GUIDANCE NOTES
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CHINA CLASSIFICATION SOCIETY

GUIDELINES FOR ASSESSMENT OF SLOSHING LOADS AND STRUCTURAL SCANTLING OF TANKS

2020

Effective from 1 Sep. 2020

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Section 1 General Provisions

1.1 General requirements

1.1.1 The Guidelines specify the calculation methods of ship's tank sloshing loads, and the assessment methods and requirements for the hull structural members of tank region under sloshing loads.

1.1.2 The Guidelines are applicable to cargo tanks, ballast tanks and other tanks where free surface motion is allowed on tankers such as oil tankers, chemical tankers, liquefied gas carriers, and bulk carriers, ore carriers and dry cargo carriers etc.

1.1.3 The assessment of structural member scantling under sloshing loads may be carried out for other ships and tanks by referring to the Guidelines.

1.2 Sloshing assessment terms and relevant provisions

1.2.1 Sloshing resonance means the phenomenon of resonance which occurs when the natural period of the ship's motion is close to that of the liquid sloshing motion in the tank, leading to significant liquid level change and increased loads in the tank.

1.2.2 Sloshing motion level characterizes the severity of the liquid sloshing motion in the tank and the magnitude of the sloshing load. According to the judgment criteria of the sloshing resonance motion of ship and tank, it is divided into levels 1, 2 and 3 sloshing motion.

(1) Level 1 sloshing motion is a static or quasi-static process. The loads due to sloshing motion at this level are mainly static loads.

(2) Level 2 sloshing motion is an initial dynamic process of sloshing motion. The loads due to sloshing motion at this level include static and dynamic loads, but the latter have not involved the impact loads, and there is no dynamic amplification.

(3) Level 3 sloshing motion is a dynamic and magnification process of sloshing motion. The loads due to sloshing motion at this level include static and dynamic loads where the latter are the main loads involving impact loads.

1.2.3 Filling height means the liquid filling height in the tank. For tanks with internal members, the filling height used for sloshing assessment is generally $0.1h$ to $0.9h$ (h is given in 1.3.1); for smooth tanks without internal members, the filling height used for sloshing assessment is generally $0.05h$ to $0.95h$. The filling height used for sloshing assessment does not include the filling height limited in the loading manual. The calculated step length is not to be greater than $0.05h$.

1.2.4 Net scantling: when scantling assessment is carried out in accordance with the Guidelines, the net offered scantling as a result of subtracting relevant corrosion addition t_c (see 3.1.6) from the total offered scantling (as-built scantling) is used for structural members, and the net offered scantling is to be greater than or equal to the required scantling. For hull girder bending stress calculation, the net offered scantling as a result of subtracting $0.5t_c$ from the total offered scantling (as-built scantling) is used for relevant structural members.

1.3 Definitions of parameters and symbols

1.3.1 The geometry of typical tanks is as shown in Figure 1.3.1 and the basic parameters are defined in Table 1.3.1.

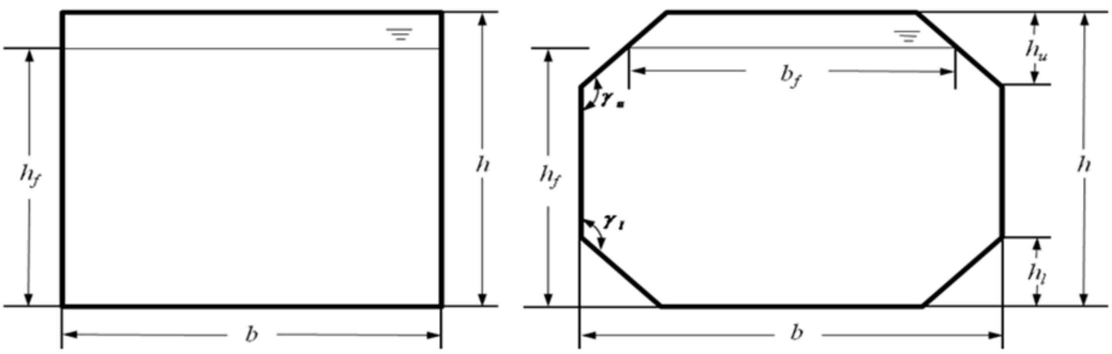


Figure 1.3.1(1) Transverse section of typical tanks

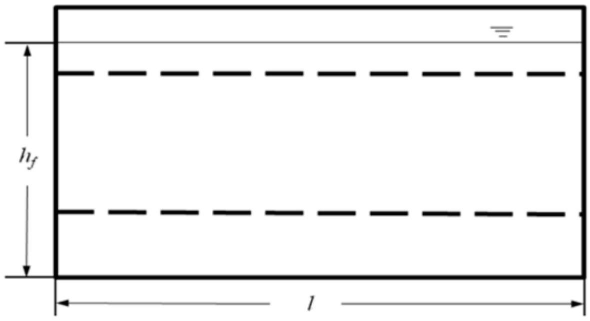


Figure 1.3.1(2) Longitudinal section of typical tanks (plane bulkhead)

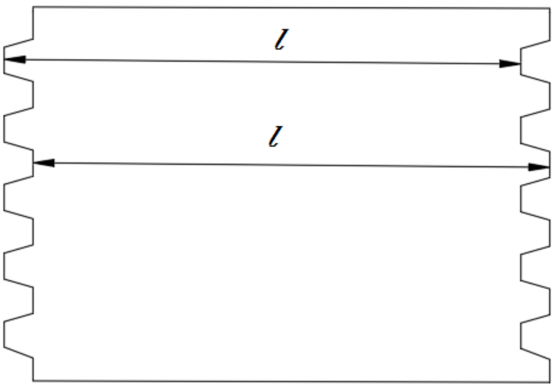


Figure 1.3.1(3) Plan view of typical tanks (corrugated bulkhead)

Definitions of geometric parameters of tanks **Table 1.3.1**

No.	Variable	Definition	Unit
1	l	Length	m
2	b	Breadth	m
3	b_u	Breadth of tank top	m
4	b_l	Breadth of tank bottom	m
5	h	Depth	m
6	h_f	Filling height	m
7	b_f	Tank breadth at corresponding filling height	m
8	l_f	Tank length at corresponding filling height	m
9	h_u	Upper chamfer height	m
10	γ_u	Upper chamfer angle	deg
11	h_L	Lower chamfer height	m
12	γ_l	Lower chamfer angle	deg

1.3.2 Symbols

(1) The following symbols are the same as those defined in Section 1, Chapter 1 of PART TWO of CCS Rules for Classification of Sea-going Steel Ships:

L – length of ship, in m;
B – breadth of ship, in m;
D – moulded depth, in m;
d – draught, in m;
C_b – block coefficient, but not to be taken less than 0.6.

(2) Unless otherwise specified, the following symbols are defined as follows in the Guidelines:

d_i – draught in the loading condition under consideration of ship, in m;
g – gravitational acceleration, g = 9.81 m/s^2;
ρ_w – seawater density, being 1.025 t/m^3;
ρ_L – liquefied natural gas density, being 0.50 t/m^3;

ρ – liquid density, in t/m^3, taken as ρ_w or ρ_L or the density of other liquids as applicable;

T_r – natural period of transverse hull motion, in s, to be calculated in accordance with 2.3.1, Section 2 of the Guidelines;

T_p – natural period of longitudinal hull motion, in s, to be calculated in accordance with 2.3.2, Section 2 of the Guidelines;

l_s – longitudinal effective sloshing length, in m, to be calculated in accordance with relevant requirements of 2.4.1, Section 2 of the Guidelines;

b_s – transverse effective sloshing length, in m, to be calculated in accordance with relevant requirements of 2.4.1, Section 2 of the Guidelines;

T – natural period of liquid sloshing motion in the tank, in s, to be calculated in accordance with relevant requirements of 2.4.3, Section 2 of the Guidelines;

R_{eH} – yield strength of material, in N/mm^2, in accordance with the provisions of Section 3, Chapter 1 of PART TWO of CCS Rules for Classification of Sea-going Steel Ships;

K – material factor, as defined in Section 3, Chapter 1 of PART TWO of CCS Rules for Classification of Sea-going Steel Ships;

E – elastic modulus of material, E=2.06×10^5 N/mm^2 or E=2.06×10^{11} N/m^2 for steel;

ν – Poisson's ratio of material, ν=0.3 for steel;

k_r – roll radius of gyration of the loading condition under consideration, in m;

GM – metacentric height of the loading condition under consideration (after free surface correction), in m.

1.3.3 Unless otherwise specified, a right-hand coordinate system is used for the purpose of the Guidelines:

(1) x axis: along longitudinal direction of hull, positive stern to bow;

(2) y axis: along transverse direction of hull, positive longitudinal centerline to port;

(3) z axis: along vertical direction of hull, positive from baseline up.

Section 2 Calculation of Sloshing Loads

2.1 General provisions

2.1.1 This Section specifies the calculation methods of sloshing loads induced by sloshing motion of the tank liquid as a result of ship motion.

2.1.2 The results of tank sloshing model test and numerical simulation may be used as sloshing design loads subject to the approval of CCS.

2.1.3 If determined values of roll radius of gyration k_r, natural period of ship motion T_r and T_p are provided by designer, the values may be inputted directly with the approval of CCS.

2.1.4 Unless specially provided, sloshing motion and loads specified in this Section are to include two directions, i.e. transverse sloshing and longitudinal sloshing.

2.2 Judgment of sloshing motion level

2.2.1 Ship's loading conditions, values of draught d_i, roll radius of gyration k_r and metacentric height GM related to judgment of sloshing motion level and the calculation of loads are given in Table 2.2.1.

Loading conditions **Table 2.2.1**

No.	Condition	Draught d_i	k_r	GM
LC1	Full load condition	Maximum full load draught(1)	$0.35B$	$0.12B$(2)
LC2	Partial load condition (3)	$0.67d$	$0.39B$	$0.24B$
LC3	Ballast condition	Minimum ballast draught(4)	$0.45B$	$0.33B$(5)
LC4	Partial ballast condition(6)	$0.6d$	$0.40B$	$0.25B$

Note:

(1) Draught d_i is taken as the maximum value of all full load conditions in the loading manual, and not to be less than 0.9d.

(2) If a clear value is given in the loading manual, GM is taken as the minimum value of all full load conditions in the loading manual, and not to be greater than 0.12B.

(3) Partial load condition is only used for level 3 sloshing calculation. k_r and GM of this condition are to be determined based on 0.67d draught. If there are other partial load conditions specified in the loading manual, the corresponding k_r and GM can be calculated by linear interpolation of the value of LC1 and LC2according to the draught.

(4) Draught d_i is taken as the minimum value of all ballast conditions in the loading manual, and not to be greater than 0.6d.

(5) If a clear value is given in the loading manual, GM is taken as the maximum value of all ballast conditions in the loading manual, and not to be less than 0.33B.

(6) Partial ballast condition is only used for level 3 sloshing calculation. k_r and GM of this condition are to be determined based on 0.6d draught. If there are other partial ballast conditions specified in the loading manual, the corresponding k_r and GM can be calculated by linear interpolation of the value of LC3 and LC4 according to the draught.

2.2.2 Tank filling height h_f specified in 1.2.3 is selected for judgment of the sloshing motion level. When $0.7T_{bal} < T < 1.2T_{full}$ (where T is the natural period of liquid sloshing motion in the tank), the tank is within the sloshing resonance range as shown in Figure 2.2.2, where T_{bal} and T_{full} are natural period of ship motion in LC3 ballast and LC1 full load conditions of Table 2.2.1 respectively, to be calculated in accordance with 2.3. F_i is filling height corresponding to each natural period of ship motion.

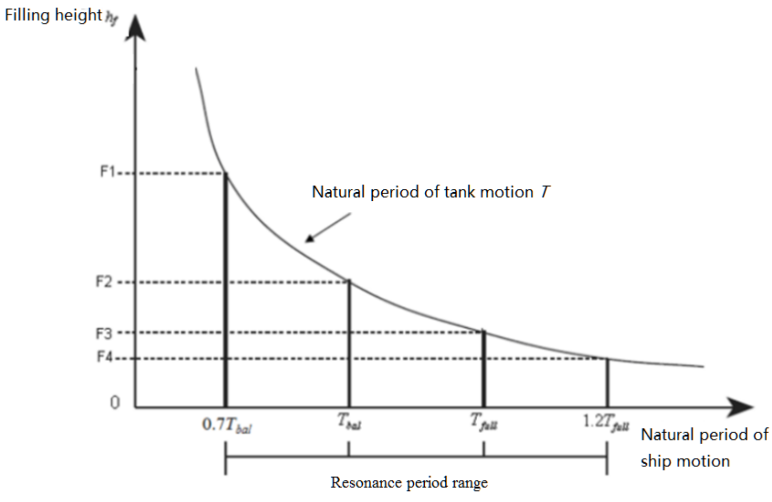


Figure 2.2.2 Resonance period range of tanks

2.2.3 The judgment criteria of sloshing motion level are as follows:

(1) Longitudinal sloshing motion: when $l_s \leq 0.13L$, and the natural period of tank longitudinal sloshing motion is not within the resonance period range, only level 1 sloshing motion needs to be considered; when $l_s \leq 0.13L$, and the natural period of tank longitudinal sloshing motion is within the resonance period range, or when $l_s > 0.13L$, and the natural period of tank longitudinal sloshing motion is not within the resonance period range, level 2 sloshing motion is considered; when $l_s > 0.13L$, and the natural period of tank longitudinal sloshing motion is within the resonance period range, level 3 sloshing motion is considered. The judgment of longitudinal sloshing motion level is given in Table 2.2.3(1).

Longitudinal sloshing motion level **Table 2.2.3(1)**

Tank effective sloshing length	Natural period of tank longitudinal sloshing motion	Sloshing motion level
$l_s \leqslant 0.13L$	Non-resonance	Level 1
	Resonance	Level 2
$l_s > 0.13L$	Non-resonance	Level 2
	Resonance	Level 3

(2) Transverse sloshing motion: when $b_s \leqslant 0.56B$, and the natural period of tank transverse sloshing motion is not within the resonance period range, only level 1 sloshing motion needs to be considered; when $b_s \leqslant 0.56B$, and the natural period of tank transverse sloshing motion is within the resonance period range, or when $b_s > 0.56B$, and the natural period of tank transverse sloshing motion is not within the resonance period range, level 2 sloshing motion is considered; when $b_s > 0.56B$, and the natural period of tank transverse sloshing motion is within the resonance period range, level 3 sloshing motion is considered. The judgment of transverse sloshing motion level is given in Table 2.2.3(2).

Transverse sloshing motion level **Table 2.2.3(2)**

Tank effective sloshing length	Natural period of tank transverse sloshing motion	Sloshing motion level
$b_s \leqslant 0.56B$	Non-resonance	Level 1
	Resonance	Level 2
$b_s > 0.56B$	Non-resonance	Level 2
	Resonance	Level 3

2.3 Parameters of ship motion

2.3.1 The ship roll period, T_r, is calculated in accordance with the following formula:

$$T_r = \frac{2.3\pi k_r}{\sqrt{gGM}} \quad \text{s}$$

2.3.2 The ship pitch period, T_p, is calculated in accordance with the following formula:

$$T_p = \sqrt{\frac{2\pi\lambda_\varphi}{g}} \quad \text{s}$$

where: $\lambda_\phi = 0.6\left(1 + f_T\right)L$, $f_T = \frac{d_i}{d}$.

2.3.3 The angle of roll θ is calculated in accordance with the following formula:

$$\theta = \frac{9000\left(1.25 - 0.025T_r\right) f_\gamma f_{BK}}{\left(B + 75\right)\pi} \quad \text{deg}$$

where: T_r —ship roll period, in s, which is generally taken as the minimum value calculated from LC1 full load condition and LC3 ballast condition specified in Table 2.2.1, when it is calculated in accordance with 2.3.1.

f_γ — service coefficient, and service area is defined in 2.1.3, Chapter 2, PART ONE of the Rules for Classification of Sea-going Steel Ships.

f_γ =1.0 for unrestricted service;

f_γ =0.9 for service category 1;

f_γ =0.85 for service category 2;

f_γ =0.8 for service category 3.

f_{BK} —coefficient, to be taken as follows:

$f_{BK}=1.2$ for ships without bilge keel;

$f_{BK}=1.0$ for ships with bilge keel;

$f_{BK}=0.8$ for ships with activated stabilizers.

2.3.4 The angle of pitch φ is calculated in accordance with the following formula:

$$\varphi = 1350 f_\gamma L^{-0.94}\left[1.0+\left(\frac{2.57}{\sqrt{gL}}\right)^{1.2}\right] \quad \text{deg}$$

where: f_γ — same as 2.3.3.

2.3.5 In accordance with the judgment of 2.2.3, where $l_s \leqslant 0.13L$ or $b_s \leqslant 0.56B$, the natural period of ship motion used for calculation of level 2 sloshing loads is to comply with the following provisions:

(1) if $F_2 < h_f \le F_1$ (where h_f is filling height), the natural period of ship motion is taken as T_{bal};

(2) if $F_4 \le h_f < F_3$ (where h_f is filling height), the natural period of ship motion is taken as T_{full};

(3) if $F_3 \le h_f \le F_2$ (where h_f is filling height), the natural period of ship motion is taken as the natural period of tank motion corresponding to filling height h_f;

2.3.6 In accordance with the judgment of 2.2.3, where l_s>0.13L or b_s>0.56B, the natural period of ship motion used for calculation of level 2 and 3 sloshing loads is to comply with the following provisions:

(1) if $h_f > F_1$ (where h_f is filling height), the ship motion period used for calculation of level 2 sloshing loads is taken as T_{bal};

(2) if $h_f < F_4$ (where h_f is filling height), the ship motion period used for calculation of level 2 sloshing loads is taken as T_{full};

(3) if $F_4 \le h_f \le F_1$ (where h_f is filling height), the ship motion period used for calculation of level 2 and 3 sloshing loads is taken as tank natural period corresponding to filling height h_f.

2.4 Parameters of tank liquid motion

2.4.1 Tank effective sloshing length and breadth

(1) For tanks with internal members, longitudinal effective sloshing length l_s is calculated in accordance with the following formula:

$$l_s = \frac{(1+n_{WT}\alpha_{WT})(1+f_{wf}\alpha_{wf})l_f}{(1+n_{WT})(1+f_{wf})} \quad \text{m}$$

where: n_{WT} —number of transverse wash bulkheads in the tank;

α_{WT} —coefficient of transverse wash bulkheads, $\alpha_{WT}=\frac{A_{OWT}}{A_{tk-t-h}}$;

α_{wf} —coefficient of transverse web frame, $\alpha_{wf}=\frac{A_{O-wf-h}}{A_{tk-t-h}}$; where the tank shape changes along the length or transverse web frames of different shapes are provided, α_{wf} is taken as the weighted average value of all the web frames in the tank, i.e.:

$$\alpha_{wf}=\frac{\sum_{i=1}^{n}\frac{A_{O-wf-h_i}}{A_{tk-t-h_i}}}{n_{wf}};$$

A_{OWT} —total area of opening of transverse section in way of the wash bulkhead below the filling height under consideration, in m^2;

A_{tk-t-h} —total area of tank transverse section below the filling height under consideration, in m^2;

A_{O-wf-h} —total area of opening of transverse section in way of the web frame below the filling height under consideration, in m^2;

$f_{wf} = n_{wf} / (1 + n_{WT})$;

n_{wf} —number of transverse web frames in the tank, excluding wash bulkheads.

(2) For tanks with internal members, transverse effective sloshing breadth b_s is calculated in accordance with the following formula:

$$b_s = \frac{(1 + n_{WL}\alpha_{WL})(1 + f_{grd}\alpha_{grd})b_f}{(1 + n_{WL})(1 + f_{grd})} \quad \text{m}$$

where: n_{WL} —number of longitudinal wash bulkheads in the tank;

α_{WL} —coefficient of longitudinal wash bulkheads, $\alpha_{WL} = \dfrac{A_{OWL}}{A_{tk-L-h}}$;

α_{grd} —coefficient of girder, $\alpha_{grd} = \dfrac{A_{O-grd-h}}{A_{tk-L-h}}$;

A_{OWL} —total area of opening of longitudinal section in way of the wash bulkhead below the filling height under consideration, in m^2;

A_{tk-L-h} —total area of tank longitudinal section below the filling height under consideration, in m^2;

$A_{O-grd-h}$ —total area of opening of longitudinal section below the filling height under consideration, in m^2;

$f_{grd} = n_{grd} / (1 + n_{WL})$;

n_{grd} —number of girders in the tank, excluding longitudinal wash bulkheads.

(3) For smooth tanks without internal members, longitudinal effective sloshing length l_s is taken as tank length l_f at the corresponding filling height, and transverse effective sloshing breadth b_s is taken as tank breadth b_f at the corresponding filling height. Where a cargo containment system is arranged in the smooth tank, the thickness of cargo containment system may be deducted when calculating effective sloshing length and breadth.

2.4.2 Tank effective filling height

(1) For tanks with internal members, longitudinal effective filling height h_l is calculated in accordance with the following formula:

$$h_l = h_f - h_{l1}[n/(n+4)]^{1/2} - 0.45h_{l2} \quad \text{m}$$

where: h_{l1} —height of transverse member of tank bottom, in m, as shown in Figure 2.4.2(1);

h_{l2} —distance from the lowest opening of non-tight transverse bulkhead to the upper edge of transverse member of tank bottom (or tank bottom if transverse member of tank bottom is not provided), in m, and to be taken not less than 0, as shown in Figure 2.4.2(1);

n —number of transverse member of tank bottom.

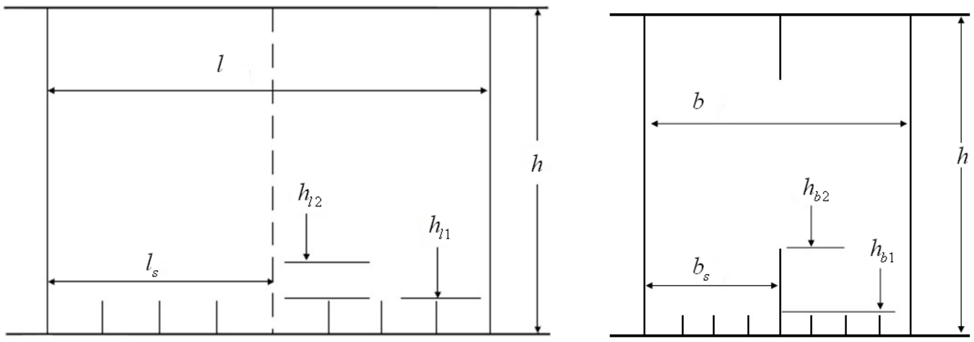
(2) For tanks with internal members, transverse effective filling height h_b is calculated in accordance with the following formula:

$$h_b = h_f - h_{b1}[m/(m+4)]^{1/2} - 0.45h_{b2} \quad \text{m}$$

where: h_{b1} —height of longitudinal member of tank bottom, in m, as shown in Figure 2.4.2(2);

h_{b2} —distance from the lowest opening of non-tight longitudinal bulkhead to the upper edge of longitudinal member of tank bottom (or tank bottom if longitudinal member of tank bottom is not provided), in m, and to be taken not less than 0, as shown in Figure 2.4.2(2);

m —number of longitudinal member of tank bottom.



(1) Tank longitudinal section (2) Tank transverse section

Figure 2.4.2 Structural members of tank bottom

(3) For smooth tanks without internal members, tank effective filling height is the corresponding filling height h_f. Where a cargo containment system is arranged in the smooth tank, the thickness of cargo containment system may be deducted when calculating tank effective filling height.

2.4.3 Sloshing motion natural period of tank liquid

The natural period of longitudinal sloshing motion:

$$T_x = \frac{2\pi}{\sqrt{\frac{g\pi}{l_s}\tanh\left(\frac{\pi h_l}{l_s}\right)}} \quad \text{s}$$

The natural period of transverse sloshing motion:

$$T_y = \frac{2\pi}{\sqrt{\frac{g\pi}{b_s}\tanh\left(\frac{\pi h_b}{b_s}\right)}} \quad \text{s}$$

2.5 Calculation of sloshing loads

2.5.1 Level 1 sloshing load p_1 is linearly distributed along the direction of compartment height and calculated in accordance with the following formulae:

Transverse sloshing load: $p_1 = \rho g(h_f - z + h_{T1})$ kN/m^2, and not to be less than 20 kN/m^2;

Longitudinal sloshing load: $p_1 = \rho g(h_f - z + h_{L1})$ kN/m^2, and not to be less than 20 kN/m^2;

where: $h_{T1} = \frac{b}{2}\tan\left(\frac{\pi\theta}{180}\right)$, to be taken not greater than $h - h_f$, in m;

$h_{L1} = \frac{l}{2}\tan\left(\frac{\pi\varphi}{180}\right)$, to be taken not greater than $h - h_f$, in m;

z —distance from the tank bottom to the calculation point, in m.

2.5.2 Level 2 sloshing load p_2 is calculated in accordance with the following formula:

$$p_2 = p_0 + p_s \quad \text{kN/m}^2$$

where: p_0 — static load component of level 2 sloshing load, to be calculated in accordance with the following formula:

$$p_0 = \rho g\left(h_f - z\right) \quad \text{kN/m}^2\text{, and not to be less than 0;}$$

where: z —distance from the tank bottom to the calculation point, in m.

p_s — dynamic load component of level 2 sloshing load, to be calculated in accordance with the following formulae respectively:

(1) Transverse sloshing load

$$p_s = \rho g h_{T2} \quad \text{kN/m}^2$$

where:

$$h_{T2} = \theta \cdot b_s \left[a \cdot \frac{4\alpha\gamma + \beta}{b(\delta - 1)^2 + d(\delta - 1) + 1} + c\gamma \frac{h_f}{h} \left(1 - \frac{h_f}{h} \right) \right] \quad \text{m}$$

$\alpha = h_f / b_s$;

$\beta = 0.91\alpha^2 - 2.77\alpha + 1.05$;

$\gamma = \dfrac{\pi^2 b_s}{g T_r^2}$;

$\delta = T_r / T_y$;

when $b_s \le 0.56B$,

$a = 0.06 b_s / B - 0.0104$; $b = 8.43$; $c = 26.6a$; $d = -2.32$;

when $b_s > 0.56B$,

$a = 0.0146$; $b = 21.24$; $c = 0.274$; $d = -4.73$;

(2) Longitudinal sloshing load

$$p_s = \rho g h_{L2} \quad \text{kN/m}^2$$

where:

$$h_{L2} = \varphi \cdot l_s \left[a \cdot \frac{4\alpha\gamma + \beta}{b(\delta - 1)^2 + d(\delta - 1) + 1} + c\gamma \frac{h_f}{h} \left(1 - \frac{h_f}{h} \right) \right] \frac{1}{k_L} \quad \text{m}$$

$\alpha = h_f / l_s$;

$\beta = 0.91\alpha^2 - 2.77\alpha + 1.05$;

$\gamma = \dfrac{\pi^2 l_s}{g T_p^2}$;

$\delta = T_p / T_x$;

$k_L = -0.021L + 4.15 \qquad L < 150\text{m}$;

$\quad = 1.0 \qquad L \ge 150\text{m}$;

when $l_s \le 0.13L$,

$a = -0.19 l_s / L + 0.044$; $b = a / (79.7a^2 - 2.38a + 0.0169)$;

$c = 1608a^2 - 33.7a + 0.35$; $d = 0.015b^2 - 0.494b - 0.495$;

when $l_s > 0.13L$,

$a = 0.03$; $b = 20.4$; $c = 0.34$; $d = -4.08$.

2.5.3 The static component of level 2 sloshing load is linearly distributed along the direction of compartment height while the dynamic component is evenly distributed along the direction of compartment height, as shown in Figure 2.5.3.

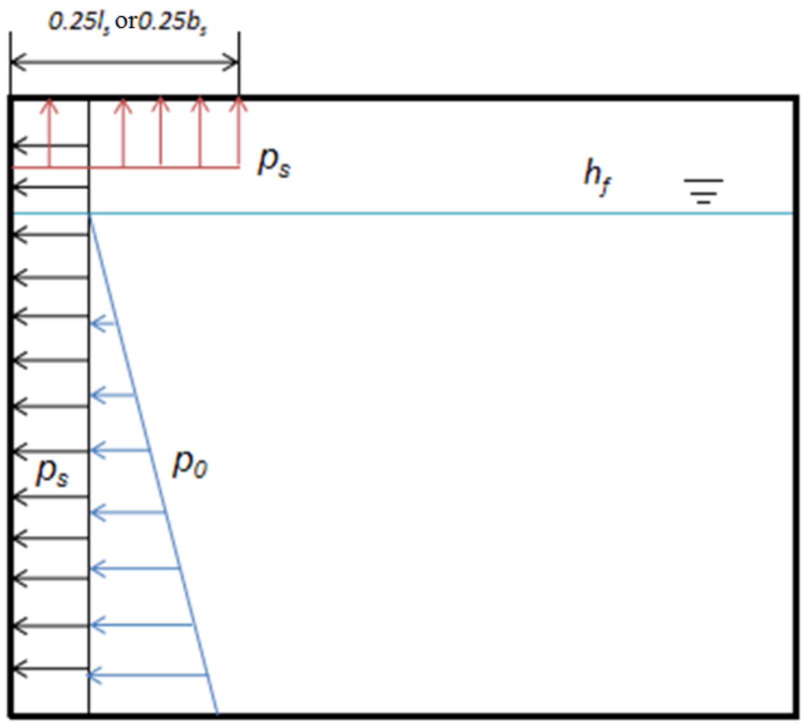


Figure 2.5.3 Distribution of level 2 sloshing load

2.5.4 Level 3 sloshing load p_3 is to be calculated in accordance with Appendix 1. The use of other numerical analysis method is to be approved by CCS. The input of relevant calculation parameters is to comply with the following requirements:

(1) When the target tank is a cargo tank, the roll angle or pitch angle corresponding to the LC2 partial load conditions specified in Table 2.2.1 may be selected as the tank excitation parameter.

(2) When the target tank is a ballast tank, the roll angle or pitch angle corresponding to the LC4 partial ballast conditions specified in Table 2.2.1 may be selected as the tank excitation parameter.

(3) In general, 0.7 to 1.2 times the natural period of tank motion is selected as the tank excitation parameter.

2.5.5 The application of sloshing load is also to comply with the following requirements:

(1) The calculation of level 1 and 2 sloshing loads is not superimposed with the pressure of the air pipe; when the design pressure of the compartment exceeds 25 kN/m^2, the excess is to be superimposed with level 1 and 2 sloshing loads.

(2) When the filling height of tanks with internal members does not exceed the height of tank bottom member h_{l1} or h_{b1}, or h_l or h_b calculated in accordance with 2.4.2 is not greater than 0, sloshing assessment may not be considered.

(3) When the filling height of tanks with internal members does not exceed 0.2h, level 2 sloshing load is only considered to the uppermost edge of bulkhead and level 3 sloshing assessment may not be considered.

(4) When the filling height of smooth tanks without internal members does not exceed 0.1h, level 2 sloshing load is only considered to the uppermost edge of bulkhead and level 3 sloshing assessment may not be considered.

Section 3 Assessment of Tank Structural Scantling under Sloshing Loads

3.1 General requirements

3.1.1 This Section specifies the scantling requirements for tank structure under sloshing loads.

3.1.2 Scantling assessment under sloshing loads is to be carried out to the following structural members:

(1) plating forming tank boundaries, stiffeners;

(2) plating and stiffeners on wash bulkheads in the tank;

(3) web of primary support members, web stiffeners in the tank;

(4) tripping brackets of primary support members in the tank.

3.1.3 Scantling assessment under sloshing loads due to longitudinal motion is to be carried out to the following structural members:

(1) transverse watertight bulkheads;

(2) transverse wash bulkheads;

(3) girders on transverse watertight bulkheads or wash bulkheads;

(4) plating and stiffeners on tank longitudinal boundaries within the range of $0.25l_s$ or the spacing of the first web frame (whichever is lesser) from the transverse bulkhead;

(5) primary support members (if any) within the range of (4) above.

3.1.4 Scantling assessment under sloshing loads due to transverse motion is to be carried out to the following structural members:

(1) longitudinal watertight bulkheads;

(2) longitudinal wash bulkheads;

(3) stringers or vertical girders on longitudinal watertight bulkheads or wash bulkheads;

(4) plating and stiffeners on tank transverse boundaries within the range of $0.25b_s$ or the spacing of the first girder (whichever is lesser) from the longitudinal bulkhead;

(5) primary support members (if any) within the range of (4) above.

3.1.5 For all tanks, scantling assessment under level 1 sloshing load is to be carried out. For tanks complying with sloshing motion level 2, scantling assessment under levels 1 and 2 sloshing loads is to be carried out. For tanks complying with sloshing motion level 3, scantling assessment under levels 1, 2 and 3 sloshing loads is to be carried out.

3.1.6 The assessment of tank structure of this Section is based on net scantling. Unless provided otherwise, the corrosion addition t_c of tanks for different ship types is to be considered, see Table 3.1.6.

Corrosion addition t_c used for sloshing assessment Table 3.1.6

Type of structural members		Corrosion addition t_c (mm)
In the ballast tank (including boundary plating)	All structural members	2.0
In the cargo tank (including boundary plating)	Inner bottom plating	2.0
	Other structural members	1.5
Other structural members exposed to air or in the dry tank		1.0

Note: (1) For boundary plating common to the ballast tank and the cargo tank, 2.0 mm is taken.

(2) For CSR ships, corrosion addition is to be determined in accordance with relevant requirements of PART NINE of the Rules for Classification of Sea-going Steel Ships.

(3) For tank structures using stainless steel materials or in non-corrosive environment, corrosion addition is taken as 0.5 mm.

3.2 Scantling assessment of tank structure under level 1 sloshing load

3.2.1 Plating forming tank boundaries

(1) The net thickness of plating forming tank boundaries subjected to level 1 sloshing load is not to be less than:

$$t_{net}=0.0158\alpha_p s\sqrt{\frac{p_1}{C_a R_{eH}}} \text{ mm}$$

where: α_p — correction factor of aspect ratio of plate panel:

$$\alpha_p = 1.2 - \frac{s}{2100 l_p}$$, but is not to be taken greater than 1.0;

s — stiffener spacing, in mm;

l_p —length of plate panel, to be taken as the spacing of primary support members, in m;

p_1 —level 1 sloshing load at the calculation point, see 2.5.1;

C_a —permissible plate bending stress coefficient:

$$C_a = \beta_a - \alpha_a \frac{|\sigma_{hg}|}{R_{eH}}$$, but not to be taken greater than $C_{a-\max}$;

α_a , β_a , $C_{a-\max}$ — permissible bending stress factors and are to be taken according to Table 3.2.1;

σ_{hg} —hull girder bending stress calculated at the load calculation point and to be taken as:

$$\sigma_{hg} = \left(\frac{(z - z_{NA-net50}) M_{sw-perm-sea}}{I_{v-net50}} \right) \times 10^{-3} \quad \text{N/mm}^2;$$

z —vertical coordinate of the load calculation point, in m;

$z_{NA-net50}$ —distance from the baseline to the horizontal neutral axis, in m;

$M_{sw-perm-sea}$ —permissible hull girder hogging and sagging still water bending moment for seagoing operation at the location being considered, in kN·m. The greatest of the sagging and hogging bending moment is to be used;

$I_{v-net50}$ —net vertical hull girder moment of inertia, at the longitudinal position being considered, in m^4.

(2) Where the plating forming tank boundaries is corrugated bulkhead, the net thickness t_{net} of web and face plate is not to be less than:

$$t_{net} = 0.0158 b_p \sqrt{\frac{p_1}{C_a R_{eH}}} \quad \text{mm}$$

where: b_p — width of web or face plate, in mm;

p_1 —level 1 sloshing load at the calculation point, see 2.5.1;

C_a —permissible plate bending stress coefficient, to be taken as 0.75.

Permissible bending stress factor **Table 3.2.1**

Structural member		β_a	α_a	$C_{a-\max}$
Longitudinal strength members in the cargo tank region, including but not limited to: —decks; —longitudinal plane bulkheads; —horizontal longitudinal corrugated bulkheads; —longitudinal girders and stringers within the cargo tank region	Longitudinally stiffened plating	0.9	0.5	0.8
	Transversely or vertically stiffened plating	0.9	1.0	0.8
Other strength members including: —vertical longitudinal corrugated bulkheads; —transverse plane bulkheads; —transverse corrugated bulkheads; —transverse stringers and web frames; —tank boundaries and plating of primary support members outside the cargo tank region		0.8	0	0.8

3.2.2 Stiffeners on tank boundaries

The net section modulus, Z_{net} , of stiffeners on tank boundaries is not to be less than:

$$Z_{net} = \frac{p_1 s l_{bdg}^2}{f_{bdg} C_s R_{eH}} \quad \text{cm}^3$$

where: p_1 —level 1 sloshing load at the calculation point, see 2.5.1;

s — stiffener spacing, in mm;

l_{bdg} —effective bending span of stiffeners, in m;

C_s —permissible bending stress coefficient:

$$C_s = \beta_s - \alpha_s \frac{|\sigma_{hg}|}{R_{eH}}$$, but not to be taken greater than $C_{s-\max}$;

α_s, β_s, $C_{s-\max}$ — permissible bending stress factors and are to be taken according to Table 3.2.2;

f_{bdg} — bending moment factor:

$f_{bdg} = 12$, for stiffeners with both ends constrained. This is generally to be applied for scantlings of all continuous stiffeners;

$f_{bdg} = 8$, for stiffeners with one or both ends simply supported. This is generally to be applied to discontinuous stiffeners.

Permissible bending stress factor of stiffeners **Table 3.2.2**

Structural member		β_s	α_s	$C_{s-\max}$
Longitudinal strength members in the cargo tank region, including but not limited to: —deck longitudinals; —stiffeners on longitudinal bulkheads; —stiffeners on longitudinal girders and stringers within the cargo tank region	Longitudinal members	0.85	1.0	0.75
	Transverse or vertical members	0.7	0	0.7
Other strength members including: —stiffeners on transverse bulkheads; —stiffeners on transverse stringers and web frames; —stiffeners on tank boundaries and primary support members outside the cargo tank region		0.75	0	0.75

3.3 Scantling assessment of tank structure under level 2 sloshing load

3.3.1 Plating forming tank boundaries

(1) The net thickness of plating forming tank boundaries is not to be less than:

$$t_{net} = 0.0158 \alpha_p s \sqrt{\frac{p_2}{C_a R_{eH}}} \text{ mm}$$

where: α_p — correction factor of aspect ratio of plate panel:

$$\alpha_p = 1.2 - \frac{s}{2100 l_p}$$, but is not to be taken greater than 1.0;

s — stiffener spacing, in mm;

l_p —length of plate panel, to be taken as the spacing of primary support members, in m;

p_2 — level 2 sloshing load at the calculation point, see 2.5.2;

C_a —permissible plate bending stress coefficient:

$$C_a = \beta_a - \alpha_a \frac{|\sigma_{hg}|}{R_{eH}}$$, but not to be taken greater than $C_{a-\max}$;

α_a, β_a, $C_{a-\max}$ — permissible bending stress factors and are to be taken according to Table 3.3.1;

Permissible bending stress factors **Table 3.3.1**

Structural members		β_a	α_a	$C_{a-\max}$
Longitudinal strength members in the cargo tank region, including but not limited to: —deck; —plane longitudinal bulkhead; —horizontal longitudinal corrugated bulkhead; —longitudinal girders and stringers within the cargo tank region	Longitudinally stiffened plating	1.05	0.5	0.9
	Transversely or vertically stiffened plating	1.05	1.0	0.9
Other strength members including: —vertical corrugated longitudinal bulkhead; —plane transverse bulkhead; —corrugated transverse bulkhead; —transverse stringers and web frames; —tank boundaries and plating of primary support members outside the cargo tank region		0.95	0	0.95

σ_{hg} — hull girder bending stress calculated at the load calculation point and to be taken as:

$$\sigma_{hg}=\left(\frac{\left(z_0-z_{NA-net50}\right)M_{sw-perm-sea}}{I_{v-net50}}\right)\times10^{-3}\quad \text{N/mm}^2;$$

z_0 — vertical coordinate of the load calculation point, in m;

$z_{NA-net50}$ — distance from the baseline to the horizontal neutral axis, in m;

$M_{sw-perm-sea}$ — permissible hull girder hogging and sagging still water bending moment for seagoing operation at the location being considered, in kN.m. The greatest of the sagging and hogging bending moment is to be used;

$I_{v-net50}$ — net vertical hull girder moment of inertia, at the longitudinal position being considered, in m^4.

(2) Where the plating forming tank boundaries is corrugated bulkhead, the net thickness t_{net} of web and face plate is not to be less than:

$$t_{net}=0.0158b_p\sqrt{\frac{p_2}{C_aR_{eH}}}\quad \text{mm}$$

where: b_p — width of web or face plate, in mm;

C_a —permissible plate bending stress coefficient, to be taken as 0.85.

3.3.2 Stiffeners on tank boundaries

The net section modulus, Z_{net} , of stiffeners on tank boundaries is not to be less than:

$$Z_{net}=\frac{p_2sl_{bdg}{}^2}{f_{bdg}C_sR_{eH}}\quad \text{cm}^3$$

where: s — stiffener spacing, in mm;

l_{bdg} —effective bending span of stiffeners, in m;

p_2 — level 2 sloshing load at the calculation point, see 2.5.2;

C_s —permissible bending stress coefficient:

$$C_s=\beta_s-\alpha_s\frac{|\sigma_{hg}|}{R_{eH}}$$, but not to be taken greater than $C_{s-\max}$;

α_s , β_s , $C_{s-\max}$ — permissible bending stress factors and are to be taken according to Table 3.3.2;

f_{bdg} — bending moment factor:

$f_{bdg}=12$, for stiffeners with both ends constrained. This is generally to be applied for scantlings of all continuous stiffeners;

$f_{bdg}=8$, for stiffeners with one or both ends simply supported. This is generally to be applied to discontinuous stiffeners.

Permissible bending stress factor of stiffeners **Table 3.3.2**

Structural member		β_s	α_s	$C_{s-\max}$
Longitudinal strength members in the cargo tank region including but not limited to: —deck longitudinals; —stiffeners on longitudinal bulkheads; —stiffeners on longitudinal girders and stringers within the cargo tank region	Longitudinal members	0.95	1.0	0.85
	Transverse or vertical members	0.8	0	0.8
Other strength members including: —stiffeners on transverse bulkheads; —stiffeners on transverse stringers and web frames; —stiffeners on tank boundaries and primary support members outside the cargo tank region		1.0	0	0.85

3.3.3 Wash bulkheads in the tank

(1) Plating of wash bulkheads

The net thickness of plating of wash bulkheads is not to be less than:

$$t_{net}=0.0158\alpha_p s\sqrt{\frac{p_s}{C_a R_{eH}}} \quad \text{mm}$$

where: α_p — correction factor of aspect ratio of plate panel:

$$\alpha_p=1.2-\frac{s}{2100 l_p}$$, but is not to be taken greater than 1.0;

s — stiffener spacing, in mm;

l_p — length of plate panel, to be taken as the spacing of primary support members, in m;

p_s — dynamic load component in level 2 sloshing load, see 2.5.2;

C_a — permissible plate bending stress coefficient:

$$C_a=\beta_a-\alpha_a\frac{|\sigma_{hg}|}{R_{eH}}$$, but not to be taken greater than $C_{a-\max}$;

α_a, β_a, $C_{a-\max}$ — permissible bending stress factors and are to be taken according to Table 3.2.1;

σ_{hg} — hull girder bending stress calculated at the load calculation point and to be taken as:

$$\sigma_{hg}=\left(\frac{(z_0-z_{NA-net50})M_{sw-perm-sea}}{I_{v-net50}}\right)\times10^{-3} \quad \text{N/mm}^2;$$

z_0 —vertical coordinate of the load calculation point, in m;

$z_{NA-net50}$ —distance from the baseline to the horizontal neutral axis, in m;

$M_{sw-perm-sea}$ —permissible hull girder hogging and sagging still water bending moment for seagoing operation at the location being considered, in kN.m. The greatest of the sagging and hogging bending moment is to be used;

$I_{v-net50}$ —net vertical hull girder moment of inertia, at the longitudinal position being considered, in m^4.

(2) Stiffeners

The net section modulus, Z_{net}, of stiffeners on wash bulkheads is not to be less than:

$$Z_{net}=\frac{p_s s l_{bdg}^{\ 2}}{f_{bdg} C_s R_{eH}} \text{ cm}^3$$

where:

p_s — dynamic load component in level 2 sloshing load, see 2.5.2;

s — stiffener spacing, in mm;

l_{bdg} — effective bending span of stiffeners, in m;

C_s — permissible bending stress coefficient:

$C_s = \beta_s - \alpha_s \frac{|\sigma_{hg}|}{R_{eH}}$, but not to be taken greater than $C_{s-\max}$;

α_s, β_s, $C_{s-\max}$ — permissible bending stress factors and are to be taken according to Table 3.3.2;

f_{bdg} — bending moment factor:

$f_{bdg} = 12$, for stiffeners with both ends constrained. This is generally to be applied for scantlings of all continuous stiffeners;

$f_{bdg} = 8$, for stiffeners with one or both ends simply supported. This is generally to be applied to discontinuous stiffeners.

(3) Stringers

The net section modulus, Z_{net}, of stringers on wash bulkheads in the tank is not to be less than:

$$Z_{net} = 1000 \frac{p_s S l_{bdg}{}^2}{f_{bdg} C_s R_{eH}} \text{ cm}^3$$

where:

p_s — dynamic load component in level 2 sloshing load, see 2.5.2;

S— spacing of primary support members, in m;

l_{bdg} — effective bending span of primary support members, in m;

f_{bdg} — bending moment factor:

$f_{bdg} = 12$, for primary support members with both ends constrained and subjected to uniformly distributed loads;

C_s — permissible bending stress coefficient, to be taken as 0.7.

The net shear area, A_{net}, of stringers on wash bulkheads in the tank is not to be less than:

$$A_{net} = 10 \frac{f_{shr} p_s S l_{shr}}{C_t \tau_{eH}} \text{ cm}^2$$

where: p_s — dynamic load component in level 2 sloshing load, see 2.5.2;

f_{shr} — shear force factor:

$f_{shr} = 0.5$, for primary support members with both ends constrained and subjected to uniformly distributed loads;

l_{shr} — effective shear span of primary support members, in m;

$\tau_{eH} = R_{eH} / \sqrt{3}$ N/mm²;

C_t — permissible shear stress coefficient, to be taken as 0.7.

(4) Vertical girders

The net section modulus, Z_{net}, of vertical girders on wash bulkheads in the tank is not to be less than:

$$Z_{net} = 1000 \frac{p_s S l_{bdg}{}^2}{f_{bdg} C_s R_{eH}} \text{ cm}^3$$

where: p_s — dynamic load component in level 2 sloshing load, see 2.5.2;

S— spacing of primary support members, in m;

l_{bdg} —effective bending span of primary support members, in m;

C_s — permissible bending stress coefficient, to be taken as 0.7;

$f_{bdg} = 12$, for primary support members with both ends constrained and subjected to uniformly distributed loads.

The net shear area, A_{net}, of vertical girders on wash bulkheads in the tank is not to be less than:

$$A_{net}=10\frac{f_{shr}p_sSl_{shr}}{C_t\tau_{eH}} \qquad \text{cm}^2$$

where: p_s — dynamic load component in level 2 sloshing load, see 2.5.2;

S — spacing of primary support members, in m;

l_{shr} — effective shear span of primary support members, in m;

C_t — permissible shear stress coefficient, to be taken as 0.7;

$\tau_{eH}=R_{eH}/\sqrt{3}$ N/mm^2;

$f_{shr}=0.5$.

3.3.4 Primary support members in the tank

(1) The net thickness, t_{net}, of web of primary support members in the tank is not to be less than:

$$t_{net}=0.0158\alpha_p s\sqrt{\frac{p_s}{C_aR_{eH}}} \qquad \text{mm}$$

where: α_p — correction factor of aspect ratio of plate panel:

$\alpha_p=1.2-\frac{s}{2100l_p}$, but is not to be taken greater than 1.0;

s — stiffener spacing, in mm;

l_p —length of plate panel, average spacing of local support members on longer side of plate panel, generally to be taken as the spacing of tripping brackets, in m;

p_s — dynamic load component in level 2 sloshing load, see 2.5.2;

C_a —permissible plate bending stress coefficient, the calculation formula is given in Table 3.2.1.

(2) The net section modulus, Z_{net}, of web stiffeners of primary support members in the tank is not to be less than:

$$Z_{net}=\frac{p_ssl_{bdg}^{\ 2}}{f_{bdg}C_sR_{eH}} \qquad \text{cm}^3$$

where: p_s — dynamic load component in level 2 sloshing load, see 2.5.2;

s — stiffener spacing, in mm;

l_{bdg} — effective bending span of stiffeners, in m;

C_s — permissible bending stress coefficient:

$C_s=\beta_s-\alpha_s\frac{|\sigma_{hg}|}{R_{eH}}$, but not to be taken greater than $C_{s-\max}$;

α_s, β_s, $C_{s-\max}$ — permissible bending stress factors and are to be taken according to Table 3.2.2;

f_{bdg} — bending moment factor:

$f_{bdg}=12$, for stiffeners with both ends constrained. This is generally to be applied for scantlings of all continuous stiffeners;

$f_{bdg}=8$, for stiffeners with one or both ends simply supported. This is generally to be applied to discontinuous stiffeners.

(3) Tripping brackets of primary support members

The net section modulus, Z_{net}, in way of the base within the effective length *d* of tripping brackets and the net shear area, A_{net}, after deduction of cut-outs and slots are not to be less than:

$$Z_{net}=\frac{1000P_ss_{trip}h^2}{2C_sR_{eH}} \qquad \text{cm}^3$$

$$A_{net} = 10\frac{P_s s_{trip} h}{C_t \tau_{eH}} \qquad \text{cm}^2$$

Where: p_s — dynamic load component in level 2 sloshing load, see 2.5.2;

s_{trip} — average spacing between tripping brackets or between tripping brackets and other primary support members or bulkheads, in m;

h — height of tripping brackets, in m, see Figure 3.3.4;

C_s — permissible bending stress coefficient of tripping brackets, to be taken as 0.75;

C_t — permissible shear stress coefficient of tripping brackets, to be taken as 0.75.

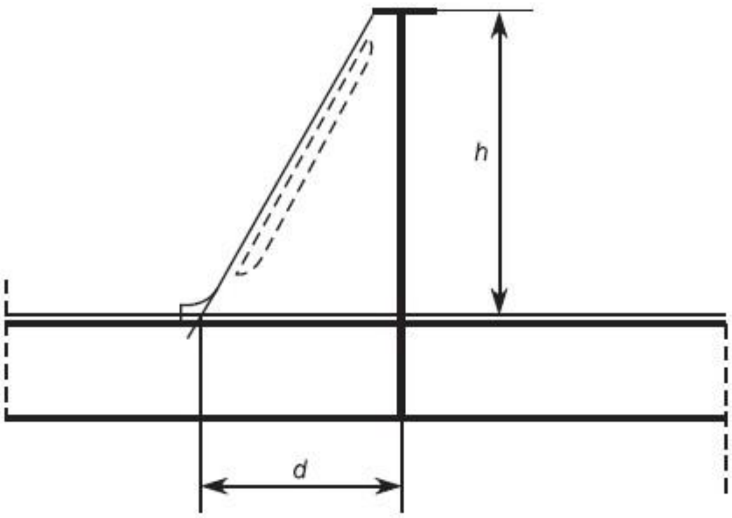


Figure 3.3.4 Effective length of tripping brackets

3.4 Scantling assessment of tank structure under level 3 sloshing load

3.4.1 Plating on tank watertight boundaries

(1) The net thickness of plating forming tank boundaries is not to be less than:

$$t_{net} = \frac{0.0158\alpha_p s}{C_d}\sqrt{\frac{p_3}{C_a R_{eH}}} \qquad \text{mm}$$

where: α_p — correction factor of aspect ratio of plate panel:

$\alpha_p = 1.2 - \frac{s}{2100 l_p}$, but is not to be taken greater than 1.0;

s — stiffener spacing, in mm;

l_p — length of plate panel, to be taken as the spacing of primary support members or intercostal members of plate panel, in m;

p_3 — impact pressure at the calculation point, see 2.5.4;

C_a — permissible plate bending stress coefficient, to be taken as 1.0; For CSR oil tankers, it is to be taken as 1.05;

C_d — plate capacity correction coefficient, to be taken as 1.2.

(2) Where the plating forming tank boundaries is corrugated bulkhead, the net thickness t_{net} of web and face plate is not to be less than:

$$t_{net} = \frac{0.0158 b_p}{C_d}\sqrt{\frac{p_3}{C_a R_{eH}}} \qquad \text{mm}$$

where: b_p — width of web or face plate, in mm;

C_a — permissible plate bending stress coefficient, to be taken as 0.9; For CSR oil tankers, it is to be taken as 0.95;

The other definitions are the same as above.

3.4.2 Stiffeners on tank watertight boundaries

The net plastic section modulus, Z_{P-net}, of stiffeners on tank boundaries subjected to impact pressure is not to be less than:

$$Z_{P-net} = \frac{p_3 s l_{bdg}{}^2}{f_{bdg} C_s R_{eH}} \quad \text{cm}^3$$

where: p_3 — impact pressure at the calculation point, see 2.5.4;

s— stiffener spacing, in mm;

l_{bdg} — effective bending span of stiffeners, in m;

C_s — permissible bending stress coefficient, to be taken as 0.9; For CSR oil tankers, it is to be taken as 0.95;

f_{bdg} — bending moment factor, to be taken as 16.

3.4.3 Primary support members on tank boundaries

(1) Stringers

The net section modulus, Z_{net}, of stringers on tank boundaries is not to be less than:

$$Z_{net} = 1000 \frac{p_3 S l_{bdg}{}^2}{f_{bdg} C_s R_{eH}} \quad \text{cm}^3$$

where: p_3 —impact pressure at the height of stringer, see 2.5.4;

S— spacing of primary support members, in m;

l_{bdg} — effective bending span of primary support members, in m;

f_{bdg} — bending moment factor:

$f_{bdg} = 12$, for primary support members with both ends constrained and subjected to uniformly distributed loads;

C_s — permissible bending stress coefficient, to be taken as 0.7; For CSR oil tankers, it is to be taken as 0.75.

The net shear area, A_{net}, of stringers on tank boundaries is not to be less than:

$$A_{net} = 10 \frac{f_{shr} p_3 S l_{shr}}{C_t \tau_{eH}} \quad \text{cm}^2$$

where: f_{shr} — shear force factor:

$f_{shr} = 0.5$, for primary support members with both ends constrained and subjected to uniformly distributed loads;

p_3 —impact pressure at the height of stringer, see 2.5.4;

S— spacing of primary support members, in m;

l_{shr} —effective shear span of primary support members, in m;

$\tau_{eH} = R_{eH} / \sqrt{3}$ N/mm²;

C_t —permissible shear stress coefficient, to be taken as 0.7; For CSR oil tankers, it is to be taken as 0.75.

(2) Vertical girders

The net section modulus, Z_{net}, of vertical girders on tank boundaries is not to be less than:

$$Z_{net} = 1000 \frac{p_3 S l_{bdg}{}^2}{f_{bdg} C_s R_{eH}} \quad \text{cm}^3$$

where: p_3 —impact pressure on vertical girders, to be taken as the maximum value of calculation results within the range of impact action, see 2.5.4;

S— spacing of primary support members, in m;

l_{bdg} — effective bending span of primary support members, in m;

C_s — permissible bending stress coefficient, to be taken as 0.7; For CSR oil tankers, it is to be taken as 0.75;

For the top of vertical girders:

$$f_{bdg} = 12\frac{l_{bdg}^4}{(l_{bdg} - b)^3 (l_{bdg} + 3b)};$$

For the bottom of vertical girders:

$$f_{bdg} = 12\frac{l_{bdg}^4}{(l_{bdg} - b)^2\ (l_{bdg}^2 + 2bl_{bdg} + 3b^2)}\ ;$$

b— distance from the top of area under the impact load to the top of effective span of vertical girders.

The net shear area, A_{net}, of vertical girders on tank boundaries is not to be less than:

$$A_{net} = 10\frac{f_{shr} p_3 S l_{shr}}{C_t \tau_{eH}} \quad \text{cm}^2$$

where: p_3—impact pressure on vertical girders, to be taken as the maximum value of calculation results within the range of impact action, see 2.5.4;

S— spacing of primary support members, in m;

l_{shr}— effective shear span of primary support members, in m;

$\tau_{eH} = R_{eH} / \sqrt{3}$ N/mm^2;

C_t— permissible shear stress coefficient, to be taken as 0.7; For CSR oil tankers, it is to be taken as 0.75;

For the top of vertical girders:

$$f_{shr} = \frac{(l_{bdg} - b)^3 l_{bdg} - 0.5(l_{bdg} - b)^4}{l_{bdg}^4};$$

For the bottom of vertical girders:

$$f_{shr} = \frac{(l_{bdg} - b) l_{bdg}^3 - (l_{bdg} - b)^3 l_{bdg} + 0.5(l_{bdg} - b)^4}{l_{bdg}^4};$$

b— distance from the top of area under the impact load to the top of effective span of vertical girders.

3.4.4 Wash bulkheads in the tank

(1) Plating of wash bulkheads

The net thickness of plating of wash bulkheads is not to be less than:

$$t_{net} = \frac{0.0158\alpha_p s}{C_d}\sqrt{\frac{p_3}{C_a R_{eH}}} \quad \text{mm}$$

where: α_p— correction factor of aspect ratio of plate panel:

$\alpha_p = 1.2 - \frac{s}{2100 l_p}$, but is not to be taken greater than 1.0;

s— stiffener spacing, in mm;

l_p— length of plate panel, to be taken as the spacing of primary support members or intercostal members of plate panel, in m;

p_3— impact pressure at the calculation point, see 2.5.4;

C_a— permissible plate bending stress coefficient, to be taken as 1.0; For CSR oil tankers, it is to be taken as 1.05;

C_d— plate capacity correction coefficient, to be taken as 1.2.

(2) Stiffeners on wash bulkheads

The net plastic section modulus, Z_{P-net}, of stiffeners on wash bulkheads is not to be less than:

$$Z_{P-net} = \frac{p_3 s l_{bdg}{}^2}{f_{bdg} C_s R_{eH}} \quad \text{cm}^3$$

where: p_3— impact pressure at the calculation point, see 2.5.4;

s — stiffener spacing, in mm;

l_{bdg} — effective bending span of stiffeners, in m;

C_s — permissible bending stress coefficient, to be taken as 0.9; For CSR oil tankers, it is to be taken as 0.95;

f_{bdg} — bending moment factor, to be taken as 16.

(3) Stringers

The net section modulus, Z_{net}, of stringers on wash bulkheads in the tank is not to be less than:

$$Z_{net} = 1000 \frac{p_3 S l_{bdg}^{\ 2}}{f_{bdg} C_s R_{eH}} \quad \text{cm}^3$$

where: p_3 —impact pressure at the height of stringer, see 2.5.4;

S — spacing of primary support members, in m;

l_{bdg} — effective bending span of primary support members, in m;

f_{bdg} — bending moment factor:

$f_{bdg} = 12$, for primary support members with both ends constrained and subjected to uniformly distributed loads;

C_s — permissible bending stress coefficient, to be taken as 0.7; For CSR oil tankers, it is to be taken as 0.75.

The net shear area, A_{net}, of stringers on wash bulkheads in the tank is not to be less than:

$$A_{net} = 10 \frac{f_{shr} p_3 S l_{shr}}{C_t \tau_{eH}} \quad \text{cm}^2$$

where: f_{shr} — shear force factor:

$f_{shr} = 0.5$, for primary support members with both ends constrained and subjected to uniformly distributed loads;

p_3 —impact pressure at the height of stringer, see 2.5.4;

S — spacing of primary support members, in m;

l_{shr} — effective shear span of primary support members, in m;

$\tau_{eH} = R_{eH} / \sqrt{3}$ N/mm^2;

C_t — permissible shear stress coefficient, to be taken as 0.7; For CSR oil tankers, it is to be taken as 0.75.

(4) Vertical girders

The net section modulus, Z_{net}, of vertical girders on wash bulkheads in the tank is not to be less than:

$$Z_{net} = 1000 \frac{p_3 S l_{bdg}^{\ 2}}{f_{bdg} C_s R_{eH}} \quad \text{cm}^3$$

where: p_3 —impact pressure on vertical girders, to be taken as the maximum value of calculation results within the range of impact action, see 2.5.4;

S — spacing of primary support members, in m;

l_{bdg} — effective bending span of primary support members, in m;

C_s — permissible bending stress coefficient, to be taken as 0.7; For CSR oil tankers, it is to be taken as 0.75;

For the top of vertical girders:

$$f_{bdg} = 12 \frac{l_{bdg}^4}{(l_{bdg} - b)^3 (l_{bdg} + 3b)};$$

For the bottom of vertical girders:

$$f_{bdg} = 12 \frac{l_{bdg}^4}{(l_{bdg} - b)^2\ (l_{bdg}^2 + 2b l_{bdg} + 3b^2)};$$

b — distance from the top of area under the impact load to the top of effective span of vertical girders.

The net shear area, A_{net}, of vertical girders on wash bulkheads in the tank is not to be less than:

$$A_{net} = 10\frac{f_{shr}p_3 S l_{shr}}{C_t \tau_{eH}} \quad \text{cm}^2$$

where: p_3 —impact pressure on vertical girders, to be taken as the maximum value of calculation results within the range of impact action, see 2.5.4;

S — spacing of primary support members, in m;

l_{shr} — effective shear span of primary support members, in m;

C_t — permissible shear stress coefficient, to be taken as 0.7; For CSR oil tankers, it is to be taken as 0.75;

$\tau_{eH} = R_{eH}/\sqrt{3}$ N/mm^2;

For the top of vertical girders:

$$f_{shr} = \frac{(l_{bdg}-b)^3 l_{bdg} - 0.5(l_{bdg}-b)^4}{l_{bdg}^4};$$

For the bottom of vertical girders:

$$f_{shr} = \frac{(l_{bdg}-b)l_{bdg}^3 - (l_{bdg}-b)^3 l_{bdg} + 0.5(l_{bdg}-b)^4}{l_{bdg}^4};$$

b — distance from the top of area under the impact load to the top of effective span of vertical girders.

3.4.5 Primary support members in the tank

(1) The net thickness, t_{net}, of web of primary support members is not to be less than:

$$t_{net} = \frac{0.0158\alpha_p s}{C_d}\sqrt{\frac{p_3}{C_a R_{eH}}} \quad \text{mm}$$

where: α_p — correction factor of aspect ratio of plate panel:

$\alpha_p = 1.2 - \frac{s}{2100 l_p}$, but is not to be taken greater than 1.0;

s — stiffener spacing, in mm;

l_p — length of plate panel, to be taken as the spacing of primary support members or intercostal members of plate panel, in m;

p_3 — impact pressure at the calculation point, see 2.5.4;

C_a — permissible plate bending stress coefficient, to be taken as 1.0; For CSR oil tankers, it is to be taken as 1.05;

C_d — plate capacity correction coefficient, to be taken as 1.2.

(2) The net plastic section modulus, Z_{P-net}, of web stiffeners of primary support members in the tank is not to be less than:

$$Z_{P-net} = \frac{p_3 s {l_{bdg}}^2}{f_{bdg} C_s R_{eH}} \quad \text{cm}^3$$

where: p_3 — impact pressure at the calculation point, see 2.5.4;

s — stiffener spacing, in mm;

l_{bdg} — effective bending span of stiffeners, in m;

C_s — permissible bending stress coefficient, to be taken as 0.9; For CSR oil tankers, it is to be taken as 0.95;

f_{bdg} — bending moment factor, to be taken as 16.

Appendix 1　Direct Calculation of Sloshing Loads

1　Basic principles

The volume of fluid method is used in this Appendix for direct calculation of sloshing loads of cargo tanks, in association with the following assumptions:

(1) the fluid is non-compressible and viscous;

(2) free surface exists in fluid motion and no loss of fluid in tanks occurs during the motion;

(3) temperature change is not taken into consideration.

2　Sloshing calculation program

CCS software for direct calculation of sloshing is employed for the calculation of sloshing loads and motion. The examples of software input and output and basic requirements for modeling are given in this Appendix while detailed procedures may be referred to in the relevant program manual.

(1) Input

Software input includes geometric scantling (as shown in Figure A1) and excitation parameters (as shown in Figure A2) of the target tank.

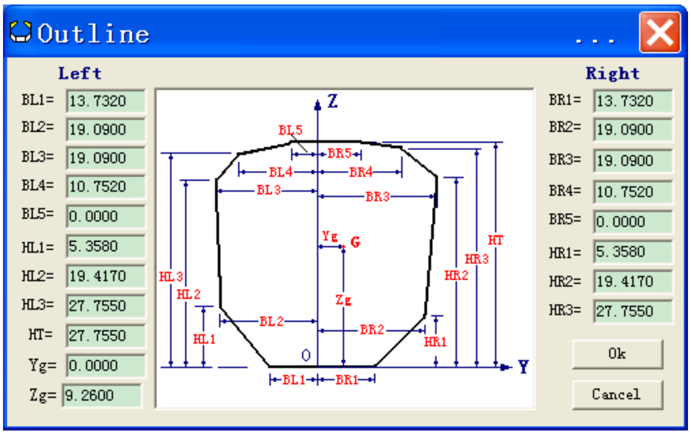


Figure A1　Setting of geometric scantling of tank

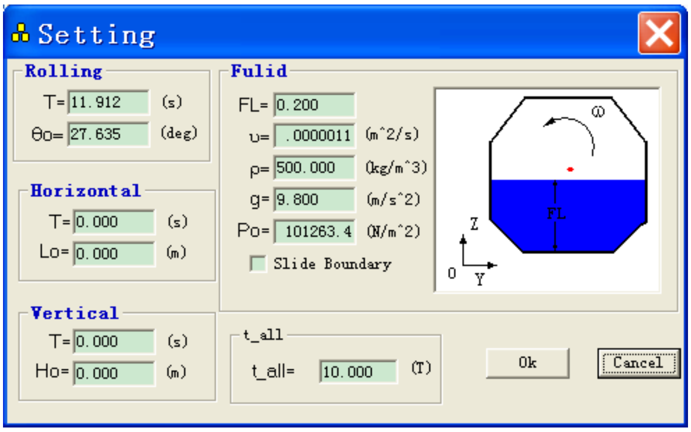
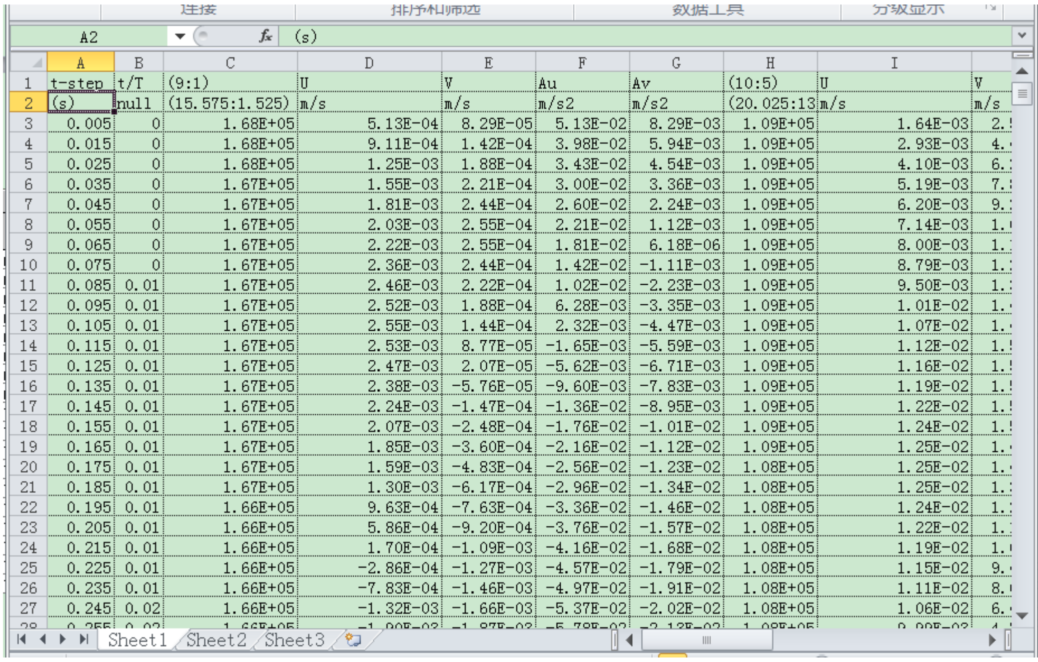


Figure A2　Setting of excitation parameters of tank

(2) Output

Software output may include speed of measuring point, time-history data of acceleration and pressure time-history data after dynamic amplification, as shown in Figure A3.



	A	B	C	D	E	F	G	H	I	
1	t-step	t/T	(9:1)	U	V	Au	Av	(10:5)	U	V
2	(s)	null	(15.575:1.525)	m/s	m/s	m/s2	m/s2	(20.025:13	m/s	m/s
3	0.005	0	1.68E+05	5.13E-04	8.29E-05	5.13E-02	8.29E-03	1.09E+05	1.64E-03	2.
4	0.015	0	1.68E+05	9.11E-04	1.42E-04	3.98E-02	5.94E-03	1.09E+05	2.93E-03	4.
5	0.025	0	1.68E+05	1.25E-03	1.88E-04	3.43E-02	4.54E-03	1.09E+05	4.10E-03	6.
6	0.035	0	1.67E+05	1.55E-03	2.21E-04	3.00E-02	3.36E-03	1.09E+05	5.19E-03	7.
7	0.045	0	1.67E+05	1.81E-03	2.44E-04	2.60E-02	2.24E-03	1.09E+05	6.20E-03	9.
8	0.055	0	1.67E+05	2.03E-03	2.55E-04	2.21E-02	1.12E-03	1.09E+05	7.14E-03	1.
9	0.065	0	1.67E+05	2.22E-03	2.55E-04	1.81E-02	6.18E-06	1.09E+05	8.00E-03	1.
10	0.075	0	1.67E+05	2.36E-03	2.44E-04	1.42E-02	-1.11E-03	1.09E+05	8.79E-03	1.
11	0.085	0.01	1.67E+05	2.46E-03	2.22E-04	1.02E-02	-2.23E-03	1.09E+05	9.50E-03	1.
12	0.095	0.01	1.67E+05	2.52E-03	1.88E-04	6.28E-03	-3.35E-03	1.09E+05	1.01E-02	1.
13	0.105	0.01	1.67E+05	2.55E-03	1.44E-04	2.32E-03	-4.47E-03	1.09E+05	1.07E-02	1.
14	0.115	0.01	1.67E+05	2.53E-03	8.77E-05	-1.65E-03	-5.59E-03	1.09E+05	1.12E-02	1.
15	0.125	0.01	1.67E+05	2.47E-03	2.07E-05	-5.62E-03	-6.71E-03	1.09E+05	1.16E-02	1.
16	0.135	0.01	1.67E+05	2.38E-03	-5.76E-05	-9.60E-03	-7.83E-03	1.09E+05	1.19E-02	1.
17	0.145	0.01	1.67E+05	2.24E-03	-1.47E-04	-1.36E-02	-8.95E-03	1.09E+05	1.22E-02	1.
18	0.155	0.01	1.67E+05	2.07E-03	-2.48E-04	-1.76E-02	-1.01E-02	1.09E+05	1.24E-02	1.
19	0.165	0.01	1.67E+05	1.85E-03	-3.60E-04	-2.16E-02	-1.12E-02	1.09E+05	1.25E-02	1.
20	0.175	0.01	1.67E+05	1.59E-03	-4.83E-04	-2.56E-02	-1.23E-02	1.08E+05	1.25E-02	1.
21	0.185	0.01	1.67E+05	1.30E-03	-6.17E-04	-2.96E-02	-1.34E-02	1.08E+05	1.25E-02	1.
22	0.195	0.01	1.66E+05	9.63E-04	-7.63E-04	-3.36E-02	-1.46E-02	1.08E+05	1.24E-02	1.
23	0.205	0.01	1.66E+05	5.86E-04	-9.20E-04	-3.76E-02	-1.57E-02	1.08E+05	1.22E-02	1.
24	0.215	0.01	1.66E+05	1.70E-04	-1.09E-03	-4.16E-02	-1.68E-02	1.08E+05	1.19E-02	1.
25	0.225	0.01	1.66E+05	-2.86E-04	-1.27E-03	-4.57E-02	-1.79E-02	1.08E+05	1.15E-02	9.
26	0.235	0.01	1.66E+05	-7.83E-04	-1.46E-03	-4.97E-02	-1.91E-02	1.08E+05	1.11E-02	8.
27	0.245	0.02	1.66E+05	-1.32E-03	-1.66E-03	-5.37E-02	-2.02E-02	1.08E+05	1.06E-02	6.

Figure A3　Output of calculation results

(3) Modeling principles

① The boundary is to be so set as to be close to the actual geometric shape of tank insofar as practicable. Z axis is to be set in the middle area of the horizontal direction of tank insofar as practicable, see Figure A4.

② The internal member is added by inputting the end coordinates of members. The grid cells are to be so divided that the internal members are close to the boundary of grid cells insofar as practicable. The pressure output method in way of internal members is the same as that of common solid wall boundary, see Figure A5.

③ The grid cells are to be so divided that the aspect ratio is close to 1 insofar as practicable.

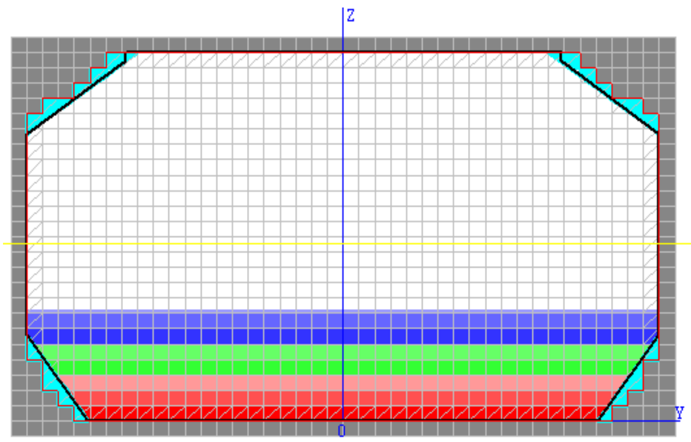


Figure A4　Grid cells in sloshing calculation

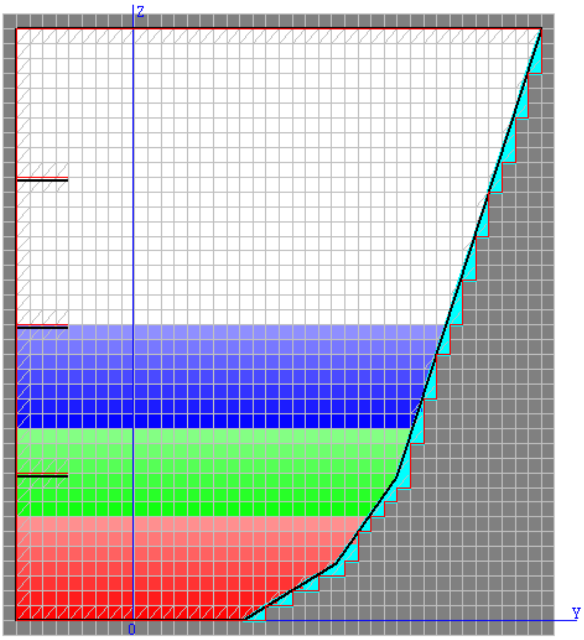


Figure A5 Modeling and division of grid cells

Appendix 2 Example of Application

The process of sloshing load calculation and scantling assessment of tank may consist of three steps, see Figure B1. The calculation process is illustrated below by taking an oil tanker of 27,000 t and a membrane tank LNG carrier as an example.

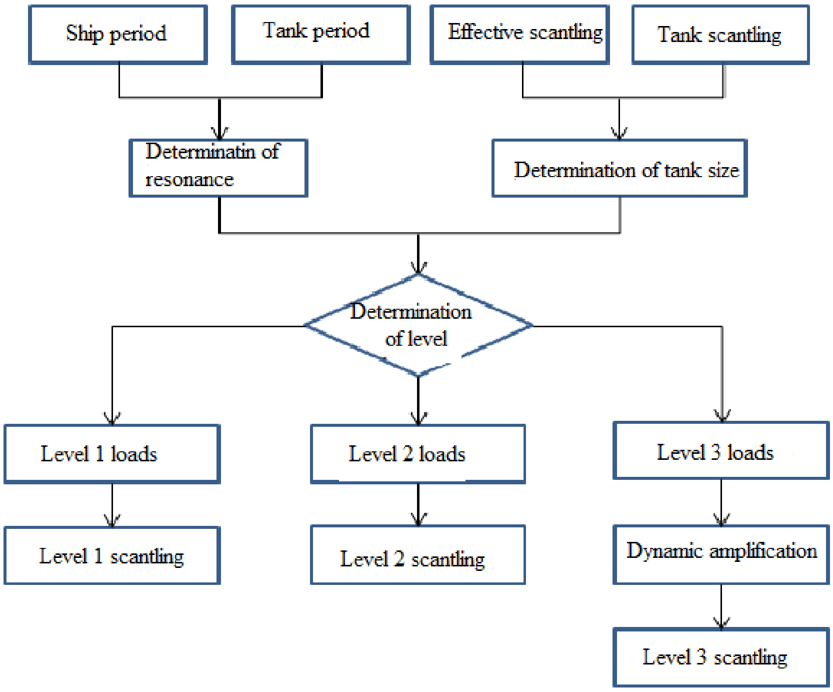


Figure B1 Calculation process

1 Ship type data

1.1 The principal dimension and main parameters of tank of an oil tanker of 27,000 t are given in Table 1.1.

Principal dimension of an oil tanker of 27,000 t Table 1.1

Parameter	Unit	Value
Length of ship	m	168
Breadth of ship	m	27
Full load draught	m	9.2
Ballast draught	m	6.4
Block coefficient	-	0.84
Design speed	knot	14
Length of tank	m	21.6
Breadth of tank	m	11.62
Depth of tank	m	12.42

1.2 The principal dimension and main parameters of tank of a membrane tank LNG carrier are given in Table 1.2.

Principal dimension of a membrane tank LNG carrier Table 1.2

Parameter	Unit	Value
Length of ship	m	266
Breadth of ship	m	43.5
Full load draught	m	12.3
Ballast draught	m	9.4

2 Determination of sloshing level

2.1 Longitudinal sloshing of an oil tanker of 27,000 t

2.1.1 Determination of tank size

$$l / L = 0.129 < 0.13$$

According to the criteria for determining tank size, it is a small tank.

2.1.2 Determination of resonance level

The calculation results of period and amplitude of ship motion in full load and ballast conditions are given in Table 2.1.2(1).

Period and amplitude of ship motion Table 2.1.2(1)

Full load		Ballast	
Period/s	Amplitude/°	Period /s	Amplitude /°
11.36	11.33	10.46	11.33

The calculation results of tank natural period for different filling levels are given in Table 2.1.2(2).

Tank natural period for different filling levels Table 2.1.2(2)

Filling level	Period/°	Filling level	Period/°
5%	17.52	55%	6.04
10%	12.44	60%	5.90
15%	10.23	65%	5.79
20%	8.94	70%	5.70
25%	8.09	75%	5.62
30%	7.48	80%	5.56
35%	7.03	85%	5.51
40%	6.69	90%	5.47
45%	6.42	95%	5.43
50%	6.21		

According to the criteria for determining sloshing level, 10%~30% are level 2 sloshing while the remaining are level 1 sloshing.

2.2 Transverse sloshing of a membrane tank LNG carrier

2.2.1 Determination of tank size

$$b_s / B = 0.87 > 0.56$$

According to the criteria for determining tank size, it is a big tank.

2.2.2 Determination of resonance level

By calculating the results of ship motion period in full load and ballast conditions and tank natural period for different filling levels, and according to the criteria for determining sloshing level, the filling levels of 10%~70% are level 3 sloshing under the condition of not restricting the load,

3 Calculation of sloshing loads

3.1 Longitudinal sloshing of an oil tanker of 27,000 t

3.1.1 Level 1 sloshing loads

According to the level 1 calculation formula, the increased calculation head and load of level 1 calculation loads due to the rise of surface are as follows:

$$h_{level1} = 2.164 \quad \text{m}$$

$$P_{level1} = 21.74$$

3.1.2 Level 2 sloshing loads

According to the level 2 calculation formula, level 2 calculation loads (excluding static pressure) are given in Table 3.1.2.

Level 2 sloshing loads Table 3.1.2

Filling level	Head/m	Pressure/kPa
10%	3.45	34.67
15%	6.67	67.06
20%	7.40	74.43
25%	6.34	63.72
30%	5.61	56.38

3.2 A membrane tank LNG carrier

3.2.1 Level 1 sloshing loads

According to the level 1 calculation formula, level 1 calculation loads are obtained.

3.2.2 Level 2 sloshing loads

According to the level 2 calculation formula, level 2 calculation loads are obtained.

3.2.3 Level 3 sloshing loads

Level 3 pressure is calculated by taking the transverse sloshing of a tank of a membrane tank LNG carrier with filling level of 25% as an example. Tank type, grid cells and measuring point setting is shown in Figure B2. The parameter setting is given in Table 3.2.3(1). Taking plating as an example, the results of p_3 are given in Table 3.2.3(2).

Scantling and motion parameters of tanks Table 3.2.3(1)

Parameter	Definition	Unit	Value
l	Length	m	47.7
b	Breadth	m	38.2
h	Depth	m	27.8
hu	Height of topside tank sloped plating	m	8.3
γu	Angle of topside tank sloped plating	deg	135
hd	Height of hopper tank sloped plating	m	5.4
γb	Angle of hopper tank sloped plating	deg	135
fl	Filling level	-	25%
ρ	Liquid density	t/m^3	0.5
T	Excitation period	s	11.9
θ	Excitation amplitude	deg	27.6

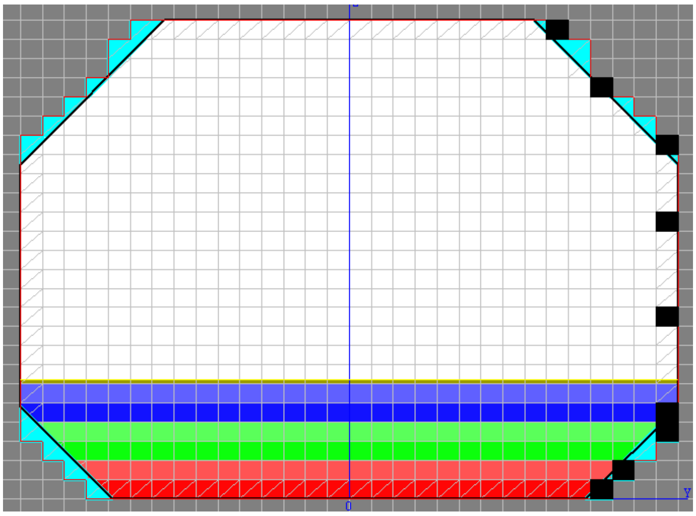


Figure B2 Diagram of tank

Calculation results of level 3 pressure Table 3.2.3(2)

Height of measuring point	Amplification coefficient	Pressure/kPa
2%	1.007	201.1
6%	1.000	194.2
14%	1.052	231.8
18%	1.074	270.8
38%	1.000	250.5
58%	1.099	153.8
74%	1.000	70.6
86%	1.000	0
98%	1.000	0

4 Calculation of boundary scantling

4.1 Longitudinal sloshing of an oil tanker of 27,000 t

According to the assessment method of tank structural members under levels 1 and 2 sloshing loads, the thickness of transverse bulkhead plating is given in Table 4.1 (taking the thickness of bulkhead plating as an example).

Calculation results of transverse bulkhead plating Table 4.1

Calculation height (m)	Thickness of face plate of transverse corrugated bulkhead (mm)	Thickness of web of transverse corrugated bulkhead (mm)
0	14.8	13.9
0.509	14.5	13.6
2.068	13.5	12.7
4.57	11.8	11.1
6.729	11.3	10.6
10.237	11.3	10.6

4.2 Transverse sloshing of a membrane tank LNG carrier

According to the assessment method of tank structural members under level 3 sloshing loads and at 25% filling level, the required values for thickness of longitudinal bulkhead plating are given in Table 4.2 (taking the thickness of bulkhead plating as an example).

Calculation results of level 3 transverse bulkhead plating Table 4.2

Calculation height	Thickness of inner shell plating (mm)
2%	11.6
6%	11.4
14%	11.5
18%	12.4
38%	12.0
58%	9.4
74%	6.4
86%	0.0
98%	0.0