Structure.

4.4 Fatigue damage calculation

4.4.1 Fatigue damage calculation is to be carried out according to the following requirements and process (see Figure 4.4.1):

1) For each stress distribution *g*(*S*), structural damage *dD* due to each stress increment is to be calculated by the following formula:

$$dD = \frac{dn(S)}{N(S)} = \frac{N_T g(S)}{N(S)} dS = \frac{T/T_a}{N(S)} g(S) dS$$

where: N_T — number of stress cycle contained in its distribution, see 4.1.5;

T — time of duration corresponding to the stress distribution;

T_a — average period;

$N(S)$— structural fatigue life within the stress range, to be determined according to the selected S-N curve;

$g(S)$— probability density function of stress range, see 4.1.4.

2) Damage D_{ijk} under the given loading condition, sea condition and wave heading angle (corresponding to a stress distribution) is to be calculated by the following formula:

$$D_{ijk} = \frac{T}{T_a}\int_0^{\infty}\frac{g(S)}{N(S)}dS$$

When calculating damage by numerical integration, step length of component for each stress range is generally not to be greater than 7 MPa, and the intermediate value may be taken for damage calculation formula.

3) The above-mentioned process is to be repeated for all wave heading angles, after summarizing, damage due to a certain sea condition is obtained.

4) The above-mentioned process is to be carried out for all sea conditions so as to obtain damage due to a certain loading condition.

5) The above-mentioned process is to be repeated for each loading condition so as to obtain total structural damage.

$$D = \sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{k=1}^{K}D_{ijk}$$

where: D_{ijk} — structural damage under the given loading condition, sea condition and wave heading angle;

I — number of loading condition;

J — number of sea condition;

K — number of wave heading angle.

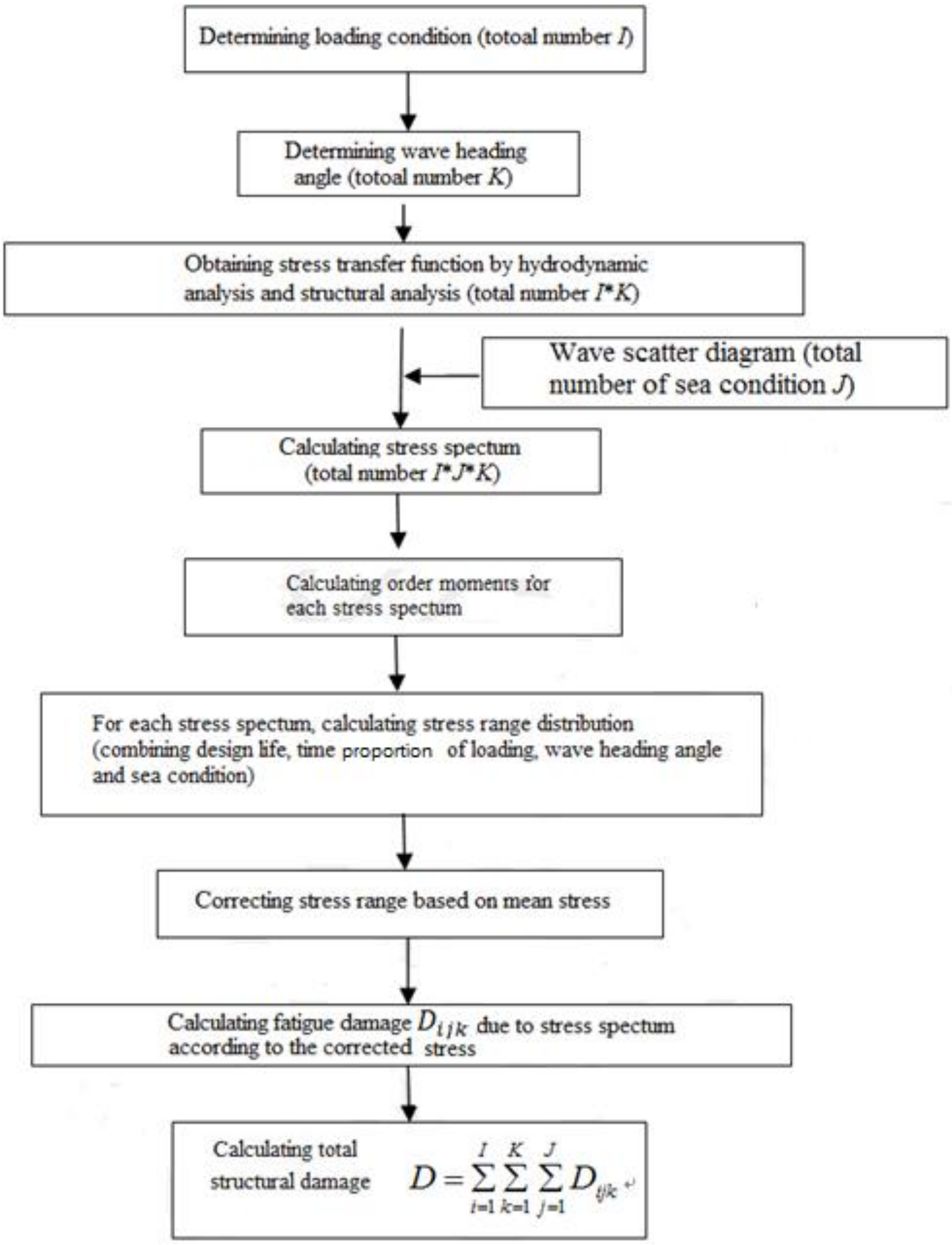

Figure 4.4.1 Flow Chart of Fatigue Damage Calculation

4.5 Acceptance criteria

4.5.1 For given design requirements (sea condition, fatigue life), the total damage of structural joints is not to be more than 1.0.