GUIDANCE NOTES
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ISClass

INTERNATIONAL SHIP CLASSIFICATION

GUIDELINES ON ASSESSMENT OF SHIP SECOND GENERATION INTACT STABILITY CRITERIA

2024

Effective from 1 July 2024

CONTENTS

CHAPTER 1 GENERAL

Section 1 GENERAL PROVISIONS

1.1.1 Purpose

1.1.1.1 Based on statics theory and accident experience, the ship intact stability criteria (the first generation intact stability criteria) provide the basic technical requirements for the static stability of ships and the dead ship mode. The above criteria make a highly simplified and indirect assessment of the dynamic stability failure of ships in waves, and only the dead ship mode is considered for the dynamic stability failure mode. In addition to the dead ship mode, the accident modes such as parametric roll, pure loss of stability and synchronous roll motion may also cause the ship to encounter dangerous stability failure in waves. It is to be fully recognized that the above failure modes may cause serious harm to the navigation safety of the ship.

1.1.1.2 The purpose of the Guidelines is to provide the methods and technical requirements for the assessment of the dynamic stability failure mode of ships in waves based on the theoretical methods of hydrodynamics. As a supplement to the first generation intact stability criteria, it provides technical means for ship optimization design scheme and necessary hedging operation guidance for shipping industry. It aims to reduce the risk of ships sailing under severe sea conditions from the source and enhance the safety of life and ship/cargo at sea.

1.1.2 Application

1.1.2.1 Unless otherwise specified, the Guidelines is applicable to ships engaged on international voyages, ships engaged on domestic voyages in open sea zones, ships in greater coastal navigation zones and ships in coastal navigation zones, but not applicable to:

(1) Military ship, public security boat;
(2) Sports boat;
(3) Yacht;
(4) Fishing boat;
(5) Multihull boat;
(6) High speed craft;
(7) Sailboat;
(8) Motor sailboat;
(9) Pusher-barge combination.

1.1.2.2 Upon application, ships that meet the relevant requirements of the Guidelines may apply for a document of compliance.

1.1.2.3 Upon application, ships that meet the relevant requirements of the Guidelines may be granted with corresponding class notations in 1.1.6 of this Chapter.

1.1.3 Definitions

1.1.3.1 Unless otherwise specified, the definitions of the Guidelines are as follows:

(1) Tank test means model test of ship motion response in waves, which is carried out in tank.

(2) Numerical calculation means computer-aided hydrodynamic calculation which is solved by using modern computational fluid dynamics (CFD) software/procedure that can be based on potential flow theory method or viscous flow theory method. The method or numerical model used in the numerical calculation can be accepted as equivalent to the tank test provided that it has been verified by the tank test results.

(3) Permissible safe zone means the permutation and combination range of virtual loading conditions that meet the requirements of the first or second level criteria.

1.1.4 Drawings and information

1.1.4.1 Following drawings and information are to be submitted to ISC for information:

(1) Ship lines plan and offset table;
(2) General arrangement of ship;
(3) Ship loading manual;
(4) Container loading arrangement (if applicable);

(5) Bilge keel structure (if applicable);
(6) Stabilizer plan (if applicable);
(7) Ship second generation intact stability calculation;
(8) Shipborne software for verification of dynamic stability in waves and related documents (if applicable).

1.1.4.2 Ship second generation intact stability calculation is to be available onboard so as to provide the master with sufficient loading information which meet the requirements of the Guidelines and provide guidance for ship navigation. The report is to contain at least the following:

(1) Main parameters of the ship;
(2) A summary of basic information on ship loading conditions under sailing conditions contained in Ship Stability Report or Ship Loading Manual;
(3) Calculation results of roll moment of inertia under various loading conditions;
(4) Check results of synchronous roll motion criteria under various loading conditions;
(5) Check results of parametric roll criteria under various loading conditions;
(6) Check results of pure loss of stability criteria under various loading conditions.

1.1.5 Verification of compliance of loading conditions

1.1.5.1 For loading conditions that have not been checked for dynamic stability, compliance can be verified by either of following two ways to determine whether the requirements of the Guidelines are met, including

(1) Permissible safe zone can be used for verification of compliance and is to be provided in Ship Second Generation Intact Stability Calculation;
(2) Shipborne software for verification of dynamic stability in waves can be used for verification of compliance of loading conditions.

1.1.5.2 For following ships, shipborne software for verification of dynamic stability in waves is to be used for verification of compliance of loading conditions:

(1) Bulk carriers;
(2) Container ships;
(3) Ships without steel weathertight cover at cargo hatch.

1.1.6 Class notations in second generation intact stability criteria

1.1.6.1 For ships engaged on international voyages, application for class notation SGISC (X) is to comply with the provisions of paragraph 2.1.1.2 of Chapter 2, where X represents one or more suffixes, the meaning of which is as follows:

PR_N: parametric roll failure mode;
PL_N: pure loss of stability failure mode;
EA_N: excessive acceleration failure mode;
DS_N: dead ship failure mode;
SRB_N: surf-riding/broaching failure mode.

where: N=1 means that all loading conditions meet level 1 vulnerability criteria;
N=2 means that all loading conditions meet level 2 vulnerability criteria;
N=M means that there are loading conditions which do not meet the vulnerability criteria, and information on the stability of ship in waves has been prepared for the master.

1.1.6.2 For ships engaged on domestic voyages in open sea zones, ships in greater coastal navigation zones and ships in coastal navigation zones, application for class notation SGISC (X) is to comply with the provisions of paragraph 2.1.1.3 of Chapter 2, where X represents one or more suffixes, the meaning of which is as follows:

PR_N: parametric roll failure mode;
PL_N: pure loss of stability failure mode;
SR_N: synchronous roll motion failure mode.

where: N=1 means that all loading conditions meet level 1 vulnerability criteria;
N=2 means that all loading conditions meet level 2 vulnerability criteria;
N=M means that there are loading conditions which do not meet the vulnerability criteria, and information on the stability of ship in waves has been prepared for the master.

CHAPTER 2 CRITERIA FOR DYNAMIC STABILITY FAILURE MODES IN WAVES

Section 1 GENERAL PROVISIONS

2.1.1 General requirements

2.1.1.1 In order to improve the safety of ships sailing under severe sea conditions, the risk of dynamic stability failure in waves is to be assessed.

2.1.1.2 Ships engaged on international voyages are to meet vulnerability criteria for the corresponding failure modes in IMO MSC.1/Circ.1627 and MSC.1/Circ.1652. A ship that meets the requirements of Chapter 2, Part A of 2008 International Intact Stability Code is deemed to automatically meet level 1 vulnerability criteria for dead ship failure mode.

2.1.1.3 Ships engaged on domestic voyages are to meet the criteria for the corresponding failure modes in this Chapter.

2.1.2 Dynamic stability failure modes in waves

2.1.2.1 When ships engaged on international voyages encounter severe sea conditions at sea, the dynamic stability failure modes to be considered include:

(1) parametric roll;
(2) Pure loss of stability;
(3) Surf-riding/broaching;
(4) Excessive acceleration;
(5) Dead ship condition.

2.1.2.2 When ships engaged on domestic voyages encounter severe sea conditions at sea, the dynamic stability failure modes to be considered include:

(1) parametric roll;
(2) Pure loss of stability;
(3) synchronous roll motion.

Section 2 REQUIREMENTS FOR DYNAMIC STABILITY IN WAVES

2.2.1 parametric roll criteria

2.2.1.1 Under various ship sailing loading conditions under consideration, it is to check whether the requirements of level 1 parametric roll criteria are met in accordance with paragraph 2.2.1.2. If level 1 parametric roll criteria are not met, it may check whether the requirements of level 2 parametric roll criteria are met in accordance with paragraph 2.2.1.5.

2.2.1.2 Level 1 parametric roll criteria

Under various sailing loading conditions calculated by the ship, the requirements of following formula are to be met:

$$\frac{\delta\ GM_1}{GM} \leq R_{PR}$$

where: R_{PR} — standard value of level 1 criteria, to be obtained according to paragraph 2.2.1.3 of this Chapter;

δGM_1 — amplitude of change in metacentric height in waves, in m, to be obtained according to paragraph 2.2.1.4 of this Chapter;

GM — metacentric height of the loading condition in calm water, in m, with correction for free surface effect.

2.2.1.3 For a ship with sharp bilge, $R_{PR} = 1.87$. For other ship types, R_{PR} is calculated as follows:

(1) If $C_{m,full} > 0.96$, $R_{PR} = 0.17 + 0.425\left(\frac{100A_k}{LB}\right)$

If $0.94 \leq C_{m,full} \leq 0.96$, $R_{PR} = 0.17 + \left(10.625 \times C_{m,full} - 9.775\right)$

If $C_{m,full} < 0.94$, $R_{PR} = 0.17 + 0.2125\left(\frac{100A_k}{LB}\right)$

where: L — length of the ship, in m;

B — moulded breadth of the ship, in m;

A_k — total overall area of the bilge keels (no other appendages), in m^2;

$C_{m,full}$ — midship section coefficient of the fully loaded departure condition in calm water;

(2) $\left(\frac{100A_k}{LB}\right)$ is not to exceed 4.0. If it exceeds 4.0, 4.0 is to be taken;

(3) Non-retractable anti-roll fins can be considered as a kind of bilge keel and counted to the total bilge keel area. Deadwood cannot be considered as a type of bilge keel;

(4) A ship having sharp bilges means that the bilge radius is less than 1% of the moulded breadth of the ship and the bilge angle formed by the section line of the middle section is less than 120°。

2.2.1.4 δGM_1 is one -half the difference between the maximum and minimum values of the metacentric height calculated for the ship corresponding to the loading condition under consideration, which is to be determined by following methods:

(1) Calculation is to be based on the Froude-Krylov assumption and include the free surface effect correction;

(2) The free trim method is to be used to calculate the metacentric height in waves, i.e. the ship is to be balanced in trim and sinkage in equivalent regular waves;

(3) For length of equivalent regular wave, $\lambda = L$. For wave steepness factor S_w, $S_w = 0.0167$ in open sea zone, $S_w = 0.0303$ in greater costal navigation zone and $S_w = 0.0292$ in costal navigation zone;

(4) When δGM_1 is calculated, the fact that the ship is in different ship-wave relative positions in equivalent regular waves is to be considered, i.e. the wave crest is to be centred amidships, and at 0.1λ, 0.2λ, 0.3λ, 0.4λ and 0.5λ forward and 0.1λ, 0.2λ, 0.3λ and 0.4λ aft thereof.

2.2.1.5 Level 2 parametric roll criteria

The ship is to meet the following requirements under various sailing loading conditions under consideration:

$$C2 \leq R_{PR2}$$

where: C2 — ship parametric roll sensitivity index, to be obtained according to 2.2.1.6;

R_{PR2} — standard value of level 2 criteria, $R_{PR2} = 0.025$ characterizing acceptable parametric roll risk level.

2.2.1.6 The value of C2 is calculated as an average of values of $C2(Fn_i, \beta_i)$, each of which is a weighted average of the occurrence probability of irregular wave sea condition given by the table of wave distribution in the navigation zone:

$$C2 = \left[\sum_{i=1}^{12} C2(Fn_i, \beta_h) + \frac{1}{2}\{C2(0, \beta_h) + C2(0, \beta_f)\} + \sum_{i=1}^{12} C2(Fn_i, \beta_f)\right] / 25$$

where: $C2(Fn_i, \beta_h)$ — C2(Fn, β) calculated as specified in 2.2.1.7 with the ship proceeding in head waves with a speed equal to V_i;

$C2(Fn_i, \beta_f)$ — C2(Fn, β) calculated as specified in 2.2.1.7 with the ship proceeding in following waves with a speed equal to V_i;

Fn_i —Froude number corresponding to ship speed V_i, $Fn_i = V_i / \sqrt{L \cdot g}$;

V_i — ship speed, in m/s, $V_i = V_s \cdot K_i$;

L — length of ship, in m;

V_s — ship speed in service, in m/s;

K_i — speed coefficient, to be obtained from Table 2.2.1.6.

Speed Coefficient K_i **Table 2.2.1.6**

i	1	2	3	4	5	6	7	8	9	10	11	12
Ki	1.0	0.991	0.966	0.924	0.866	0.793	0.707	0.609	0.500	0.383	0.259	0.131

2.2.1.7 The weighted criteria C2(Fn, β) are calculated as a weighted average of the short-term parametric roll failure index considering the irregular wave sea condition given by the table of wave distribution in the navigation zone, for a given Froude number and wave direction, as follows:

$$C2(Fn, \beta) = \sum_{i=1}^{N} W_i \cdot C_{S,i}$$

where: W_i — weighting factor for the irregular wave sea condition given by the table of wave distribution in the navigation zone, to be taken as the value of irregular wave sea condition characterized by average zero-crossing wave period Tz and significant wave height Hs in table of wave distribution in the navigation zone divided by total number of observations;

$C_{S,i}$ — sensitivity index corresponding to irregular wave sea condition given by the table of wave distribution in the navigation zone, to be obtained according to 2.2.1.8;

N — total number of irregular wave sea conditions given by the table of wave distribution in the navigation zone, for which the maximum roll angle of parametric roll is assessed for a combination of specified speed and heading.

2.2.1.8 $C_{S,i}$ is to be calculated by following methods:

(1) Based on assessment results of the maximum roll angle of parametric roll under each wave height h_j in head and following waves in a series of equivalent regular waves at speed Vi, to be obtained according to 2.2.1.9;

(2) Each cell of the table of wave distribution in the navigation zone corresponds to an irregular wave sea condition characterized by an average zero-crossing wave period Tz and a significant wave height Hs, which is to be obtained according to 2.2.4. A representative wave height Hri characterizing equivalent regular wave under irregular wave sea condition is to be calculated according to average zero-crossing wave period and significant wave height, to be obtained according to 2.2.5;

(3) The maximum roll amplitude and maximum lateral acceleration of parametric roll corresponding to the representative wave height Hri are to be obtained by linear interpolation of the maximum roll amplitude and maximum lateral acceleration of parametric roll for different equivalent regular wave height hj;

(4) If the maximum roll amplitude of parametric roll is not less than 25° (20° for dry cargo carrier carrying bulk cargo), or the maximum lateral acceleration is not less than R_1, $C_{S,i}$= 1. In other cases, $C_{S,i}$= 0.

2.2.1.9 For roll amplitude and lateral acceleration of parametric roll under wave height hj, assessment is to be carried out using time domain simulation method and based on calculated value of righting level (GZ):

(1) Calculation of righting lever in waves (GZ) for assessment is to be based on the Froude-Krylov assumption and include the free surface effect correction. Assuming that the ship is kept balanced in trim and sinkage on a series of equivalent regular waves:

For length of equivalent regular wave, $\lambda = L$;

For height of equivalent regular wave, $h_j = 0.01j\lambda$, where j = 0, 1,..., 10.

When righting lever in waves (GZ) is calculated, the fact that the ship is in different ship-wave relative positions in equivalent regular waves is to be considered, i.e. the wave crest is to be centred amidships, and at 0.1λ, 0.2λ, 0.3λ, 0.4λ and 0.5λ forward and 0.1λ, 0.2λ, 0.3λ and 0.4λ aft thereof;

(2) Roll amplitude of parametric roll is to be assessed using following single degree of freedom of roll equation:

$$\left(\frac{I_{xx} + \Delta I_{xx}}{1000}\right)(\ddot{\varphi} + \delta_1\dot{\varphi} + \delta_3\dot{\varphi}^3) + sign(\varphi)\rho\nabla gGZ(t, |\varphi|) = 0$$

$$sign(\varphi) = \begin{Bmatrix} 1 & \varphi \geq 0 \\ -1 & \varphi < 0 \end{Bmatrix}$$

where: $I_{xx} + \Delta I_{xx}$ — ship roll rotating moment of inertia and additional roll rotating moment of inertia, in t m^2, to be obtained according to Chapter 3;

$\ddot{\varphi}, \dot{\varphi}, \varphi$ — angular acceleration, speed and angle of ship roll motion, in rad/s^2, rad/s and rad;

δ_1, δ_3 — roll damping coefficient, to be obtained according to Chapter 4;

ρ —density of sea water, in kg/m^3, taken as 1025.0;

g — acceleration due to gravity, in m/s^2, taken as 9.81;

∇ — volume of displacement corresponding to the loading condition under consideration, in m^3;

$GZ(t, |\phi|)$ — value of righting lever in t time wave, in m.

During time domain simulation, the fourth-order Runge-Kutta method is to be used for solution, where initial boundary condition $\dot{\varphi} = 0$, $\varphi = \frac{5\pi}{180}$;

(3) The lateral acceleration is calculated by the following formula:

$$a_y = k_L \cdot (\ddot{\varphi} \cdot h_r - \sin\varphi \cdot g)$$

where: k_L — correction factor for simultaneous action of roll, yaw and pitch under consideration, to be obtained according to 2.2.3.4;

h_r — the position of the acceleration under consideration is the vertical height above the assumed roll axis, in m. The roll axis can be assumed to be located at the midpoint between the waterline and the vertical position of the gravity center. The position of the acceleration under consideration is to be obtained according to 2.2.3.7.

2.2.2 Pure loss of stability criteria

2.2.2.1 Under various ship sailing loading conditions under consideration, it is to check whether the requirements of level 1 pure loss of stability criteria are met in accordance with paragraph 2.2.2.2. If level 1 pure loss of stability criteria are not met, it may check whether the requirements of level 2 pure loss of stability criteria are met in accordance with paragraph 2.2.2.4.

2.2.2.2 Level 1 pure loss of stability criteria

The ship is to meet following requirements under various sailing loading conditions under consideration:

$$GM_{\min} \geq \mathrm{PLA}$$

where: $GM_{\min}$ — minimum value of the metacentric height in waves, in m, to be obtained according to 2.2.2.3;

R_{PLA} — standard value of level 1 criteria, in m, $R_{PLA} = 0.05$.

2.2.2.3 $GM_{\min}$ is the minimum value of the metacentric height calculated for the ship corresponding to the loading condition under consideration, which is to be determined by following methods:

(1) Calculation is to be based on the Froude-Krylov assumption and include the free surface effect correction;

(2) The free trim method is to be used to calculate the metacentric height in waves, i.e. the ship is to be balanced in trim and sinkage in equivalent regular waves;

(3) For length of equivalent regular wave, $\lambda = L$. For wave steepness factor S_w, $S_w = 0.0334$ in open sea zone, $S_w = 0.0607$ in greater costal navigation zone and $S_w = 0.0584$ in costal navigation zone;

(4) When $GM_{\min}$ is calculated, the fact that the ship is in different ship-wave relative positions in equivalent regular waves is to be considered, i.e. the wave crest is to be centred amidships, and at 0.1λ, 0.2λ, 0.3λ, 0.4λ and 0.5λ forward and 0.1λ, 0.2λ, 0.3λ and 0.4λ aft thereof.

2.2.2.4 Level 2 pure loss of stability criteria

The ship is to meet following requirements under various sailing loading conditions under consideration:

$$\max(CR_1, CR_2) \leq R_{PL0}$$

where: $\max(CR_1, CR_2)$ — ship pure loss of stability sensitivity index, to be obtained according to 2.2.2.5;

R_{PL0} — standard value of level 2 criteria, $R_{PL0} = 0.06$ characterizing acceptable pure loss of stability risk level.

2.2.2.5 The criteria values CR_1 and CR_2 are the weighted average values calculated according to the stability parameters when it is assumed that the ship in equivalent regular waves is in static equilibrium. The wave height of equivalent regular wave for calculation is Hi, and wave length $\lambda = L$, where L is length of ship, in m.

$$CR_1 = \sum_{i=1}^{N} W_i C1_i$$

$$CR_2 = \sum_{i=1}^{N} W_i C2_i$$

where: CR_1 — weighted criteria value of level 1 criteria, to be calculated using criteria value $C1_i$ of level 1 criteria and obtained according to 2.2.2.6;

CR_2 — weighted criteria value of level 2 criteria, to be calculated using criteria value $C2_i$ of level 2 criteria and obtained according to 2.2.2.6;

Wi — weighting factor for the irregular wave sea condition given by the table of wave distribution in the navigation zone, to be taken as the value of irregular wave sea condition characterized by average zero-crossing wave period Tz and significant wave height Hs in table of wave distribution in the navigation zone divided by total number of observations, to be obtained according to 2.2.4;

N — total number of irregular wave sea conditions given by the table of wave distribution in the navigation zone for assessing $C1_i$ and $C2_i$, and to be obtained according to 2.2.4.

2.2.2.6 Calculation of $C1_i$ and $C2_i$ need to be based on the assessment results of Φv and Φsw obtained from each wave height h_j when the ship sails in following or head waves in a series of equivalent regular waves.

(1) Each cell of the table of wave distribution in the navigation zone corresponds to an irregular wave sea condition characterized by an average zero-crossing wave period Tz and a significant wave height Hs, which is to be obtained according to 2.2.4. A representative wave height Hi characterizing equivalent regular wave under irregular wave sea condition is to be calculated according to average zero-crossing wave period and significant wave height, to be obtained according to 2.2.5;

(2) $C1_i$ and $C2_i$ corresponding to the representative wave height Hi are to be obtained by linear interpolation based on the assessment results of Φv and Φsw under different equivalent regular wave height h_j;

(3) Criterion 1, $C1_i$, is a criterion based on the calculation of the angle of vanishing stability Φv , as provided in the following formula:

$$C1_i = \begin{cases} 1 & \phi_V < K_{PL1} \\ 0 & \text{otherwise} \end{cases}$$

where: K_{PL1} — standard value, $K_{PL1} = 30^o$;

Φv — angle of vanishing stability, the minimum value obtained according to righting lever curve (GZ curve) in waves, without consideration of the angle of downflooding;

(4) Criterion 2, $C2_i$, is a criterion based on the calculation of the angle of heel Φsw under action of heeling lever specified by l_{PL2} as provided in the following formula:

$$C2_i = \begin{cases} 1 & \phi_{sw} > K_{PL2} \\ 0 & \text{otherwise} \end{cases}$$

where: ϕ_{sw} — maximum value of heeling angle balanced by the righting lever curve (GZ curve) in waves under the action of heeling lever l_{PL2} , without consideration of the angle of downflooding;

K_{PL2} — standard value, $K_{PL2} = 15^o$ for passenger ships, and $K_{PL2} = 25^o$ for other ships;

l_{PL2} — heeling lever, in m, $l_{PL2} = 8(h_j/\lambda)dFn^2$;

Fn — Froude number corresponding to service speed Vs, $Fn = V_S / \sqrt{L \cdot g}$;

d — mean draught, i.e. draught amidships corresponding to the loading condition under consideration in calm water, in m;

Righting lever curve (GZ curve) in waves is to be obtained according to 2.2.2.7.

2.2.2.7 The calculation of righting lever curve (GZ curve) in waves is to be determined using following methods:

(1) Calculation is to be based on the Froude-Krylov assumption and include the free surface effect correction;

(2) Assuming that the ship is kept balanced in trim and sinkage on a series of equivalent regular waves:

For length of equivalent regular wave, λ = L;

For height of equivalent regular wave, $h_j = 0.01j\lambda$, where $j = 0, 1, \ldots, 10$.

When righting lever in waves (GZ) is calculated, the fact that the ship is in different ship-wave relative positions in equivalent regular waves is to be considered, i.e. the wave crest is to be centred amidships, and at 0.1λ, 0.2λ, 0.3λ, 0.4λ and 0.5λ forward and 0.1λ, 0.2λ, 0.3λ and 0.4λ aft thereof.

2.2.3 Synchronous roll motion criteria

2.2.3.1 Under various ship sailing loading conditions under consideration, it is to check whether the requirements of level 1 synchronous roll motion criteria are met in accordance with paragraph 2.2.3.2. If level 1 synchronous roll motion criteria are not met, it may check whether the requirements of level 2 synchronous roll motion criteria are met in accordance with paragraph 2.2.3.8.

2.2.3.2 Level 1 synchronous roll motion criteria

The ship is to meet following requirements under various sailing loading conditions under consideration:

$$\varphi \cdot k_L \cdot (g + 4\pi^2 h_r / T_r^2) \le R_{EA1} \quad \text{and} \quad \varphi \le R_{SR1}$$

where: φ — characteristic roll amplitude, in rad, to be obtained according to 2.2.3.3;

k_L — factor taking into account simultaneous action of roll, yaw and pitch motions, to be obtained according to 2.2.3.4;

T_r — natural rolling period, in s, to be obtained according to 2.2.3.5;

h_r — height above the assumed roll axis of the location of acceleration under consideration, in m, the roll axis may be assumed to be located at the midpoint between the waterline and the vertical centre of gravity, and the location of acceleration under consideration is to be obtained according to 2.2.3.7;

R_{EA1} — standard acceleration value of level 1 criteria, $R_{EA1} = 4.64$ m/s^2;

R_{SR1} — standard roll amplitude value of level 1 criteria. For dry cargo carrier carrying bulk cargo, $R_{SR1} = 12^\circ$, for other ship type, $R_{SR1} = 20^\circ$.

2.2.3.3 Characteristic roll amplitude φ is calculated by the following formulae:

$$\varphi = 4.43rs/\delta_\varphi^{0.5}$$

$$r = [K_1 + K_2 + OG \cdot F] \big/ \left[(B^2/12 \cdot C_B \cdot d) - 0.5C_B \cdot d - OG\right]$$

$$K_1 = g \cdot \beta \cdot {T_r}^2 \cdot \left(\tau + \tau \cdot \widetilde{T} - 1/\widetilde{T}\right)/(4\pi^2)$$

$$K_2 = g \cdot \tau \cdot {T_r}^2 \cdot \left(\beta - \cos\widetilde{B}\right)/(4\pi^2)$$

$$OG = KG - d$$

$$F = \beta\left(\tau - 1/\widetilde{T}\right)$$

$$\beta = \sin\widetilde{B}/\widetilde{B}$$

$$\tau = \exp\left(-\widetilde{T}\right)/\widetilde{T}$$

$$\widetilde{B} = 2\pi^2 \cdot B \big/ \left(g \cdot {T_r}^2\right)$$

$$\widetilde{T} = 4\pi^2 \cdot C_B \cdot d \big/ \left(g \cdot {T_r}^2\right)$$

where: r — effective wave slope coefficient;

s — navigation zone wave steepness factor of level 1 criteria, to be obtained according to 2.2.3.6;

δ_φ — non-dimensional logarithmic decrement of roll decay, $\delta_\varphi = 0.5\pi R_{PR}$, where R_{PR} is to be obtained according to 2.2.1.3;

B — moulded breath of ship, in m;

C_B — block coefficient under sailing condition under consideration;

KG — the height from the center of gravity to baseline corresponding to the loading condition under consideration, in m, and the free surface effect correction is not to be included;

d — mean draught, i.e. draught amidships corresponding to the loading condition under consideration in calm water, in m.

2.2.3.4 Correction factor k_L is calculated by the following formulae:

$$k_L = 1.125 - 0.625x/L \ \text{ if } x < 0.2L$$

$$k_L = 1.0 \text{ if } 0.2L \le x \le 0.65L$$

$$k_L = 0.527 + 0.727x/L \text{ if } x > 0.65L$$

where: x is longitudinal distance of the location of acceleration under consideration from the aft end of ship length L, in m.

2.2.3.5 The natural rolling period T_r is to be calculated according to following formula:

$$T_r = 2\pi \cdot \frac{\sqrt{1000\left(I_{xx} + \Delta I_{xx}\right)}}{\sqrt{\rho g \nabla GM}}$$

where: $I_{xx} + \Delta I_{xx}$ — ship roll rotating moment of inertia and additional roll rotating moment of inertia, in t m^2, to be obtained according to Chapter 3;

ρ — density of sea water, in kg/m^3, taken as 1025.0;

g — acceleration due to gravity, in m/s^2, taken as 9.81;

∇ — volume of displacement corresponding to the loading condition under consideration, in m^3;

GM — metacentric height in calm water, in m, without correction for free surface effect.

2.2.3.6 The navigation zone wave steepness factor of level 1 criteria is to be interpolated from Figure 2.2.3.6 according to ship loading condition T_r value and navigation zone.

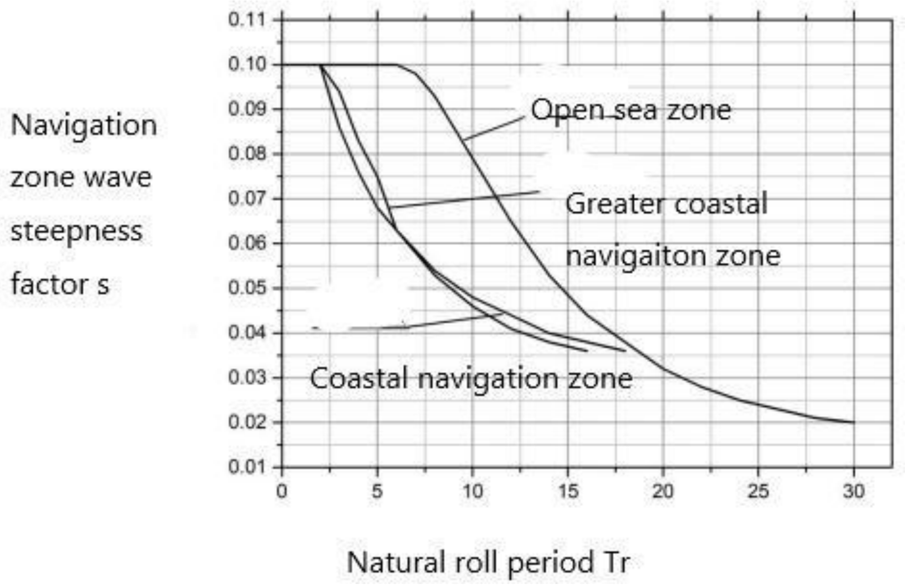

Figure 2.2.3.6 Navigational zone wave steepness factor s

Note: When $T_r \geq 30$s, for open sea zone, s = 0.02; When $T_r \geq 16$s, for greater coastal navigation zone, s = 0.036; When $T_r \geq 18$s, for coastal navigation zone, s = 0.036.

2.2.3.7 For the location of acceleration under consideration, the farthest position from midship that the crew can reach on the pilot deck is to be selected for cargo ship, and the farthest position from midship at the bow and stern of the ship that the crew can reach on the highest deck above the waterline is to be selected for passenger ship.

2.2.3.8 Level 2 synchronous roll motion criteria

The ship is to meet following requirements under various sailing loading conditions under consideration:

$$C_{EA} \leq R_{SR2}$$
$$C_{SR} \leq R_{SR2}$$

where: C_{EA} — ship acceleration sensitivity index, to be obtained according to 2.2.3.9;

C_{SR} — ship roll amplitude sensitivity index, to be obtained according to 2.2.3.9;

R_{EA2} — standard value of level 2 criteria, R_{EA2} = 0.00039 characterizing acceptable acceleration risk level;

R_{SR2} — standard value of level 2 criteria, R_{SR2} = 0.025 characterizing acceptable roll amplitude risk level.

2.2.3.9 The values of C_{EA} and C_{SR} are the weighted average values calculated according to a series of short-term environmental conditions.

(1) The value of C_{EA} is long-term probability index obtained from acceleration sensitivity index calculated based on the probability of occurrence of short-term environmental conditions and according to the loading condition under consideration and position of acceleration under consideration, which is calculated according to following formula:

$$C_{EA} = \sum_{i=1}^{N} W_i \cdot C_{S1,i}$$

(2) The value of C_{SR} is long-term probability index obtained from roll amplitude sensitivity index calculated based on the probability of occurrence of short-term environmental conditions and according to the loading condition under consideration, which is calculated according to following formula:

$$C_{SR} = \sum_{i=1}^{N} W_i \cdot C_{S2,i}$$

where: Wi — weighting factor for the irregular wave sea condition given by the table of wave distribution in the navigation zone, to be taken as the value of irregular wave sea condition characterized by average zero-crossing wave period Tz and significant wave height Hs in table of wave distribution in the navigation zone divided by total number of observations, to be obtained according to 2.2.4;

$C_{S1,i}$ — short-term acceleration sensitivity index obtained by calculation of irregular wave sea condition given by the table of wave distribution in the navigation zone (i.e. short-term environmental condition), to be obtained according to 2.2.3.10;

$C_{S2,i}$ — short-term roll amplitude sensitivity index obtained by calculation of irregular wave sea condition given by the table of wave distribution in the navigation zone (i.e. short-term environmental condition), to be obtained according to 2.2.3.11;

N — total number of irregular wave sea conditions given by the table of wave distribution in the navigation zone, to be obtained according to 2.2.4.

2.2.3.10 For the calculation of $C_{S1,i}$, the probability of the ship exceeding a specific lateral acceleration value is used for measurement, using following formula:

$$C_{S1,i} = \exp\left(-R_1^2/\left(2\cdot\sigma_{LAi}^2\right)\right)$$

where: R_1 — standard value of acceleration, in m/s², $R_1 = 9.81$;

σ_{LAi} — standard difference of the ship lateral acceleration parallel to the deck direction at the position of acceleration under consideration in a zero speed beam wave, to be obtained according to 2.2.3.12.

2.2.3.11 For the calculation of $C_{S2,i}$, the probability of the ship exceeding a specific roll amplitude value is used for measurement, using following formula:

$$C_{S2,i} = \exp\left(-R_2^2/\left(2\cdot\sigma_{RLi}^2\right)\right)$$

where: R_2 — standard roll value, in rad. For dry cargo carrier carrying bulk cargo, $R_2 = 20\cdot\frac{\pi}{180}$, for other ship type, $R_2 = 25\cdot\frac{\pi}{180}$;

σ_{RLi} — standard deviation of ship roll amplitude in a zero speed beam wave, in rad, to be obtained according to 2.2.3.12.

2.2.3.12 σ_{LAi} and σ_{RLi} are to be determined by roll motion response under the action of wave and calculated by the following formulae:

$$\sigma_{LAi}^2 = \frac{3}{4}\cdot\sum_{j=1}^{N}\left(a_y(\omega_j)\right)^2\cdot S_{zz}(\omega_j)\cdot\Delta\omega$$

$$\sigma_{RLi}^2 = \frac{3}{4}\cdot\sum_{j=1}^{N}\left(\varphi_a(\omega_j)\right)^2\cdot S_{zz}(\omega_j)\cdot\Delta\omega$$

where: $\Delta\omega$ — interval of wave frequency, in rad/s, $\Delta\omega = (\omega_2 - \omega_1)/N$;

ω_2 — upper frequency limit of the wave spectrum in the assessment range, in rad/s,

$\omega_2 = \min((25/T_r), 2.0)$;

ω_1 — lower frequency limit of the wave spectrum in the assessment range, in rad/s,$\omega_1 = \max((0.5/T_r), 0.2)$;

N — number of intervals of wave frequency in the assessment range, not to be taken less than 100;

ω_j — wave frequency at the mid-point of the considered frequency interval， in rad/s, $\omega_j = \omega_1 + ((2j-1)/2)\cdot\Delta\omega$;

$S_{zz}(\omega_j)$ — sea wave elevation spectrum, $S_{zz}(\omega_j) = \frac{H_s^2}{4\pi}\cdot\left(\frac{2\pi}{T_z}\right)^4\omega_j{}^{-5}\exp\left(-\frac{1}{\pi}\left(\frac{2\pi}{T_z}\right)^4\omega_j{}^{-4}\right)$;

H_s — significant wave height corresponding to W_i, in m, to be obtained according to 2.2.4;

T_z — average zero-crossing wave period corresponding to W_i, in s, to be obtained according to 2.2.4;

$a_y(\omega_j)$ — lateral acceleration per unit wave amplitude at the position of acceleration under consideration, in m/s^2/m, $a_y(\omega_j) = k_L\cdot(g + h_r\cdot\omega_j^2)\cdot\varphi_a(\omega_j)$;

k_L — correction factor for simultaneous action of roll, yaw and pitch under consideration, to be obtained according to 2.2.3.4;

h_r — the position of the acceleration under consideration is the vertical height above the assumed roll axis, in m. The roll axis can be assumed to be located at the midpoint between the waterline and the vertical position of the gravity center. The position of the acceleration under consideration is to be obtained according to 2.2.3.7;

$\varphi_a(\omega_j)$ — roll amplitude in regular beam waves of unit amplitude and circular frequency ω_j at zero speed, in rad/m， to be obtained according to 2.2.3.13.

2.2.3.13 $\varphi_a(\omega_j)$ is to be calculated by the following formulae:

$$\varphi_a(\omega_j) = \left(\varphi_r(\omega_j)^2 + \varphi_i(\omega_j)^2\right)^{0.5}$$

$$\varphi_r(\omega_j) = \frac{a\cdot\left(\frac{\rho g\nabla GM}{1000} - (I_{xx}+\Delta I_{xx})\cdot\omega_j^2\right) + b\cdot B_e\cdot\omega_j}{\left(\frac{\rho g\nabla GM}{1000} - (I_{xx}+\Delta I_{xx})\cdot\omega_j^2\right)^2 + (B_e\cdot\omega_j)^2}$$

$$\varphi_i(\omega_j) = \frac{b\cdot\left(\frac{\rho g\nabla GM}{1000} - (I_{xx}+\Delta I_{xx})\cdot\omega_j^2\right) - a\cdot B_e\cdot\omega_j}{\left(\frac{\rho g\nabla GM}{1000} - (I_{xx}+\Delta I_{xx})\cdot\omega_j^2\right)^2 + (B_e\cdot\omega_j)^2}$$

where: a, b — cosine and sine components, respectively, of the Froude-Krylov roll moment in regular beam waves of unit amplitude, in kN·m/m;

ρ — density of sea water, in kg/m^3, taken as 1025.0;

g — acceleration due to gravity, in m/s^2, taken as 9.81;

∇ — volume of displacement corresponding to the loading condition under consideration, in m^3;

GM — metacentric height in calm water, in m, without correction for free surface effect;

B_e — equivalent linear roll damping factor, in kN · m · s, $B_e = 2\cdot(I_{xx}+\Delta I_{xx})\cdot\mu_e$, to be obtained according to Chapter 4;

μ_e — equivalent linear roll damping coefficient, in 1/s, to be obtained according to Chapter 4;

$I_{xx}+\Delta I_{xx}$ — ship roll rotating moment of inertia and additional roll rotating moment of inertia, in t m^2, to be obtained according to Chapter 3.

Table of wave scatter in navigation zone

2.2.3.14 Wave scatter table provides following information on irregular wave sea conditions of various navigation zones:

(1) weighting factor W_i for the irregular wave sea conditions;

(2) average zero-crossing wave period T_z for the irregular wave sea conditions;
(3) significant wave height H_s for the irregular wave sea conditions;
(4) total number N for the irregular wave sea conditions.

2.2.3.15 Information on irregular wave sea conditions of open sea zone is obtained from Table 2.2.4.2.

Table of Wave Scatter in Open Sea Zone **Table 2.2.4.2**

Hs/Tz	1.5	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5	12.5	13.5	14.5	15.5	16.5	17.5	18.5	sum
0.5	0	0	1.3	133.7	865.6	1186	634.2	186.3	36.9	5.6	0.7	0.1	0	0	0	0	0	0	3050.4
1.5	0	0	0	29.3	986	4976	7738	5569.7	2375.7	703.5	160.7	30.5	5.1	0.8	0.1	0	0	0	22575.4
2.5	0	0	0	2.2	197.5	2158.8	6230	7449.5	4860.4	2066	644.5	160.2	33.7	6.3	1.1	0.2	0	0	23810.4
3.5	0	0	0	0.2	34.9	695.5	3226.5	5675	5099.1	2838	1114.1	337.7	84.3	18.2	3.5	0.6	0.1	0	19127.7
4.5	0	0	0	0	6	196.1	1354.3	3288.5	3857.5	2685.5	1275.2	455.1	130.9	31.9	6.9	1.3	0.2	0	13289.4
5.5	0	0	0	0	1	51	498.4	1602.9	2372.7	2008.3	1126	463.6	150.9	41	9.7	2.1	0.4	0.1	8328.1
6.5	0	0	0	0	0.2	12.6	167	690.3	1257.9	1268.6	825.9	386.8	140.8	42.2	10.9	2.5	0.5	0.1	4806.3
7.5	0	0	0	0	0	3	52.1	270.1	594.4	703.2	524.9	276.7	111.7	36.7	10.2	2.5	0.6	0.1	2586.2
8.5	0	0	0	0	0	0.7	15.4	97.9	255.9	350.6	296.9	174.6	77.6	27.7	8.4	2.2	0.5	0.1	1308.5
9.5	0	0	0	0	0	0.2	4.3	33.2	101.9	159.9	152.2	99.2	48.3	18.7	6.1	1.7	0.4	0.1	626.2
10.5	0	0	0	0	0	0	1.2	10.7	37.9	67.5	71.7	51.5	27.3	11.4	4	1.2	0.3	0.1	284.8
11.5	0	0	0	0	0	0	0.3	3.3	13.3	26.6	31.4	24.7	14.2	6.4	2.4	0.7	0.2	0.1	123.6
12.5	0	0	0	0	0	0	0.1	1	4.4	9.9	12.8	11	6.8	3.3	1.3	0.4	0.1	0	51.1
13.5	0	0	0	0	0	0	0	0.3	1.4	3.5	5	4.6	3.1	1.6	0.7	0.2	0.1	0	20.5
14.5	0	0	0	0	0	0	0	0.1	0.4	1.2	1.8	1.8	1.3	0.7	0.3	0.1	0	0	7.7
15.5	0	0	0	0	0	0	0	0	0.1	0.4	0.6	0.7	0.5	0.3	0.1	0.1	0	0	2.8
16.5	0	0	0	0	0	0	0	0	0	0.1	0.2	0.2	0.2	0.1	0.1	0	0	0	0.9
sum	0	0	1.3	165.4	2091.2	9279.9	19921.8	24879	20869.9	12898.4	6244.6	2479	836.7	247.3	65.8	15.8	3.4	0.7	100000

2.2.3.16 Information on irregular wave sea conditions of greater coastal navigation zone is obtained from Table 2.2.4.3.

Table of Wave Scatter in Greater Coastal Navigation Zone

Table 2.2.4.3

Hs/Tz	1.5	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5	12.5	13.5	14.5	15.5	16.5	17.5	18.5	SUM
0.5	112.7	1650.7	2874.8	4746.6	3046.4	480.4	114.6	19.2	9.2	2.3	1.5	0.8	0	0	0	0	0	0	13059
1.5	26.5	3120.6	19453.9	11634.7	9331	2944.4	614.6	157.3	51.2	25.4	20.8	13.5	0	0	0	0	0	0	47394
2.5	0	1.2	419.6	7506.9	10060.2	2329.5	316.5	91.9	24.6	12.7	6.9	2.3	0.4	0	0	0	0	0	20773
3.5	0	0	0	16.2	5627.8	5952.3	341.5	26.9	6.9	5	0.8	4.2	0.8	0.4	1.2	0.8	0	0	11985
4.5	0	0	0	0	25.8	3097.1	2003.7	16.9	0.8	0.4	0.4	0	0	0	0	0	0	0.4	5145
5.5	0	0	0	0	1.5	58.1	1071.5	195	0	0	0	0	0	0	0	0	0	0	1326
6.5	0	0	0	0	0	2.3	58.1	195.8	3.8	0	0	0	0	0	0	0	0	0	260
7.5	0	0	0	0	0	0	5.4	39.2	2.3	0	0	0	0	0	0	0	0	0	47
8.5	0	0	0	0	0	0	0.8	7.3	1.5	0	0	0	0	0	0	0	0	0	10
9.5	0	0	0	0	0	0	0	0.8	0	0	0	0	0	0	0	0	0	0	1
10.5	0	0	0	0	0	0	0	0.8	0	0	0	0	0	0	0	0	0	0	1
11.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SUM	139	4772	22748	23904	28093	14864	4527	751	100	46	30	21	1	0	1	1	0	0	100000

2.2.3.17 Information on irregular wave sea conditions of coastal navigation zone is obtained from Table 2.2.4.4.

Table of Wave Scatter in Coastal Navigation Zone

Table 2.2.4.4

Hs/Tz	1.5	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5	12.5	13.5	14.5	15.5	16.5	17.5	18.5	SUM
0.5	103.5	1309.9	2872.1	4557.8	2867.1	448.4	113.5	28.8	9.6	2.7	2.3	0	0	0	0	0	0	0	12316
1.5	16.2	2144.9	15865.6	14994.9	12382.4	4603.2	877.6	249.2	53.8	21.5	28.1	17.3	3.5	1.5	1.5	0.8	0.4	1.2	51264
2.5	0	0.8	143.5	5997	11290.1	3730.9	520.4	151.5	33.5	20.4	8.1	6.2	0.8	1.2	0.4	0	0	0.4	21905
3.5	0	0	0	3.5	3612.5	6234.6	893.4	33.5	5.4	7.7	3.8	1.2	1.5	1.5	1.5	0.4	0	0.4	10801
4.5	0	0	0	0	15.4	1325.7	1646.4	46.5	1.5	0.8	0.8	0	0	0.8	0.4	0.4	0	0	3039
5.5	0	0	0	0	0	27.7	356.9	141.1	0	0.4	0	0	0	0	0	0	0	0	526
6.5	0	0	0	0	0	1.9	40.4	66.2	0.8	0	0	0	0	0	0	0	0	0	109
7.5	0	0	0	0	0	0	3.1	31.5	1.5	0	0	0	0	0	0	0	0	0	36
8.5	0	0	0	0	0	0	0.4	4.2	0	0	0	0	0	0	0	0	0	0	5
9.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SUM	120	3456	18881	25553	30167	16373	4452	753	106	53	43	25	6	5	4	2	0	2	100000

2.2.4 Equivalent regular wave

2.2.4.1 Height of equivalent regular wave used for parametric roll criteria is calculated by the following formula:

$$H_{ri} = 4.0043\sqrt{m_0}$$

Coefficient m_0 is obtained according to 2.2.5.3. If $H_{ri} > 0.1L$, H_{ri} is to be set as $H_{ri} = 0.1L$.

2.2.4.2 Height of equivalent regular wave used for pure loss of stability criteria is calculated by the following formula:

$$H_i = 5.9725\sqrt{m_0}$$

Coefficient m_0 is obtained according to 2.2.5.3. If $H_i > 0.1L$, H_i is to be set as $H_i = 0.1L$.

2.2.4.3 Coefficient m_0 is calculated by the following formula:

$$m_0 = \int_{0.01\omega_L}^{\omega_L} \left\{ \frac{\frac{\omega^2 L}{g} \sin\left(\frac{\omega^2 L}{2g}\right)}{\pi^2 - \left(\frac{\omega^2 L}{2g}\right)^2} \right\}^2 S_{zz}(\omega) d\omega + \int_{\omega_L}^{3\omega_L} \left\{ \frac{\frac{\omega^2 L}{g} \sin\left(\frac{\omega^2 L}{2g}\right)}{\pi^2 - \left(\frac{\omega^2 L}{2g}\right)^2} \right\}^2 S_{zz}(\omega) d\omega$$

$$\omega_L = \left(\frac{2g\pi}{L}\right)^{0.5}$$

$$S_{zz}(\omega) = \frac{H_s^2}{4\pi} \cdot \left(\frac{2\pi}{T_z}\right)^4 \omega^{-5} \exp\left(-\frac{1}{\pi}\left(\frac{2\pi}{T_z}\right)^4 \omega^{-4}\right)$$

where: L — length of ship, in m;
ρ — density of sea water, in kg/m^3, taken as 1025.0;
S_{zz} — sea wave spectrum density function;
H_s — significant wave height, in m;
T_z — average zero-crossing wave period, in s.

2.2.5 Calculation of stability characteristics in waves under loading conditions

2.2.5.1 Under any loading condition, the metacentric height in waves (GM value) and the righting lever in waves (GZ value) used to check the parametric roll and pure loss of stability criteria are to be calculated by correcting the height of the center of gravity and considering the free surface effect. The free surface effect is obtained according to paragraphs 7.2.2.11 (1) ~ (5), Chapter 7, PART FOUR of Technical Regulations for Statutory Survey of Sea-going Ships Engaged on Domestic Voyages. The height of the ship's center of gravity used for synchronous roll motion criteria check is not to include free surface effect. The dynamic effects of liquid sloshing in the liquid tank are not to be considered in criteria check.

2.2.5.2 When compliance of loading conditions is checked according to 2.2.1, 2.2.2 and 2.2.3 using parametric roll, pure loss of stability and synchronous roll motion criteria, the stability characteristics of the ship in calm water and waves, i.e. the calculation of metacentric height (GM value) and righting lever (GZ value), are to meet following requirements

(1) For ships which are not port/starboard symmetric, the most unfavorable side is to be used for calculation;

(2) The effect of watertight appendages that have a significant effect on stability characteristics is to be included;

(3) The effect of the moon pool (without closing device) and the thruster channel is to be considered, if any;

(4) The effect of superstructure and cargo hatch is to be included according to the requirements of subparagraphs (1), (2), (3), paragraph 7.2.2.9 of Technical Regulations for Statutory Survey of Sea-going Ships Engaged on Domestic Voyages;

(5) The effect of flooding angle opening is not taken into account;

(6) The effect of rudder and propulsion unit is not taken into account;

(7) The effect of sea chest is not taken into account;

(8) The effect of deckhouse on the deck above freeboard deck is not included;

(9) The effects of cargo carried on deck, equipment installed and fuel storage facilities are not included.

2.2.6 Information on ship stability in waves which is provided to the master

2.2.6.1 When parametric roll criteria is checked according to 2.2.1, if neither level 1 criteria nor level 2 criteria are met for any loading condition, following information is to be provided to the master for reference:

(1) The parametric roll amplitude value corresponding to the combination of each significant wave height and average zero-crossing period under loading condition and the acceleration response value at the position of acceleration under consideration are to be provided;

(2) For ships that may be loaded with cargo that needs to be secured, the acceleration response, in m/s^2, parallel to the deck direction for each typical position of the secured cargo corresponding to

the combination of each significant wave height and average zero-crossing period under loading condition is to be provided;

(3) The combination of significant wave height and average zero-crossing period as well as speed and wave direction that do not meet the requirements of the criteria are to be clearly identified in a prominent form.

2.2.6.2 When pure loss of stability criteria is checked according to 2.2.2, if neither level 1 criteria nor level 2 criteria are met for any loading condition, following information is to be provided to the master for reference:

(1) Whether the combination of each significant wave height and average zero-crossing period under loading condition complies with the requirements of the criteria is to be provided;

(2) The combination of significant wave height and average zero-crossing period that does not meet the requirements of the criteria is to be clearly identified in a prominent form.

2.2.6.3 When synchronous roll motion criteria is checked according to 2.2.3, if neither level 1 criteria nor level 2 criteria are met for any loading condition, following information is to be provided to the master for reference:

(1) The maximum values of roll amplitude and acceleration corresponding to the combination of each significant wave height and average zero-crossing period under loading condition are to be provided;

(2) For cargo ships that may be loaded with cargo that needs to be secured, the maximum value of acceleration response, in m/s^2, parallel to the deck direction for each typical position of the secured cargo corresponding to the combination of each significant wave height and average zero-crossing period under loading condition is to be provided;

(3) The combination of significant wave height and average zero-crossing period that does not meet the requirements of the criteria is to be clearly identified in a prominent form.

2.2.6.4 Where stability information is provided, it is to be stated in the issued document of compliance.

2.2.6.5 It is recommended that when making sailing plans and operating the ship, the master pay attention to the possible safety risks of loading conditions that do not meet the dynamic stability failure mode criteria in specific waves. It is recommended to refer to the above stability information and pay attention to avoiding sea conditions and sailing conditions that do not meet the criteria requirements (if any), including: the combination of significant wave height and average zero-crossing period, speed and wave direction (if any).

Section 3 EQUIVALENT ALTERNATIVE ASSESSMENT METHODS AND SPECIAL REQUIREMENTS FOR DYNAMIC STABILITY IN WAVES

2.3.1 General requirements

2.3.1.1 The ship may check level 2 parametric roll criteria and level 2 excessive acceleration criteria using equivalent alternative assessment method according to 2.3.2.

2.3.1.2 In addition to the provisions of Section 2 of this Chapter, the ship is to meet following special requirements for stability in waves, if applicable.

2.3.2 Equivalent alternative assessment method

2.3.2.1 It is agreed that numerical calculation or tank test can be used as equivalent alternative assessment method in place of 2.2.1.9 (2) and 2.2.1.9 (3) for calculating parametric roll amplitude and lateral acceleration. The following requirements are to be met:

(1) Tank test is to be carried out by ITTC members to measure ship acceleration response under parametric roll. Motion response measurement is to be made using inertial or optical measurement system;

(2) The ship model is to adopt an appropriate scale ratio to reduce the impact of scale effect. The scale ratio is not to be less than 130, and the length between model perpendiculars is not to be less than 2.5m. The interference of the tank wall effect on the test is to be avoided effectively;

(3) The model error is to meet following requirements:

① The mass error is to be less than 1%;

② Error of initial heeling angle is to be less than 0.5°;

③ Natural roll period is to be measured at least 3 times, and the initial heeling angle is to be kept consistent. The initial heeling angle is taken as 10° (the error is to be less than ±0.5°), and the error between average value and target value is to be less than 2%;

④ The initial heeling angle is taken as 1° (the error is to be less than ±0.25°), and the error between GM average value and the target value is to be less than 2%. When GM value is measured, the press iron is to be placed at the fixed side position corresponding to the center of gravity, and measurement is to be taken at least three times and averaged.

(4) When numerical calculation is carried out using software/program based on potential flow theory method or viscous flow theory method, at least three degrees of freedom of roll, pitch and heave are to be considered;

(5) When numerical calculation is carried out using software/program based on potential flow theory method, the influence of viscous effect on ship roll damping is to be considered. Roll damping is to be assessed according to the requirements of Chapter 4 of the Guidelines;

(6) Available software/program based on potential flow theory method includes:

① Weak nonlinear time-domain ship motion prediction method based on impulse response function theory and frequency-domain Green function;

② Weak nonlinear time-domain ship motion prediction method based on time-domain Green function matching method.

(7) Available software/program based on viscous flow theory method includes full nonlinear three-dimensional CFD ship motion prediction method based on finite volume method;

(8) It is agreed that numerical calculation may be performed using software/program other than those specified in 2.3.2.1 (6) and 2.3.2.1 (7) of this Chapter.

2.3.2.2 It is agreed that numerical calculation or tank test can be used as equivalent alternative assessment method in place of 2.2.3.12 and 2.2.3.13 for calculating σ_{LAi} and σ_{RLi} . The following requirements are to be met:

(1) Tank test is to be carried out by ITTC members using unconstrained and self-propelled test technology to measure ship acceleration response under synchronous roll motion. Motion response measurement is to be made using inertial or optical measurement system;

(2) The ship model is to adopt an appropriate scale ratio to reduce the impact of scale effect. The scale ratio is not to be less than 130, and the length between model perpendiculars is not to be less than 2.5m. The interference of the tank wall effect on the test is to be avoided effectively;

(3) The model error is to meet following requirements:

① The mass error is to be less than 1%;

② Error of initial heeling angle is to be less than 0.5°;

③ Natural roll period is to be measured at least 3 times, and the initial heeling angle is to be kept consistent. The initial heeling angle is taken as 10° (the error is to be less than ±0.5°), and the error between average value and target value is to be less than 2%;

④ The initial heeling angle is taken as 1° (the error is to be less than ±0.25°), and the error between GM average value and the target value is to be less than 2%. When GM value is measured, the press iron is to be placed at the fixed side position corresponding to the center of gravity, and measurement is to be taken at least three times and averaged.

(4) When numerical calculation is carried out using software/program based on potential flow theory method or viscous flow theory method, at least three degrees of freedom of roll, pitch and heave are to be considered. The spectrum analysis method is allowed to calculate the significant value of lateral acceleration;

(5) When numerical calculation is carried out using software/program based on potential flow theory method, the influence of viscous effect on ship roll damping is to be considered. Roll damping is to be assessed according to the requirements of Chapter 4 of the Guidelines;

(6) The error of prediction of significant values of ship roll and lateral acceleration caused by synchronous roll motion in irregular waves by software/program used for numerical calculation is to be controlled within ±25%;

(7) Available software/program based on potential flow theory method includes:

① Frequency -domain ship motion prediction method based on frequency-domain Green function;

② Weak nonlinear time-domain ship motion prediction method based on impulse response function theory and frequency-domain Green function;

③ Linear time-domain ship motion prediction method based on time-domain Green function matching method;

④ Weak nonlinear time-domain ship motion prediction method based on time-domain Green function matching method.

(8) Available software/program based on viscous flow theory method includes full nonlinear three-dimensional CFD ship motion prediction method based on finite volume method.

(9) It is agreed that numerical calculation may be performed using software/program other than those specified in 2.3.2.2 (7) and 2.3.2.2 (8) of this Chapter.

2.3.3 Ship with an extended low weather deck

2.3.3.1 A ship with an extended low weather deck means a ship in which the accommodation spaces and the bridge superstructure are at the front or middle of the ship, and the weather deck for handling cargo, carrying out operation at sea or other purposes is at the rear. The summer freeboard is less than 10% of the ship length. The length of the weather deck for handling cargo, carrying out operation at sea or other purposes is not less than 40% of the ship length.

2.3.3.2 For level 2 parametric roll and pure loss of stability criteria, when the righting lever value or curve (GZ value or GZ curve) in waves is calculated according to 2.2.1.9 and 2.2.2.7, for the calculation of GZ value or GZ curve with $h_j \geq s_c \cdot L$, it is agreed that numerical calculation using tank test or computational fluid dynamics (CFD) method based on viscous flow theory is allowed to obtain GZ value or GZ curve in waves under such loading condition.

2.3.3.3 Critical wave steepness factor s_c is to be calculated by following methods:

(1) Weather deck height factor s_{cs} is taken as the ratio of summer freeboard to ship length L;

(2) Critical significant wave height factor s_{cw}, adopting equivalent wave theory and selecting 1.5～18.5s average zero-crossing period (at interval of 1.0s), wave length is taken as ship length L, and wave steepness factor of equivalent regular wave corresponding to critical significant wave height is calculated with maximum value of s_{cw}. Critical significant wave height is taken as 6.5m for open sea zone, 4.5m for greater coastal navigation zone and 4.5m for coastal navigation zone;

(3) s_c is taken as $s_c=\min(s_{cs},s_{cw})$.

2.3.3.4 GZ value or GZ curve in waves is to be obtained in compliance with following requirements:

(1) Tank test or CFD simulation is to be carried out at zero speed and in following waves;

(2) The roll freedom degree constraint is fixed heeling angle, the heave and pitch freedom angles are not constrained, and the yaw, sway and pitch freedom angles are constrained;

(3) The heeling angle is to be taken as 10°, 15°, 20°, 25°, 30°, 40°, 50° and 60° for obtaining GZ curve value.

2.3.3.5 Tank test is to meet following requirements:

(1) Verification results are to be provided in comparison with standard model tests or other ship model tests to prove their reliability and accuracy;

(2) Detailed description and view of the ship model, model test equipment and accuracy, test method description, test time history measurement results and post-processing results are to be provided;

(3) The test time history measurement results are to include the time history curve of ship heeling moment in the waves, the time history curve of ship pitching and heave motion, and the schematic diagram of the ship, waveform and wave height when the crest and trough are near the midship respectively in the global view;

(4) The post-processing results are to include the calculation results of the time history curve of the GZ value in the waves (relative positions of different ship-wave).

2.3.3.6 Numerical calculation by computational fluid dynamics (CFD) method based on viscous flow theory is to meet following requirements:

(1) Three-dimensional time-domain simulation is to be adopted;

(2) Verification results are to be provided in comparison with standard model tests or other ship model tests to prove their reliability and accuracy;

(3) Detailed description and schematic diagram of geometric models for CFD simulation, mesh division descriptions and views, mesh convergence verification results, calculation setup instructions, CFD time-domain simulation results and post-processing results are to be provided;

(4) Mesh convergence verification results are to include at least 3 sets schemes of discrete mesh with different size and calculation results of the GZ value corresponding to the heeling angle 20^o in the waves to prove that the selected mesh scheme is reasonable;
(5) Mesh convergence verification results can be replaced by CFD simulation convergence verification results of standard model tests or other ship model tests for reliability and accuracy verification;
(6) The mesh view is to include bow, midship and stern mesh cross section, midship longitudinal profile mesh diagram and ship waterplane mesh diagram;
(7) CFD time-domain simulation results are to include the time history curve of ship heeling moment in the waves, the time history curve of ship pitching and heave motion, and the schematic diagram of the ship, waveform and wave height when the crest and trough are near the midship respectively in the global view;
(8) The post-processing results are to include the calculation results of the time history curve of the GZ value in the waves (relative positions of different ship-wave).

2.3.4 Ships without steel weathertight hatch cover at cargo hatch

2.3.4.1 Except for container ships, for ships without steel weathertight hatch cover at cargo hatch, R_{PR} , C2, R_{PL0} , R_{EA1}, R_{SR1} , R_{EA2} and R_{SR2} are taken as 0.8 times the value required in Section 2 of this Chapter, and R_{PLA} is taken as 1.2 times the value required in Section 2 of this Chapter.

2.3.4.2 For sand carriers, R_{PR}, C2, R_{PL0}, R_{EA1}, R_{SR1}, R_{EA2} and R_{SR2} are taken as 0.7 times the value required in Section 2 of this Chapter, and R_{PLA} is taken as 1.3 times the value required in Section 2 of this Chapter.

2.3.4.3 Except for container ships, for ships without steel weathertight hatch cover at cargo hatch, if the flooding angle under loading condition under consideration is less than 30^o, parametric roll criteria and pure loss of stability criteria are checked according to 2.2.1 and 2.2.2 assuming the cargo hold without steel weathertight hatch cover at cargo hatch has maximum free surface, and the height of center of gravity is corrected by elevating center of gravity.

2.3.4.4 Except for container ships, for ships without steel weathertight hatch cover at cargo hatch (including sand carriers), shipborne motion monitoring system is to be provided to automatically monitor the ship roll angle, lateral acceleration and roll period, and following requirements are to be met:
(1) When the ship roll angle amplitude exceeds R_{EA1}or the lateral acceleration amplitude exceeds R_{SR1}, the alarm is to be automatically given;
(2) When the rolling period suddenly becomes longer, the alarm is to be automatically given;
(3) Shipborne motion monitoring system is to be connected to general alarm;
(4) Two sets of independent shipborne motion monitoring systems are to be provided as mutual backup;
(5) Main power supply, emergency power supply and dedicated standby power supply for automatic changeover when the main power supply and emergency power supply fail are to be provided to ensure continuous power supply of the shipborne motion monitoring system. The power supply time of the dedicated standby power supply is not less than the requirements for the dedicated standby power supply for radio equipment.

2.3.4.5 For sand carriers, special attention is to be paid to the negative impact of sea conditions on the ship stability in waves during navigation, and necessary technical measures are to be taken to limit ship's exposure to severe sea conditions, speed and wave direction that may endanger the safety of dynamic stability in waves during route planning and navigation.

2.3.5 Permissible safety zone

2.3.5.1 Permissible safety zone is to meet following requirements:
(1) The permissible safety zone is related to metacentric height, roll rotating moment of inertia and trim, including information on combination of loading conditions that meet the requirements of level 1 or level 2 criteria;
(2) When the permissible safety zone is used, the difference between the calculation parameters of the loading condition under consideration and the corresponding information of the permissible safety zone is to comply with the requirements of Table 2.3.5.1;
(3) When establishing permissible safety zones, free surface correction for vertical position of

center of gravity or GM value in calm water is to meet relevant requirements in Section 2 of this Chapter.

Requirements for Permissible Safety Zone **Table 2.3.5.1**

Calculation parameter	Requirements for difference between the calculation parameter of the loading condition under consideration and the Table of permissible safety zone
Displacement	Less than ±5%
Trim	Less than ±0.5% times ship length
GM value in calm water	Less than ±5%
Roll rotating moment of inertia	Less than ±5%

2.3.6 Shipborne verification software for dynamic stability in waves

2.3.6.1 Shipborne verification software for dynamic stability in waves is to meet following requirements:

(1) The software is to have the calculation function in level 1 and level 2 parametric roll criteria, pure loss of stability criteria and synchronous roll motion criteria;

(2) The software is to be able to ensure that ordinary users cannot modify the real ship data such as the ship geometric features and ship type characteristics that have been inputted;

(3) The software is to check the compliance of the loading situation using a direct calculation method or an appropriate proxy model;

(4) The software is to provide the test loading condition based on the approved "Report on Dynamic Stability in Waves", and the difference between the calculation results of test loading condition obtained by the software and the results in the approved "Report on Dynamic Stability in Waves" is to comply with the requirements of Table 2.3.6.1.

Permissible Error of Software Calculation Results **Table 2.3.6.1**

According to hull shape	Error
Displacement	2%
Metacentric height in calm water	1%/maximum 5cm
Amplitude of variation of metacentric height in waves (GZ value)	1%/maximum 5cm
Minimum value of of metacentric height in waves (GZ value)	1%/maximum 5cm
Value of righting lever in waves (GZ value) （heeling 10°, 20°, 25°, 30°, 40°）	1%/maximum 10cm

CHAPTER 3 SHIP MOMENT OF INERTIA

Section 1 GENERAL PROVISIONS

3.1.1 General requirements

3.1.1.1 The moment of inertia has an important effect on the ship motion response characteristics, and the moment of inertia of ships under various loading conditions is to be accurately assessed for the assessment of dynamic stability in waves. The moment of inertia of ships is to be calculated/estimated in accordance with the requirements of Section 2 or 3 of this Chapter.

3.1.1.2 Upon submission of sufficient evidence to demonstrate the rationality of the calculation method used and approval, other appropriate direct calculation methods or empirical formulae may be used to replace the methods given in Sections 2 and 3 of this Chapter for the estimation of ship roll moment of inertia and additional roll moment of inertia.

Section 2 DIRECT CALCILATION METHOD FOR MOMENT OF INERTIA

3.2.1 Ship moment of inertia under loading conditions

3.2.1.1 The sum of the ship moment of inertia and additional moment of inertia under various loading conditions includes five components: the moment of inertia of light ship, the moment of inertia of liquid, the moment of inertia of cargo, the moment of inertia of personnel stores and the additional moment of inertia.

3.2.2 Moment of inertia of light ship

3.2.2.1 The moment of inertia is to be calculated by an analytical method after the structure and equipment composing the light ship are discretized. The calculation of ship equipment may be properly simplified based on its volume and mass. Figure 3.2.2.1 illustrates the discrete model of the light ship.

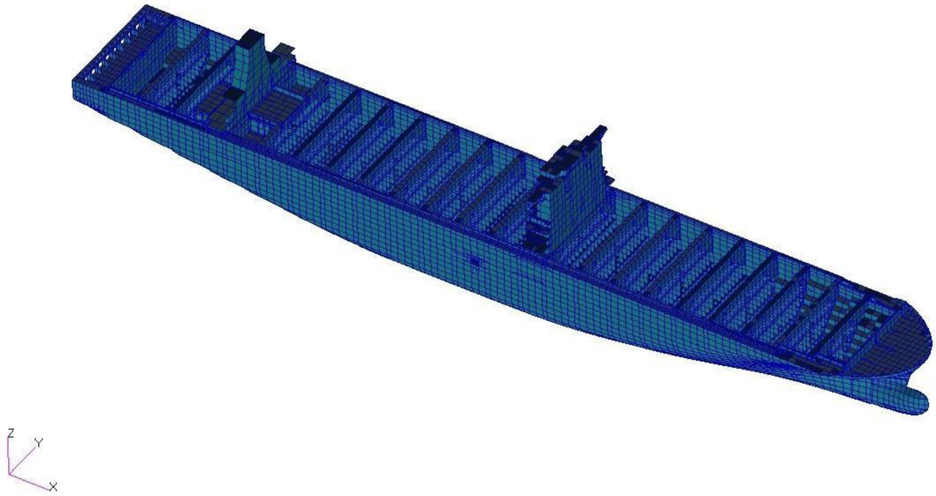

Figure 3.2.2.1 Discrete model of a light container ship

3.2.2.2 In the absence of the calculation results of the discrete model of the target ship, the empirical formula based on the calculation results of the discrete model of the same kind of ship can be used to calculate the moment of inertia of the light target ship. The following form is to be taken for the empirical formula:

$$I_{xx} = \Delta \cdot R_{xx}^2 \quad R_{xx} = R_x \cdot B$$
$$I_{yy} = \Delta \cdot R_{yy}^2 \quad R_{yy} = R_y \cdot L$$
$$I_{zz} = \Delta \cdot R_{zz}^2 \quad R_{zz} \approx R_{yy}$$
$$R_x = c_1 + c_2 \cdot (B/d) + c_3 \cdot (L/100)$$
$$R_y = c_4 + c_5 \cdot (B/d) + c_6 \cdot (L/100)$$

Where: I_{xx}, I_{yy}, I_{zz}——roll, pitch and yaw moment of inertia, in $t \cdot m^2$;
Δ——light ship displacement, in t;
R_{xx}——radius of roll moment of inertia of light ship, in m;
R_{yy}——radius of pitch moment of inertia of light ship, in m;
R_{zz}——radius of yaw moment of inertia of light ship, in m;
B——moulded breadth of the ship, in m;
L——length of the ship, in m;
d——mean moulded draught of light ship, in m;
R_x, R_y——coefficient of radius of moment of inertia;
$c_1, c_2, c_3, c_4, c_5, c_6$——fit coefficient.

3.2.2.3 When level 2 parametric roll criteria are checked in accordance with 2.2.1.9 (2) and 2.2.1.9 (3) or level 2 synchronous roll motion criteria are checked in accordance with 2.2.3.12 and 2.2.3.13, $c_1 = 0.41187$, $c_2 = -0.00383$ and $c_3 = 0.01571$ may be taken.

3.2.3 Moment of inertia of liquid

3.2.3.1 The moment of inertia corresponding to the liquid loading rate of each tank under loading conditions is to be calculated after the tank volume is discretized. The sloshing effect of the liquid inside the tank is not to be taken into account for the moment of inertia of liquid. Figure 3.2.3.1 illustrates the discrete mesh of the ballast tank.

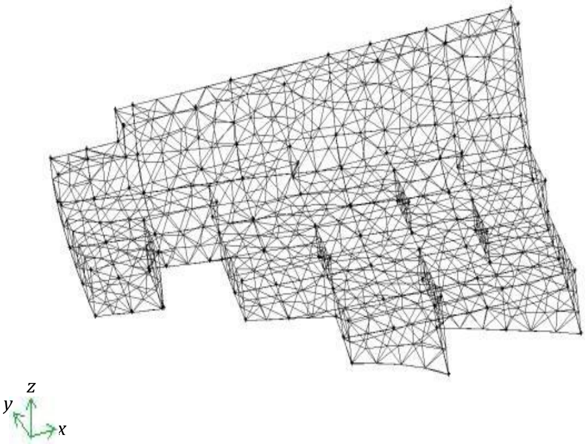

Figure 3.2.3.1 Discrete mesh of ballast tank

3.2.4 Moment of inertia of cargo

3.2.4.1 The moment of inertia of the container is to be calculated by an analytical method according to its loading position , and the moment of inertia of all container stacking may also be calculated according to the displacement. Among them, the goods in the container may be assumed to be evenly distributed in mass. Figure 3.2.4.1 illustrates the container stacking.

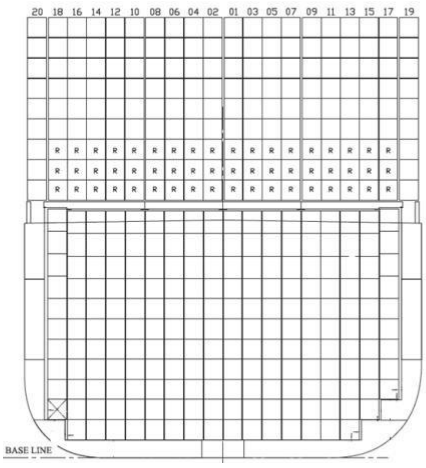

Figure 3.2.4.1 Container stacking

3.2.4.2 For tankers and dry cargo ships, the cargo is homogeneous liquid or nearly homogeneous bulk cargo. The roll moment of inertia corresponding to the loading rate of each cabin under loading conditions is to be calculated after the cabin volume is discretized. The sloshing effect of the liquid inside the tank is not to be taken into account for the roll moment of inertia of liquid.

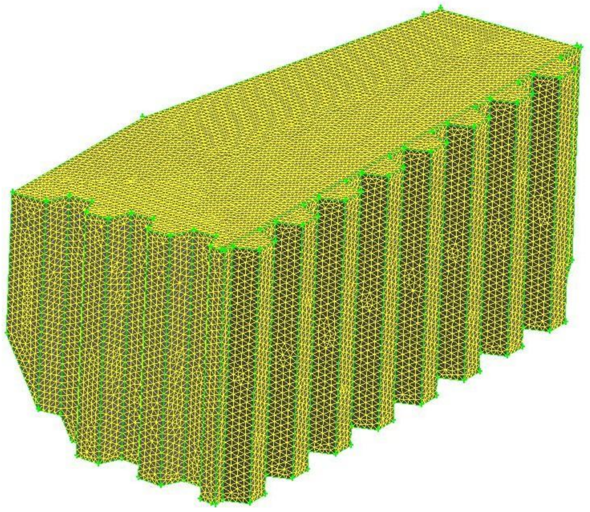

Figure 3.2.4.2 Discrete mesh of cargo hold

3.2.5 Moment of inertia of personnel stores

3.2.5.1 The roll moment of inertia of personnel stores under container loading conditions may be treated according to the lumped mass.

3.2.6 Additional moment of inertia

3.2.6.1 The additional roll moment of inertia under loading conditions can be obtained by the model test or by simulating the free decay of roll using the verified CFD method, or be calculated by three-dimensional potential flow theory method. When loading compliance is verified on board using the permissible safety zone or shipborne software verifying dynamic stability in waves, additional roll moment of inertia may be taken as 10% of the roll moment of inertia under loading conditions.

Section 3 ESTIMATION METHOD FOR EMPIRIAL FORMULAE OF ROLL MOMENT OF INERTIA

3.3.1 Empirical formula of roll moment of inertia

3.3.1.1 The sum of roll moment of inertia and additional roll moment of inertia of a ship under various loading conditions may be estimated by following empirical formulae:

(1) The roll moment of inertia of a ship under loading conditions $I_{xx} + \Delta I_{xx}$, in $t \cdot m^2$, may be estimated by the following formula:

$$I_{xx} + \Delta I_{xx} = \frac{1}{1000} \frac{\rho g \nabla GM T_r^2}{4\pi^2}$$

(2) The natural roll period T_r is to be calculated in accordance with the requirements in 2.1.8, Chapter 7, PART FOUR of Technical Regulations for Statutory Surveys of Sea-going Ships Engaged on Domestic Voyages;

(3) The loading condition of ships in the open sea zone T_r may also be calculated by the following formula:

$$T_r = \frac{2 \cdot C \cdot B}{\sqrt{GM}}$$

$$C = 0.373 + 0.023(B/d) - 0.043(L_{WL}/100)$$

where: ρ —— density of sea water, in kg/m^3, taken as $\rho = 1025.0$;
g —— acceleration due to gravity, in m/s^2, taken as $g = 9.81$;
∇ —— volume of displacement corresponding to the loading condition, in m^3;
GM —— metacentric height in calm water under loading conditions, in m, taking into account correction for free surface effect;
T_r —— natural roll period under loading conditions, in s;
B —— moulded breadth of the ship, in m;
d —— mean draught under loading conditions, in m;
L_{WL} —— waterline length under loading conditions, in m.

CHAPTER 4   SHIP ROLL DAMPING

Section 1   GENERAL PROVISIONS

4.1.1   General requirements

4.1.1.1   Roll damping is to have an important influence on the parametric roll and synchronous roll motion response, and the viscous effects on roll damping are to be considered. In addition to adopting the software/program based on viscous flow theory method or tank test as an equivalent assessment method, the ship roll damping is to be obtained in accordance with the requirements of Section 2 of this Chapter.

Section 2   ASSESSMENT METHOD FOR SHIP ROLL DAMPING

4.2.1   General requirements

4.2.1.1   Ship roll damping under loading conditions is to be obtained by the model test or the approved viscous-flow-theory based computational fluid dynamics (CFD) simulation using free roll decay in calm water.

4.2.1.2   The acquisition of ship roll damping is to meet the following requirements:

(1) For level 2 synchronous roll motion criteria, the initial heeling angle of free roll decay is to be larger than 15^o , and the equivalent linear roll damping coefficient is to be obtained from the roll decay curve. The form of linear roll damping coefficient δ_1 and cubic roll damping coefficient δ_3 may be taken for the equivalent alternative assessment method using numerical calculation;

(2) For level 2 parametric roll criteria, the initial heeling angle of free roll decay is to be larger than 25^o, and the linear roll damping coefficient δ_1 and cubic roll damping coefficient δ_3 are to be obtained from the roll decay curve;

(3) When the roll damping coefficient is obtained by model tests, the free roll decay tests under various loading conditions are to be carried out at least 4 times with different initial heeling angles;

(4) The influence of the active stabilizer is not to be considered for obtaining the roll damping coefficient. Subject to the submission of sufficient evidence to demonstrate the rationality of the calculation method adopted and approval, the roll damping coefficient may be included in the effect of the non-active stabilizer other than the bilge keel;

(5) The roll damping under loading conditions obtained by the above methods is to be provided with test/simulation methods and calculation results in the "Report on Dynamic Stability in Waves".

4.2.1.3   In the absence of model test and CFD simulation results, the roll damping coefficient can be obtained by applying the empirical formula calculation method given in 4.2.2 of this Chapter.

4.2.2   Roll damping empirical formula calculation method

4.2.2.1   The empirical formula calculation method is as follows:

(1) For ships at zero speed, the components of ship roll damping B_{44} include the skin-friction damping B_F, the wave-making damping B_W, the eddy-making damping B_E and the bilge keel damping B_{BK}. The lift damping B_L is also to be considered for forward speeds. The equivalent linear damping coefficient B_{44} is to be expressed as a function $B_{44}({}_a)$ of the roll amplitude ${}_a$.

$$B_{44} = B_F + B_W + B_E + B_L + B_{BK}$$

The roll damping coefficient B_{44} and the natural circular roll frequency $\omega = 2\pi/T_r$ corresponding to the loading condition are non-dimensionalized using the following equations:

$$\hat{B}_{44} = \frac{B_{44}}{\rho \nabla B^2}\sqrt{\frac{B}{2g}}$$

$$\hat{\omega} = \omega\sqrt{\frac{B}{2g}}$$

(2) For the numerical calculation of synchronous roll motion, B_{44} can be calculated by taking the roll amplitude as $_a = 15^\circ$, and $_e$ can be obtained from $_{44} = {}_e$;

(3) For the numerical calculation of synchronous roll motion, B_{44} can also be calculated by taking $= 1^\circ$, and δ_1 is to be obtained from $_{44} = \delta_1 \cdot (I_{xx} + \Delta I_{xx})$; B_{44} is to be calculated by taking $_a = 15^\circ$, and δ_3 is to be obtained from $B_{44} = \delta_1 \cdot (I_{xx} + \Delta I_{xx}) + \frac{3}{4}\delta_3 \cdot (I_{xx} + \Delta I_{xx}) \cdot {}_a^2 \cdot \omega^2$;

(4) For the numerical calculation of parametric roll, B_{44} is to be calculated by taking $_a = 1^\circ$, and δ_1 is to be obtained from $B_{44} = \delta_1 \cdot (I_{xx} + \Delta I_{xx})$; B_{44} is to be calculated by taking $_a = 25^\circ$, and δ_3 is to be obtained from $_{44} = {}_1 \cdot (+\Delta) + \frac{3}{4}{}_3 \cdot (+\Delta) \cdot {}^2 \cdot {}^2$;

(5) Roll damping B_{44} is to be obtained in accordance with 4.2.2.2 of this Chapter.

4.2.2.2 The skin-friction damping B_F, the wave-making damping B_W, the eddy-making damping B_E, the bilge keel damping B_{BK} and the lift damping B_L are to be calculated by the following methods:

(1) The application scope of the empirical formula is:

$$0.5 \le C_b \le 0.85$$
$$2.5 \le B/d \le 4.5$$
$$-1.5 \le \frac{OG}{d} \le 0.2$$
$$0.9 \le C_m \le 0.99$$
$$0.01 \le b_{BK}/B \le 0.06$$
$$0.05 \le l_{BK}/L_{BP} \le 0.4$$
$$\hat{\omega} \le 1.0$$

When the empirical formula is used to estimate the roll damping, if the ship parameters are out of the application scope, the boundary value is to be taken directly for calculation.

(2) The skin-friction damping at zero speed is to be calculated by the following formula:

$$B_F = \frac{4}{3\pi}\rho s_f r_f^3 \varphi_a \omega c_f$$

Where: ρ——density of sea water, taken as 1025, in kg · m^3;

c_f——frictional coefficient;

r_f——average radius from the axis of rolling, in m;

s_f——wetted surface area, in m^2.

The related coefficients are calculated as follows:

$$c_f = 0.74\frac{\sqrt{T_r \nu}}{r_f \varphi_a}$$
$$r_f = \frac{(0.887 + 0.145C_b)\cdot(1.7d + C_b B) - 2\cdot OG}{\pi}$$
$$s_f = L(1.75d + C_b B)$$

Where: φ_a —— roll amplitude, in rad;

ν —— coefficient of seawater dynamic viscosity, in m^2/s;

C_b —— block coefficient of the loading condition;

B —— moulded breadth of the ship, in m;

L —— length of the ship, in m;

d —— mean draught under loading condition, in m;

OG—— the distance from calm water surface to the centre of gravity (downward direction is positive), in m, OG = d − KG;

KG—— vertical height of center of gravity under loading condition, in m.

(3) The wave-making damping at zero speed is to be calculated by the following formula:

$$\hat{B}_W = \frac{A_1}{\hat{\omega}} \cdot exp\left(-0.6944A_2(log(\hat{\omega}) - A_3)^2\right)$$

The related coefficients are calculated as follows:

$$x_1 = B/d\ ;\ x_2 = C_b\ ;\ x_3 = C_m\ ;\ x_4 = 1 - OG/d$$

$$A_1 = AA_1 \cdot \sum_{i=1}^{3}\sum_{j=1}^{4}\sum_{k=1}^{5} Q1_{j+4(i-1),k} x_1^{5-k} x_2^{4-j} x_4^{3-i}$$

$$AA_1 = 1.0 + (1 - x_4) \cdot \sum_{i=1}^{2}\sum_{j=1}^{3}\sum_{k=1}^{5} Q1_{j+3(i-1)+12,k} x_1^{5-k} x_2^{3-j} x_3^{2-i}$$

$$A_2 = \sum_{i=1}^{5} Q2_i x_4^{5-i}$$

The coefficients Q1 and Q2 are obtained from Table 4.2.2.2 (3) a. The first subscript of the coefficient Q1 is the row number of Table 4.2.2.2 (3) a, and the second subscript is the column number of Table 4.2.2.2 (3) a. The subscript of the coefficient Q2 is the column numbers of Table 4.2.2.2 (3) a.

Coefficients 1 and Q **Table 4.2.2.2(3)a**

Coefficient Q1					
	1	2	3	4	5
1	0.00000	0.00000	0.00000	0.00000	0.00000
2	0.00000	-0.00222	0.04087	-0.28687	0.59942
3	0.00000	0.01019	-0.16118	0.90499	-1.64139
4	0.00000	-0.01542	0.22037	-1.08499	1.83417
5	-0.06287	0.49893	0.52735	-10.79187	16.61633
6	0.11407	-0.81090	-2.21868	25.12697	-37.77298
7	-0.05893	0.26397	3.19497	-21.81266	31.41135
8	0.01077	0.00187	-1.24941	6.94279	-10.20190
9	0.00000	0.19221	-2.78746	12.50785	-14.76486
10	0.00000	-0.35056	5.22235	-23.97485	29.00785
11	0.00000	0.23710	-3.53506	16.36838	-20.53991
12	0.00000	-0.06712	0.96636	-4.40754	5.89470
13	0.00000	17.945	-166.294	489.799	-493.142
14	0.00000	-25.507	236.275	-698.683	701.494
15	0.00000	9.077	-84.332	249.983	-250.787
16	0.00000	-16.872	156.399	-460.689	463.848
17	0.00000	24.015	-222.507	658.027	-660.665
18	0.00000	-8.56	79.549	-235.827	236.579
Coefficient Q2					
	0.00000	-1.402	7.189	-10.993	9.45

$$A_3 = AA_3 + \sum_{i=1}^{7}\sum_{j=1}^{7} Q3_{i,j} x_2^{7-j} x_4^{7-i}$$

$$AA_3 = \sum_{i=1}^{4} Q4_{1,i} x_1^{4-i} \cdot \sum_{j=1}^{2}\sum_{k=1}^{4} Q4_{j+1,k} x_2^{4-k} x_4^{2-j} \cdot \left(\sum_{i=1}^{10} Q5_i \left(x_4 - \sum_{j=1}^{4} Q4_{4,j} x_1^{4-j} \right)^{10-i} + \sum_{i=1}^{3} Q5_{i+9} x_1^{3-i} \right)$$

The coefficient Q3 is obtained from Table 4.2.2.2 (3) b. The first subscript of the coefficient Q3 is the row number of Table 4.2.2.2 (3) b, and the second subscript is the column number of Table 4.2.2.2 (3) b. The coefficients Q4 and Q5 are obtained from Table 4.2.2.2 (3) c. The first subscript of the coefficient Q4 is the row number of Table 4.2.2.2 (3) c, and the second subscript is the column number of Table 4.2.2.2 (3) c.

Coefficient Q **Table 4.2.2.2(3)b**

Coefficient Q3							
	1	2	3	4	5	6	7
1	-7686.0287	30131.5678	-49048.9664	42480.7709	-20665.147	5355.2035	-577.8827
2	61639.9103	-241201.0598	392579.5937	-340629.4699	166348.6917	-43358.7938	4714.7918
3	-130677.4903	507996.2604	-826728.7127	722677.104	-358360.7392	95501.4948	-10682.8619
4	-110034.6584	446051.22	-724186.4643	599411.9264	-264294.7189	58039.7328	-4774.6414
5	709672.0656	-2803850.2395	4553780.5017	-3888378.9905	1839829.259	-457313.6939	46600.823
6	-822735.9289	3238899.7308	-5256636.5472	4500543.147	-2143487.3508	538548.1194	-55751.1528
7	299122.8727	-1175773.1606	1907356.1357	-1634256.8172	780020.9393	-196679.7143	20467.0904

Coefficients Q a Q **Table 4.2.2.2(3)c**

Coefficient Q4				
	1	2	3	4
1	-0.3767	3.39	-10.356	11.588
2	-17.109	41.495	-33.234	8.8007
3	36.566	-89.203	71.8	-18.108
4	0	-0.0727	0.7	-1.2818
Coefficient Q5				
Subscript	1	2	3	4
Q5	-1.05584	12.688	-63.70534	172.84571
Subscript	5	6	7	8
Q5	-274.05701	257.68705	-141.40915	44.13177
Subscript	9	10	11	12
Q5	-7.1654	-0.0495	0.4518	-0.61655

(4) The eddy-making damping at zero speed is to be calculated by the following formula:

$$\widehat{\mathrm{B}}_{\mathrm{E}} = \frac{4\widehat{\omega}\varphi_{\mathrm{a}}}{3\pi \mathrm{x}_2 \cdot {\mathrm{x}_1}^3} \mathrm{C}_{\mathrm{R}}$$

The related coefficients are calculated as follows:

$$\mathrm{x}_1 = \mathrm{B}/\mathrm{d} \;\; ; \;\; \mathrm{x}_2 = \mathrm{C}_{\mathrm{b}} \;\; ; \;\; \mathrm{x}_3 = \mathrm{C}_{\mathrm{m}}$$

$$\mathrm{C}_{\mathrm{R}} = \mathrm{A}_{\mathrm{E}} \cdot \exp\left(\mathrm{B}_{\mathrm{E1}} + \mathrm{B}_{\mathrm{E2}} \cdot {\mathrm{x}_3}^{\mathrm{B}_{\mathrm{E3}}}\right)$$

$$\mathrm{A}_{\mathrm{E}} = (-0.0182\mathrm{x}_2 + 0.0155) \cdot (\mathrm{x}_1 - 1.8)^3 + \sum_{\mathrm{i}=1}^{5} \mathrm{Q6}_{1,\mathrm{i}} \mathrm{x}_2^{5-\mathrm{i}}$$

$$\mathrm{B}_{\mathrm{E1}} = (-0.2\mathrm{x}_1 + 1.6) \cdot (3.98\mathrm{x}_2 - 5.1525) \frac{\mathrm{OG}}{\mathrm{d}} \left(\frac{\mathrm{OG}}{\mathrm{d}} \sum_{\mathrm{i}=1}^{3} \mathrm{Q6}_{2,\mathrm{i}} \mathrm{x}_2^{3-\mathrm{i}} + \sum_{\mathrm{i}=1}^{2} \mathrm{Q6}_{2,\mathrm{i}+3} \mathrm{x}_2^{2-\mathrm{i}} \right)$$

$$\mathrm{B}_{\mathrm{E2}} = \left(0.25 \frac{\mathrm{OG}}{\mathrm{d}} + 0.95\right) \cdot \frac{\mathrm{OG}}{\mathrm{d}} + \sum_{\mathrm{i}=1}^{5} \mathrm{Q6}_{3,\mathrm{i}} \mathrm{x}_2^{5-\mathrm{i}}$$

$$\mathrm{B}_{\mathrm{E3}} = (46.5 - 15\mathrm{x}_1) \cdot \mathrm{x}_2 + 11.2\mathrm{x}_1 - 28.6$$

The coefficient Q6 is obtained from Table 4.2.2.2 (4). The first subscript of the coefficient Q6 is the row number of Table 4.2.2.2 (4), and the second subscript is the column number of Table 4.2.2.2 (4).

Coefficient Q **Table 4.2.2.2(4)**

Coefficient Q6					
	1	2	3	4	5
1	-79.414	215.695	-215.883	93.894	-14.848
2	0.9717	-1.55	0.723	0.04567	0.9408
3	0	-219.2	443.7	-283.3	59.6

(5) The bilge keel damping at zero speed is to be calculated by the following formula:

$$\widehat{\mathrm{B}}_{\mathrm{BK}} = \mathrm{A}_{\mathrm{BK}} \cdot \widehat{\omega} \cdot \exp\left(\mathrm{B}_{\mathrm{BK1}} + \mathrm{B}_{\mathrm{BK2}} \cdot {\mathrm{x}_3}^{\mathrm{B}_{\mathrm{BK3}}}\right)$$

The related coefficients are calculated as follows:

$$\mathrm{x}_1 = \mathrm{B}/\mathrm{d} \;\; ; \;\; \mathrm{x}_2 = \mathrm{C}_{\mathrm{b}} \;\; ; \;\; \mathrm{x}_3 = \mathrm{C}_{\mathrm{m}}$$

$$x_6 = \varphi_a \,(deg) \;\; ; \;\; x_7 = \frac{b_{BK}}{B} \;\; ; \;\; x_8 = \frac{l_{BK}}{L}$$

$\mathrm{A}_{\mathrm{BK}} = \mathrm{f}_1 \cdot \mathrm{f}_2 \cdot \mathrm{f}_3;$

$\mathrm{f}_1 = (\mathrm{x}_1 - 2.83)^2 \sum_{\mathrm{i}=1}^{3} \mathrm{Q7}_{1,\mathrm{i}} \mathrm{x}_2^{3-\mathrm{i}} + \sum_{\mathrm{i}=1}^{3} \mathrm{Q7}_{2,\mathrm{i}} \mathrm{x}_2^{3-\mathrm{i}};$

$\mathrm{f}_2 = \sum_{\mathrm{i}=1}^{3} \mathrm{Q7}_{3,\mathrm{i}} \mathrm{x}_6^{3-\mathrm{i}};$

$$\mathrm{f}_3 = \sum_{\mathrm{i}=1}^{2} \sum_{\mathrm{j}=1}^{3} \mathrm{Q7}_{3+\mathrm{i},\mathrm{j}} \mathrm{x}_7^{3-\mathrm{j}} \mathrm{x}_8^{3-\mathrm{i}}$$

$$\mathrm{B}_{\mathrm{BK1}} = \frac{\mathrm{OG}}{\mathrm{d}} \cdot \left(5\mathrm{x}_7 + 0.3\mathrm{x}_1 - 0.2\mathrm{x}_8 + \sum_{\mathrm{i}=1}^{3} \mathrm{Q7}_{6,\mathrm{i}} \mathrm{x}_6^{3-\mathrm{i}} \right)$$

$$B_{BK2} =- 15x_7 + 1.2x_2 - 0.1x_1 + \sum_{i=1}^{3} Q7_{7,i}\left(\frac{OG}{d}\right)^{3-i}$$

$$B_{BK3} = 2.5\frac{OG}{d} + 15.75$$

where: b_{BK}—— breadth of bilge keel, in m;
l_{BK}—— length of bilge keel, in m.

The coefficient Q7 is obtained from Table 4.2.2.2 (5). The first subscript of the coefficient Q7 is the row number of Table 4.2.2.2 (5), and the second subscript is the column number of Table 4.2.2.2 (5).

Coefficient 7 **Table 4.2.2.2(5)**

Coefficient Q7			
	1	2	3
1	0	-0.3651	0.3907
2	0	-2.21	2.632
3	0.00255	0.122	0.4794
4	-0.8913	-0.0733	0
5	5.2857	-0.01185	0.00189
6	0.00125	-0.0425	-1.86
7	-0.0657	0.0586	1.6164

(6) The lift damping at forward speeds is to be calculated by the following formula:

$$\hat{B}_L = \frac{S_L U K_n l_0 l_R}{2\nabla B^2}\left(1 - 1.4\frac{OG}{l_R} + 0.7\frac{OG^2}{l_0 l_R}\right)\sqrt{\frac{B}{2g}}$$

The related coefficients are calculated as follows:

$$K_n = \frac{2\pi d}{L_{BP}} + \kappa\left(4.1\frac{B}{L_{BP}} - 0.045\right)$$

$$S_L = L_{BP}d, \quad l_0 = 0.3d\,, \quad l_R = 0.5d, \quad U = F_n\sqrt{L_{BP}g}$$

$$\kappa = \begin{cases} 0 & C_m \le 0.92 \\ 0.1 & 0.92 < C_m \le 0.97 \\ 0.3 & 0.97 < C_m \end{cases}$$

4.2.2.3 If an empirical formula other than 4.2.2.2 in this Chapter is used, sufficient evidence is to be submitted in the Report on Dynamic Stability in Waves to prove the rationality of the empirical formula used.