CHINA CLASSIFICATION SOCIETY

Guidelines for Direct Strength Analysis Of Oil Tanker

2003

Contents

Chapter 1 General

1.1 Applications

1.1.1 For oil tankers of 190 m or more in length or of the structural configuration other than those as specified in the Rules and Regulations for the Construction and Classification of Sea-going Steel Ships (hereinafter referred to as the Rules) of CCS, direct strength analysis of hull structure ate to be carried out in accordance with the Guidelines.

1.1.2 The Guidelines present detailed requirements and methods for direct strength analysis of primary structural members of oil tankers.

1.1.3 The structural FE model and applied loads are to be capable of fully reflecting the following re- sponses of the structure resulting from the local loads and the global longitudinal bending moment;

(1) stresses of longitudinal members；

(2) stresses 0f primary transverse members， including transverse bulkheads；

(3) buckling of primary members.

1.1.4 In general. the scantlings of primary members ate to satisfy the requirements of the Rules； otherwise. it should be approved by the Society.

1.1.5 Documents 0f direct strength analysis submitted for approval：

(1) list of drawings used；

(2) detailed description of FE model of hull structure；

(3) verification of the structural model and relevant physical properties；

(4) materials；

(5) detailed description of boundary conditions；

(6) details of applied loads；

(7) figures and results showing responses of loads—related with structural FE model；

(8) summary， including figures， of the global and local deformations；

(9) summary， including figures， showing von Mises stress， stresses in X and y directions， and shear stresses of all structural members in compliance with the strength criteria；

(10) analysis and results of plate buckling；

(11) proposed structure modifications， including yielding and buckling strength， if necessary.

1.2 Definition

1.2.1 Units

Mass： t；

Length： m：

Time： s；

Force： N or kN；

Stress： N/mm^2；

Pressure：kN / m^2

1.2.2 Symbols

L——length 0f ship，in m，as defined in Section 1，Chapter 1，Part two of the Rules；

B——breadth of ship，in m，as defined in Section 1，Chapter 1，Part two of the Rules；

D——moulded depth，in m，as defined in Section 1，Chapter 1，Part two of the Rules；

d——draft，in m，as defined in Section 1，Chapter 1，Part two of the Rules；

C_b——block coefficient，as defined in Section 1，Chapter 1，Part two 0f the Rules；

$V.$——speed，in kn；

g——gravitational acceleration，g=9.81m / s^2；

C_ω——wave coefficient；

ρ——seawater specific gravity，ρ =1.025t / m^3；

σ_e——von Mises stress (N / mm^2)，$=\sigma_x^2+\sigma_y^2-\sigma_x\sigma_y+3\tau_{xy}^2$

σ_x——stress of element in x direction (N / mm^2)；

σ_y——stress of element in y direction (N / mm^2)；

τ_{xy}——shear stress of element in xy planes (N / mm^2)；

σ_1——stress in longitudinal direction of hull girder (N / mm^2)；

σ_w——stress in transverse or vertical direction of hull girder (N / mm^2)；

τ——shear stress：taken by the average shear stress of full depth of the web for girders and floors (N / mm^2)；

k——material conversion factor：

E——elastic modulus of material，$E=2.06\times10^5$ N / mm^2 for steel；

μ——Poisson's ratio of material，μ =0.3 for steel.

Chapter 2　Direct Loads Analysis

2.1　Applications

2.1.1　While at sea，ships are subjected to wave—induced load，in addition to buoyancy，cargo loads and corresponding inertial 10ads.This section defines the basic principles for calculation of still water loads and wave loads.

2.1.2　The still water loads and wave loads may be calculated by the codes approved by the Society.

2.2　Still water loads

2.2.1　Weight distribution curve
Break up the weight of various items (hull steel，equipments，fittings and cargoes) along ship's length into the trapezoid weight distribution blocks and superimpose the blocks to form weight distribution curve w(x) in the given conditions.

2.2.2　Buoyancy curve
In the balanced floating condition of the ship，the buoyancy of the ship in still water can be determined by the draft. Therefore the buoyancy curve *b*(x) along ship's length can be obtained based on the ship's lines.

2.2.3 Shear and bending moment curves
The still water shear force N_s(x) and still water bending moment M_s(x)acting on hull girder are obtained from following equations：

$$N_s(x)=\int_0^x[w(x)-b(x)]dx \quad \text{kN}$$

$$M_s(x)=\int_0^x N_s(x)\bullet dx=\int_0^x\int_0^x[w(x)-b(x)]dx \quad \text{kN.m}$$

As both fore and aft ends of the hull are free ends, the shear and bending moment curves are to be corrected while shear force and bending moment at end points are not equal to zero.

2.3　Wave loads

2.3.1　Applications
The methods recommended in this section are applied to the ships of：

L≤500m

L/D≤17

2.3.2　Methods and assumed conditions

(1)　Wave loads may be calculated by two-dimensional strip theory or three-dimensional theory.

(2)　Sea conditions：

①　The P-M spectrum is recommended，described by the following expression：

$-\frac{\pi}{2} \le \theta \le \frac{\pi}{2}$

θ as other value

$$S(\omega, H_{\frac{1}{3}}, T_2, \theta) = \begin{cases} \frac{2}{\pi} 124 H_{1/3} T_2^{-4} \omega_2^{-5} \exp(-\frac{496}{T_2^4 \omega^4}) \cos^2\theta & -\frac{\pi}{2} \le \theta \le \frac{\pi}{2} \\ 0 & \theta \text{ as other value} \end{cases}$$

where：θ——relative spreading around the main wave leading，in rad；

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

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

T_2——the average zero up—crossing wave period，in s；

ω——angular wave circular frequency，in rad / s.

② For making a long—term prediction of wave loads，the distribution of wave height for each period is assumed as Rayleigh distribution and all wave headings can be assumed to have an equal probability of occurrence.

(3) Speed is assumed as 0 knot when calculating wave bending moment and as 2/3 the ship's design speed when calculating wave pressure.

(4) Exceedance probability level is taken as 10^{-8} when calculating wave bending moment and as 10^{-4} when calculating wave pressure.

2.3.3 Ship's roll radius of gyration and critical roll damping coefficient：

For design of the ship，the roll radius of gyration may be taken as：0.35 B (full load)

0.32 B (ballast)

the critical roll damping coefficient may be taken as： 0.10

2.3.4 Wave loads

(1) Vertical wave bending moment M_V and shear force F_v

Base on the above method and definitions，the vertical wave bending moment M_w in way of mid-ship section can be obtained，and the design wave bending moment M_v along ship's length obtained from the following equations：

hogging $M_V(+) = M \bullet C_{HB} \bullet M_W$ kN.m

sagging $M_V(-) = M \bullet C_{SB} \bullet M_W$ kN.m

where: M_W — vertical bending moment in way of mid ship section by the codes，in kN·m；

M—distribution factor of bending moment along ship's length，generally by the Rules；

C_{HB}, C_{SB}—nonlinear correction coefficient，to be obtained from the following equations：

$$C_{SB} = \frac{110(C_b + 0.7)}{95C_b + 55(C_b + 0.7)}$$

$$C_{HB} = \frac{190C_b}{95C_b + 55(C_b + 0.7)}$$

where: C_b——block coefficient, but not less than 0.6.

The vertical wave shear force F_w is to be obtained by the codes, so the design vertical wave shear force F_v along ship's length can be obtained from following equations:

Hogging $F_V(+) = F_1 C_S F_W$ kN

Sagging $F_V(-) = -F_2 C_S F_W$ kN

Where : F_w——vertical wave shear force in way of mid-ship section, to be obtained by the codes, in kN;

F_1, F_2——distribution factor of shear force, to be obtained by the Rules;

C_s——correction coefficient, to be determined by Table 2.3.4.

Correction Coefficient C_s **Table 2.3.4**

Ship's length (m)	C_s	Ship's length (m)	C_s	Ship's length (m)	C_s	Ship's length (m)	C_s
90	1.5212	200	1 2727	320	1.3348	420	1.3471
100	1.4573	220	1.2771	340	1.3474	440	1 3536
120	1.3705	240	1.2870	350	1.3313	460	1.3604
140	1.3190	260	1.3003	360	1.3327	480	1.3674
160	1.2900	280	1.3152	380	1.3365	500	1.3743
180	1.2760	300	1.3276	400	1.3414		

Chapter 3 Calculation of Sloshing Load of Tanks and Strength Analysis of Structures

3.1 Applications

3.1.1 This Chapter provides the method of strength analysis of tank structure under sloshing pressure caused by liquid movement in partially loaded cargo tanks.

3.1.2 The partial loading given in this section means the cargo tank loading condition with the filling ratio f less than 0.95.The filling ratio is to be determined as following equation：

$$f = \frac{d_f}{h_f}$$

where: d_f —liquid height in cargo tank，measured from inner bottom to liquid surface，in m；

h_f — depth of cargo tank，measured from inner bottom of tank to lower edge of deck at center line of tank，in m；for double side skin cargo tanks with a hatch coaming which extended from inner skin plane，the depth of tank is measured form inner bottom to top of hatch coaming，in m.

3.1.3 When the scantling of the following structural members is determined in accordance with the Rules，the pressure due to liquid sloshing is to be taken into account as an additional load：

(1) side structure of tank with a free surface width $b_s > 0.56B$；

(2) strength members of deck within 0.25 b_b from side longitudinal bulkhead of tank when filling height (measured from bottom of tank to liquid surface) is unlimited，and deck structures without longitudinal swash bulkhead and with a free surface width $b_s > 0.56B$，in the tanks of with greater than 0.4B and bounded by deck：

(3) strength members of deck within $0.25l_b$ from top of tank when filling height is unlimited. and deck structures with out transverse web frames in narrow or transverse swash bulkhead and deck structures without transverse web frames in narrow tank or transverse swash bulkhead and with a free surface length $l_b > 0.13L$, in the tanks of length greater than 0.1Land bounded by deck;

(4) strength members of bulkhead within $0.25b_b$ from both sides in tanks where filling height is unlimited，and bulkhead structure of tanks without longitudinal swash bulkhead and With a free surface width $b_b > 0.56B$；

(5) strength members of bulkhead within $0.25l_b$ from both end bulkheads in tanks where filling height is unlimited，and bulkhead structures of the tanks without transverse web frames in narrow or transverse swash bulkhead and with a free surface length $l_b > 0.13L$.

Where：

For b_s, see 3.3.1.

b_b is the distance between side bulkheads or the effective longitudinal swash bulkheads ($a_l < 0.2$) in tanks where the strength member is located, in m;

l_b is the distance between transverse bulkheads or the effective transverse swash bulkheads (a_t <0.2) in tanks where the strength member is located, in m. The transverse web frame covering a part of cross section of tank, such as wing tank structures of oil tankers) may be considered as transverse swash bulkhead.

a_t and a_l are as defined in 3.3.1

3.1.4 In addition to the method given in this Chapter, other appropriate methods may be used to calculate liquid sloshing pressure and liquid impact pressure, subject to the provision of reliability information of calculations accepted by the Society.

3.2 Sloshing period

3.2.1 The resonance of liquid movement in a tank may be identified when the ratio of the natural period of liquid in the tank to the period of ship motion is greater than 0.7.

3.2.2 The natural period of liquid in tank is to be determined from the following equations:

Longitudinal natural period T_x:

$$T_x = \frac{2\pi}{\sqrt{\frac{g\pi}{l_t} th \frac{\pi d_f}{l_t}}} \quad \text{s}$$

Transverse natural period T_y:

$$T_y = \frac{2\pi}{\sqrt{\frac{g\pi}{b_t} th \frac{\pi d_f}{b_t}}} \quad \text{s}$$

where: l_t——length of liquid free surface under still condition, in m;

b_t——width of liquid free surface under still condition, in m.

3.2.3 The period of ship motion is to be determined from the following equations:

Pitching period T_φ:

$$T_\varphi = \frac{L}{1.33\sqrt{L} + 0.58VK_v} \quad \text{s}$$

where: L——ship's length, in m;

V—speed, in kn;

K_v——speed loss coefficient, to be determined from the equation below:

$$K_v = 1 - \frac{750}{100 + L}$$

Pitching period T_φ :

$$T_{\varphi} = 0.58\sqrt{\frac{B^2 + 4KG^2}{GM}} \quad \text{s}$$

where：B——ship's breadth，in m；

GM———initial metacentric height with free surface correction under selected loading condition, in m;

KG ——vertical distance of center of gravity to baseline under selected loading condition, in m..

3.3 Sloshing pressure

3.3.1 For strength members within a distance of less than $0.25l_s$，from transverse swash bulkheads or end bulkheads，the sloshing pressure should not be less than the value obtained by the following formula

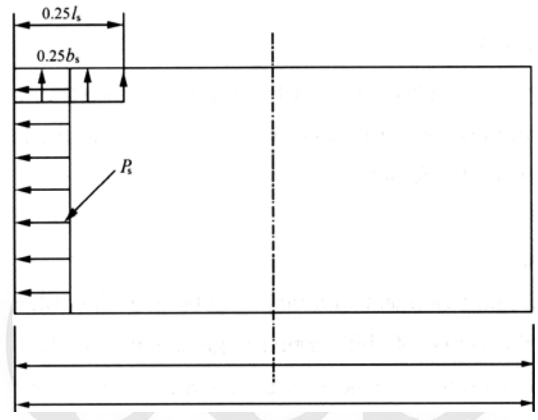


Figure 3.3 (1) Distribution of Pressure

(see Figure 3.3 (1)):

$$P = pg_0 l_s k_f [0.4 - (0.39 - \frac{1.7l_s}{L})] \quad \text{kN/m}^2$$

For strength members within a distance of less than $0.25b_s$,form longitudinal swash bulkheads or side bulkheads, the sloshing pressure should not be less than the value obtained by the following formula:

$$P = 7pg_0 l_s k_f (\frac{b_s}{B} - 0.3) GM^{0.75} \quad \text{kN/m}^2$$

where:

$$k_f = 1 - 2(0.7 - \frac{h}{H})^2, \text{ not exceeding 1}$$

$$(\frac{h}{H})_{\max} = 1$$

h——filling height, in m;

H——height of tank within $0.15l_s$ or $0.15b_s$, in m;

GM ——maximum initial met centric height with free surface correction;

$$GM_{\min} = 0.12B(m)$$

l_s——effective sloshing length, in m, to be obtained as follows:

$$l_s = \frac{(1+n_t a_t)(1+\beta_t n_2)l}{(1+n_t)(1+n_2)} \text{, for end bulkhead;}$$

$$l_s = \frac{[1+a_t(n_t-1)](1+\beta_t n_2)l}{(1+n_t)(1+n_2)}, \quad \text{for swash bulkhead;}$$

b_s ——effective sloshing width, in m, to be obtained as follows:

$$b_s = \frac{(1+n_1 a_l)(1+\beta_t n_4)b}{(1+n_1)(1+n_4)}, \qquad \text{for side bulkheads;}$$

$$b_s = \frac{[(1+a_l(n_l-1)](1+\beta_t n_4)b}{(1+n_l)(1+n_4)} \qquad \text{for swash bulkhead;}$$

l ——length of tank, in m;

b ——width of tank, in m;

n_t ——number of transverse swash bulkheads in tank with correction by $a_t < 0.5$;

a_t ——ratio of openings area on transverse swash bulkhead to total cross-sectional area of tank be- low filling height, see Figure 3.3 (2);

h ; $0.7H$ if filling height is unlimited.

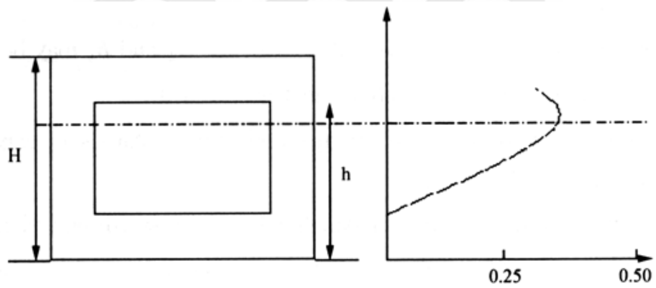


Figure 3.3 (2) Swash Bulkhead Coefficient

n_2 ——number of web transverse rings within length of $\frac{l}{(1+n_t)}$ in tank;

β_t ——ratio of openings area on web transverse ring to total cross-sectional area of tank below filling height, see Figure 3.3. (3)

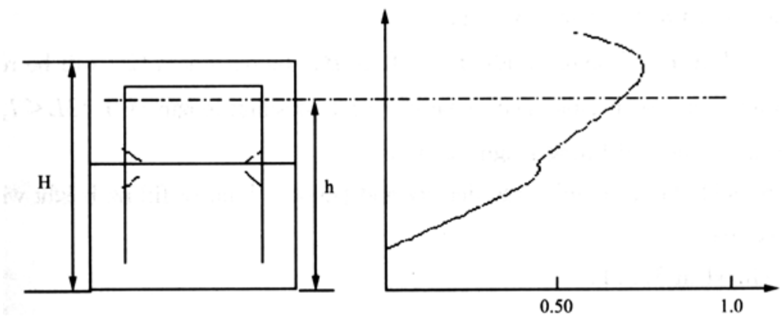


Figure 3.3 (3) Web Transvers Ring Coefficient

h : $0.7H$ if filling height is unlimited.

n_l ——number of longitudinal swash bulkheads in a tank with correction by $a_t < 0.5$;

a_l ——similar to a_t , but with reference to longitudinal swash bulkheads;

n_4 ——number of longitudinal strength web rings within width of $\frac{b}{(1+n_l)}$ in tank;

β_l ——similar to β_t , but with reference to longitudinal strength web ring.

3.3.2 For tanks with $l_b < 0.13L$ and $b_b < 0.56B$, the scantlings of structural members are to be in compliance with the requirements for unlimited filling height.

For strength members within $0.25l_b$ from swash bulkheads and end bulkheads, the pressure should not be less than the value obtained as follows:

$$p = [4 - \frac{L}{200}]l_b \qquad \text{kN / m}^2$$

For strength members within $0.25b_b$ from longitudinal swash bulkheads and side bulkheads, the pres- sure should not be 1ess than the value obtained as follows:

$$p = P[3 - \frac{B}{200}]b_b \qquad \text{kN / m}^2$$

where:

l_b and b_b are as defined in para.3.1.3.

If the swash bulkhead is not fully effective (a_t >0.2, a_l >0.2), l_b and b_b may be replaced with l_s , and b_s , given in para.5.1.2. a_t and a_l are as defined in para. 3.3.1.

3.3.3 The minimum sloshing pressure on web frames and stringer panels in cargo tanks and ballast/cargo tank should not be less than 20 kN / m^{2}.

The sloshing pressure on web framings or stringer panels adjacent to swash end plate or end bulkhead in long or wide tanks with many web rings or stringer panels is to be determined as following equations:

$$P = P_{bhd}\ (1 - \frac{s}{l_s})^2 \quad \text{kN / m}^2, \quad \text{for web ring;}$$

$$P = P_{bhd}\,(1 - \frac{s}{b_s})^2 \quad \text{kN / m}^2, \quad \text{for stringers;}$$

where: P_{bhd} ——sloshing pressure acting on swash bulkheads or end bulkheads as given in 3.3.1:

s ——distance from bulkhead to strength web ring or girder of member, in m;

b_s and l_s , are as defined in para. 3.3.1.

3.3.4 For tanks with a free sloshing width of b_s >0.56B, the maximum GM will be restricted by the specific value. In addition, such tanks and / or tanks with a sloshing length of $0.13L < l_s < 0.16L$ may be designed according to limited filling height of tanks.

The maximum permissible GM , liquid cargo density and possible limit of filling height will be indicated in the Operation Manual.

b_s and l_s are as defined in 3.3.1.

Chapter 4 Design Loads

4.1 Liquid cargo pressure

The Liquid cargo pressure in tank is to be obtained from the following equations：

$$P = \rho_o g(h + 2.5) \qquad \text{kN/m}^2$$

where： ρ_o ——density of liquid cargo in tank，but not less than 0.85 t / m^3；

h ——vertical distance from tank top to the point considered. in m.

4.2 External sea pressure

The external water pressure may be determined by direct calculations as required in 2.3 or by either of the following methods：

4.2.1 Method 1

(1) Full loading condition

External water pressure includes hydrostatic pressure and hydrodynamic wave pressure，and is determined as follows.

At baseline: $P_b = 10_d + 1.5C_w$ kN/m^2

At waterline $P_w = 3C_w$ kN/m^2

At side top: $P_s = 3P_o$ kN/m^2

Hydrodynamic pressure on deck: $P_s = 0.24P_0$ kN/m^2

where：

$P_0 = C_w - 0.67(D - d)$

$C_w = 10.75 - (\frac{300 - L}{100})^{1.5}$ 90m≤L≤300m

where :

$C_w = 10.75$ 300m≤L≤350m

$C_w = 10.75 - (\frac{L - 350}{150})^{1.5}$ 350m≤L≤500m

(2 Other loading conditions

At baseline: $P_b = 10d_a$ kN/m^2

At waterline: $P_w = 0.0$ kN/m^2

where： d_a is actual draft corresponding to the loading condition，in m.

The formula for calculation of hydrodynamic pressure at baseline，waterline and side top are given as above. The external water pressure at other side positions is to be determined by 1inear interpolation.

4.2.2 Method 2

(1) Hydrostatic pressure

At baseline： $P_b = 10d_a$ kN / m^2

At waterline： $P_w = 0.0$ kN / m^2

(2) Hydrodynamic pressure

① hydrodynamic pressure at waterline (kN/m^2)

$$P_{WL} = \frac{f}{4}\max(p_1, p_2)$$

$$p_1 = p_{11} + 135\frac{|\bar{y}|}{B+75} - 1.2(T_1 - Z_w)$$

$$p_{11} = 3k_s C + k$$

$$P_2 = 13[|\bar{y}|\frac{50c}{2(B+75)} + C_B\frac{|\bar{y}|+k_f}{14}(0.7 + 2\frac{Z_w}{T_1})]$$

at waterline $|\bar{y}| = B/2;\ \ Z_w = T_1$

② Hydrodynamic pressure at bilge (kN/m^2)

$$P_{BS} = \frac{f}{4}\max(p_1, p_2)$$

p_1 and p_2 are the same as in the formula for waterline, but $|\bar{y}| = B/2$; $Z_w = 0.0$

③ Hydrodynamic pressure at bottom (kN/m^2)

$$P_B = l_f\frac{f}{4}\max(p_1, p_2)$$

p_1 and p_2 are the same as in the formula for waterline, but $|\bar{y}| = B/4$; $Z_w = 0.0$

④ Hydrodynamic pressure above side waterline:

$$P_{DK-side} = P_{WL} - \frac{h}{2}\bullet\frac{f}{4}$$

where: h ——height from static waterline to load point, in m.

⑤ Dynamic pressure on deck (hatch cover)

$$P_{dk} = 19.6\bullet\sqrt{H}$$

where: $H = 0.14\bullet A_i\bullet\sqrt{\frac{V\bullet L}{C_B}} - d_f$

where: A_i ——coefficient relevant to longitudinal center of hatch cover, to be obtained from Table 4..2.2 (2)⑤

V —— ship's design speed, in kn, but not less than 13kn;

L ——length of ship, in m;

C_B——block coefficient;

d_f——vertical distance from summer load line to top of hatch coaming ,in m

表 4.2.2.2(2)⑤

到首垂线的距离	A_i
FP	2.70
0.05*L*	2.16
O.10*L*	1.70
O.15*L*	1.43
0 20*L*	1 22
0 25*L*	1.00

where : T_l ——draft, in m;

$C = 10.75 - [(300 - L)/100]^{3/2}$ 90m≤L≤300m

$= 10.75$ 300m≤L≤350m

$= 10.75 - [(L - 350)/150]^{3/2}$ 350m≤L≤500m

A_R——roll angle,

$= \frac{0.75c}{B^{0.34}}$;

$c = (1.25 - 0.025\frac{2k_r}{\sqrt{GM}})k$;

k =1.2 (bilge keel not fitted)

=1.0 (bilge keel fitted)

=0.8 (roll damping device provided);

k_r——rolling radius of inertia;

GM ——initial met centric height, in m;

k_r =0.39B (uniform distribution of mass)

=0.35B (under ballast condition)

$GM = 0.12B$;

y——horizontal distance from centerline to load point, $B/4 \le y \le B/2$;

k_v——speed coefficient;

V——minimum service speed, in kn;

f——probability factor

$= 4(10^{-4})$

$= 8(10^{-8})$

$k_s = C_B + \frac{0.83}{\sqrt{C_B}}$ (at and aft of AP)

$= C_B$ (between 0.2L and 0.6L)

$= C_B + \frac{1.33}{C_B}$ (at and forward of FP)

linear variation of ks at specific point;

l_f =1.0 (at and aft of AP)

=0.5 (between 0.2L and 0.6L)

=1.0 (at and forward of FP)

linear variation of if between points designated above.

k_f——Minimum of T_1 or T_f;

T_f——vertical distance from waterline to side top at selected cross section, but not greater than 0.8C.

4.3 Bending moment of end planes

4.3.1 The bending moment applied on end planes of the FE model is to be the actual moment of the planes, including still water bending moment M_s and wave bending moment M_w. When the actual bending moment is not available, alternative one may be taken as 4.3.2-4.3.5.

4.3.2 1he wave bending moment M_w is to be determined in accordance with the Rules, positive as hogging.

4.3.3 Still water bending moment M_s, is to take the maximum bending moment with the extent of the model corresponding to the loading condition. If the condition is not available. the condition under full load draft of maximum (or minimum) bending moment that occurs is to be used as for full load condition, and the condition under non—full load draft of maximum (or minimum) bending moment that occurs is to be used as for non—full load condition, subject to correction according to 4.3.4, positive as hoggig.

4.3.4 The bending moment applied on the end planes of the FE model is composed of the still water bending moment Ms, wave bending moment Mw and corrected bending moment M_γ:

$$M = M_s + M_w - M_r$$

4.3.5 Corrected bending moment M_γ

The corrected bending moment M_r is an additional moment resulting from local load.

(1 When $L_1 \approx L_2 \approx 0.5L_m$ as shown in Figure 5.1,

Q_m as the uniformly distributed linear pressure of middle hold model, and Q_e as the uniformly distributed linear pressure of both end holds, positive in forward direction along Z vertical coordinates:

$$Q_m = P_b \times b - W_{mcagro} / L_m$$

$$Q_e = P_b \times b - W_{ecagro} / L_e$$

where: P_b: external pressure on bottom, in kN/m^2, see 4.2;

W_{mcargo}: cargo weight, including weight of ballast water, in the middle hold, taking half of total weight in the tank for half—breadth model, in kN;

W_{ecargo}: cargo weight in end holds, including weight of ballast water, taking half of total weight in the tank for half—breadth model, in kN;

L_e: length of end tank corresponding to Wecargo, in m;

L_m: length of middle hold, in m;

L_0: overall length of FE model, in m;

b: breadth of mode, b=B/2, when half-breadth model is used, where B is moulded breadth of ship;

$$M_r = \frac{3}{32} \times Q_m L_0^2 + \frac{1}{32} \times Q_e L_0^2 \qquad \text{kN} \cdot \text{m}$$

(2) When $L_1 \neq L_2 \neq 0.5L_m$ as shown in Figure 5.1, the simple beam calculation method may be used. In this case, the pressure may be obtained according to (1), and maximum M_r is to be taken.

Chapter 5 Structural Model

5.1 Coordinate definitions

x——measured in the longitudinal direction，positive forward；

y——measured in the transverse direction，positive to port from the centerline；

z——measured in the vertical direction. positive upwards from the baseline.

5.2 Model meshing

5.2.1 The 3-D FE model is used for direct calculation and analysis of primary members strength of oil tanks. The extent of 1/2 hold length forward and 1 hold length in the middle and 1/2 hold length aft within mid—ship cargo area in longitudinal direction，and full depth of the ship in vertical direction, (see figure 5.1 & 5.2) In general，the results of the middle hold，including bulkhead，are used for strength assessment.

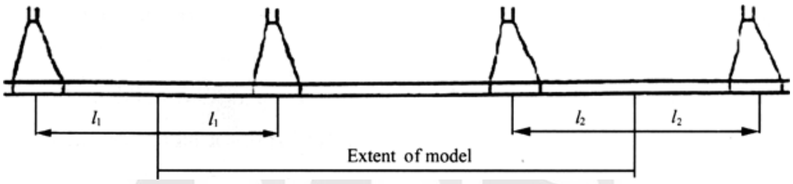


Figure 5.1 Extent of 3-Dimensional Finite Element Model

5.2.2 For oil tankers with two longitudinal bulkheads or without longitudinal bulkhead. while both pri mary members and loads are symmetrical about to longitudinal centerline plane，only half breadth，port or starboard side，of the ship hull is required to be modeled. In case of the asymmetrical loads applied， it can be equivalently divided into symmetrical and anti—symmetrical loads on to the longitudinal center plane (see fig.5.2)，otherwise a full-breadth model is to be required. For oil tankers with one longitudinal bulkhead. a full breadth model is also presented.

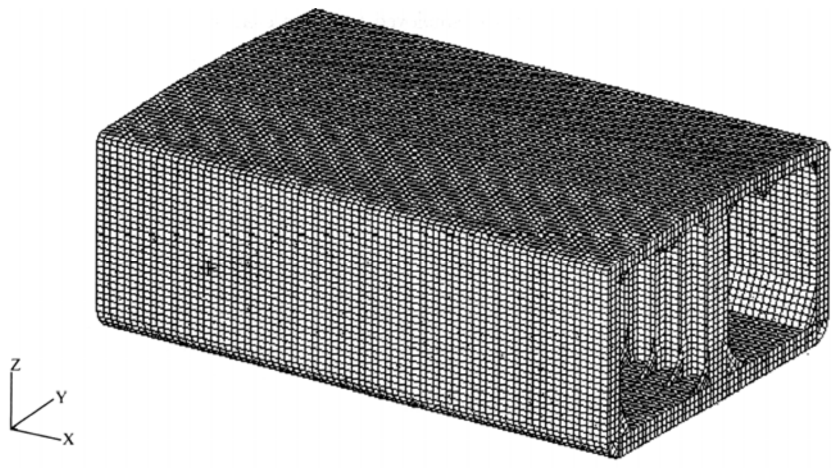


Figure 5.2 Finite Element Model

5.2.3 The meshing of the 3-D FE model of hull structure is to be carried out as the 10ngitudinal spacing or similar spacing transversely along the hull envelop，and the frame spacing or similar spacing along hull length. The meshes are to be as square as possible.

5.2.4 In general，all areas of shell plates，deep webs of transverse tings，stringers. plane bulkhead web stiffeners，frames，other members as well as corrugation bulkheads and bulkhead stools are to be modeled by 4-node plate (shell) elements. Triangular elements are to be minimized. In high stress areas and areas of significant stress changes，such as lightening holes，manholes, connection of stool to bulkhead，positions adjacent to brackets or structural discontinuities，triangular elements are to be avoided as practicable as possible.

5.2.5 All stiffeners of plates, which are subject to external water pressure and cargo pressure，are modeled by eccentric beam elements. The stiffeners and/or face plates of web transverses，frames. floors，girders and brackets may be modeled by rod elements. In view of difficulty in meshing，one line element may represent more than one beam or rod elements in some area.

5.2.6 Not less than 3 plate elements are to be arranged in vertical direction for bottom girders and floors. In general，the elements at the lowest end of bulkhead are to be divided as square as possible.

5.2.7 Corrugated bulkhead and bulkhead stools：each flange plate or web plate is to be taken at 1east as a plate element；for the plate elements at the lower end of corrugated bulkhead in the vicinity of 1ower stool and for the elements adjacent to stool plate，the aspect ratio of sides of grid is to be close to 1.

5.2.8 For lightening holes and manholes of primary members，in particular the openings on girders adjacent to bulkhead and bracket floors adjacent to lower stool in double bottom，plate elements of equivalent plate thickness may be used to consider the effect of these openings.

5.2.9 one independent point is set respectively in way of intersection of neutral axis with longitudinal centerline in fore and aft end planes，and the degree of freedom $\delta_x, \delta_z, \theta_y, \theta_z$ for nodes of longitudinal members in end planes are related to the relevant independent points.

5.2.10 The built scantlings are to be applied for the FE model.

5.2.11 Membrane stress，i.e. mid-surface stress of bending plate element is applied as permissible stress criteria for plate element. Axial stress is employed for beam element.

Chapter 6　Boundary Conditions

6.1　If the load is symmetrical on port and starboard sides，the displacements in transverse direction of nodes on longitudinal centerline plane are constrained. and the rotations about the two coordinate axes on longitudinal centerline plane are constrained，i.e. $\delta_y = \theta_x = \theta_z = 0$.

6.2　If the load is anti—symmetrical on port and starboard sides，the displacements in the directions along the two coordinate axes of the nodes in longitudinal centerline plane are constrained，and the rotations about the coordinate axis perpendicular to longitudinal centerline plane are constrained，i.e. $\delta_x = \delta_z = \theta_y = 0$.

6.3　Constraint of end planes：the independent point at one end constrains $\delta_x, \delta y, \theta_x, \theta_z$， and the independent point at the other end constrains $\delta_y, \delta_z, \theta_x, \theta_z$,， as indicated in Table 6.1.

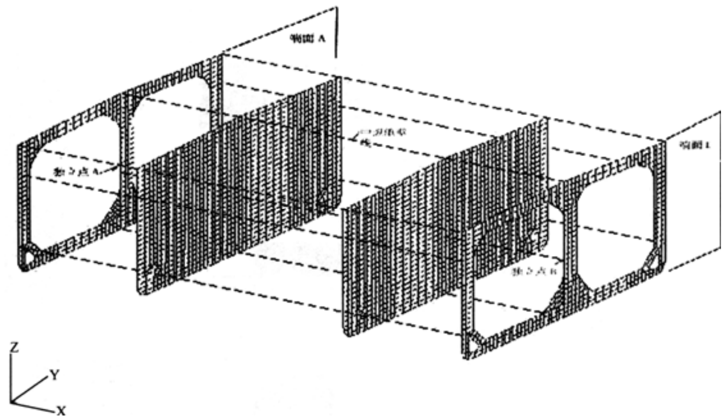


Figure 6.1 Constraint of End P1anes

Application of Boundary Conditions (Boundary with Symmetrical Load**) Table 6.1**

Position	displacement constraint			rotation constraint		
	δ_x	δ_y	δ_z	θ_x	θ_y	θ_z
Longitudinal centerline section	-	Cons..	-	Cons.	-	Cons.
End plane A	Link	-	Link	-	Link	Link
End plane B	Link	-	Link	-	Link	Link
Rigid point A	Cons.	Cons.	Cons.	Cons.	BM	Cons.
Rigid point B	-	Cons.	Cons.	Cons.	BM	Cons.

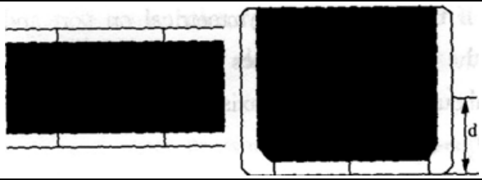
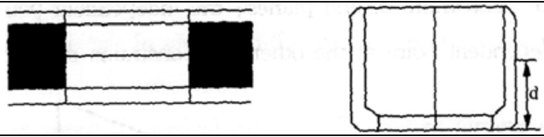
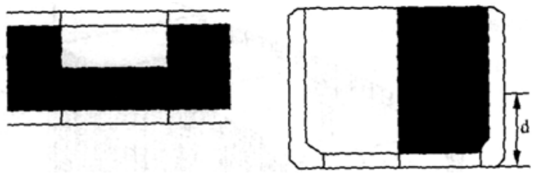
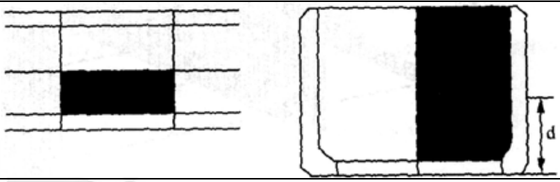
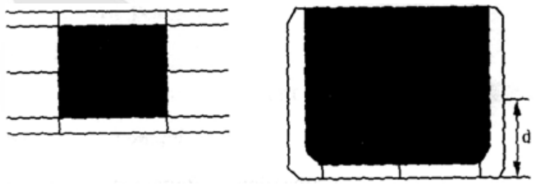
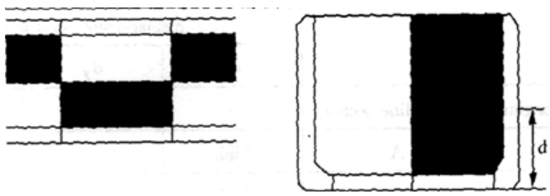
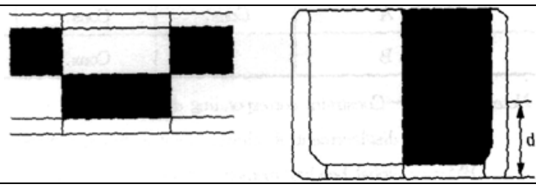
Notes：Cons.——Constraint corresponding displacement；

Link .—— displacemem of relevant point within end plane linked to independent point；

BM ——Global bending moment applied on end plane.

Chapter 7　Loading Conditions

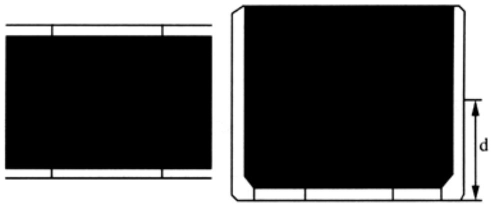
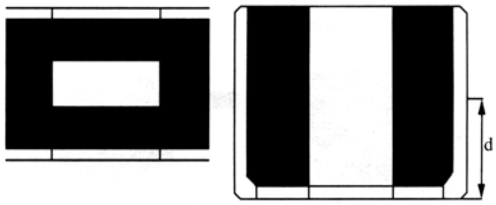
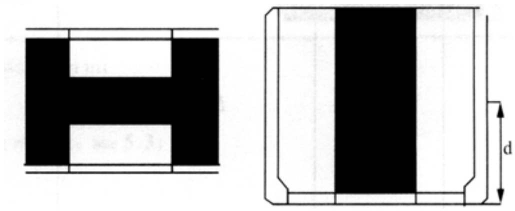
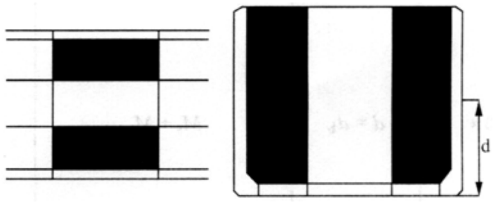
7.1 Oil tankers with one longitudinal bulkhead

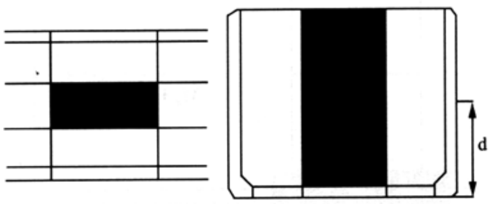
Loading condition	draft	Bending moment	scratch
1	$d = d_s$	$M_s + M_W$	
2	$d = d_s$	$M_s + M_W$	
3	$d = d_s$	$M_s + M_W$	
4	$d = 0.35D$	M_s	
5	$d = 0.35D$	M_s	
6	$d = d_s$	$M_s + M_W$	
7	d=0.25D	M_s	

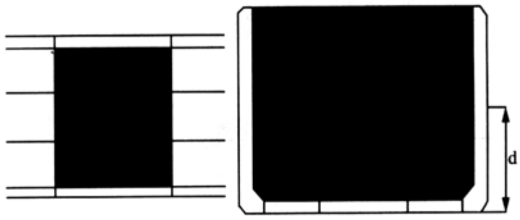
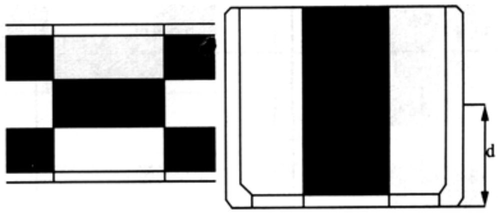
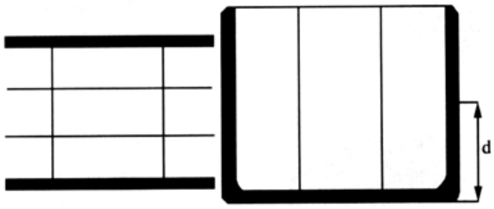
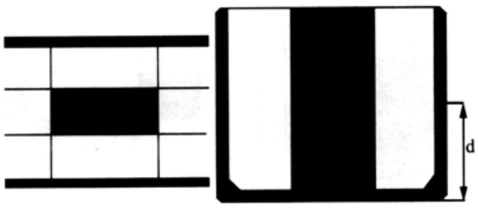
Loading condition	draft	Bending moment	scratch

8	$d = d_b$	$M_s + M_W$	
9	$d = d_b$	$M_s + M_W$	

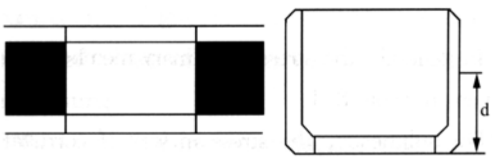
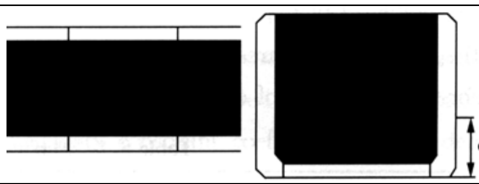
7.2 Oil tankers with two longitudinal bulkheads

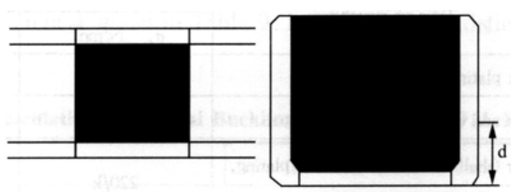
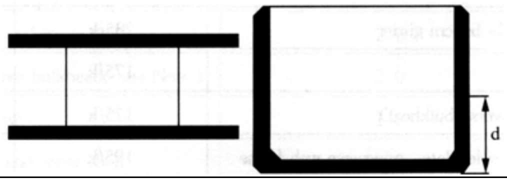
Loading condition	draft	Bending moment	scratch
1	$d = d_s$	$M_s + M_W$	
2	$d = d_s$	$M_s + M_W$	
3	$d = d_s$	$M_s + M_W$	
4	$d = 0.25D$	M_s	

Loading condition	draft	Bending moment	scratch
5	$d = 0.25D$	M_s	

6	$d = 0.35D$	M_s	
7	$d = 0.5D$	M_s	
8	$d = d_b$	$M_s + M_W$	
9*	$d = d_b$	$M_s + M_W$	
10*	$d = d_b$	$M_s + M_W$	

7.3 Oil tankers without longitudinal bulkhead:

Loading condition	draft	Bending moment	Scratch
1	$d = d_s$	$M_s + M_W$	
2	$d = d_s$	$M_s + M_W$	

3	$d = 0.35D$	M_s	
4	$d = d_b$	$M_s + M_W$	
5	$d = d_b$	$M_s + M_W$	

Notes：① d_b——ballast draft corresponding to the loading condition，in m；

d_s——scantling draft，in m；

② M_s still water bending moment and M_w wave bending moment: see 5.3；

③ condition with * is additional condition.

Chapter 8 Strength Criteria

8.1 Stresses at the mid surface of plate bending elements, and axial stress of beam elements are to be used.

8.2 In general, the stress of primary members under typical loading conditions is not to exceed the val ues given in Table 8.1.

8.3 For bulkheads, the stress in way of corrugation end may be obtained by extrapolation of average stresses of bulkhead plating.

8.4 The average shear stress r means the average shear stress over depth of web of primary members.

8.5 For those elements of concentrated stress and poor shape, the stresses are not to be considered.

Table 8.1 Maximum Permissible Stress

Type of Structure	Permissible Stress			
	σ_e N / mm^2	σ_1 N / mm^2	σ_w N / mm^2	τ N / mm^2
Deck plating	220/*k*	210/*k*	145/*k*	-
Inner and outer bottom plating	220/*k*	210/*k*	145/*k*	-
Inner shell and outside shell plating, longitudinal bulkhead	220/*k*	210/*k*	145/*k*	115/*k*
Double bottom girder	235/*k*	210/*k*	-	115/*k*
Floor	175/*k*	-	-	95/*k*
Transverse bulkheaD	175/*k*	-	-	95/*k*
Stool side plate, transverse web flame	195/*k*	-	-	95/*k*
Axial stress of beam element (N / mm^2)				
Beam on transverse members	176/*k*			
Beam on longitudinal members	206/*k*			

Chapter 9 Evaluation of Buckling Strength

9.1 Applications

9.1.1 Plate buckling is to be checked for stress components of girders and primary transverse members，and plate buckling is also to be checked for attached plates of primary members such as deck，side，inner shell，longitudinal and transverse bulkhead plating.

9.1.2 The assessment of plate buckling is based on the standard thickness deduction as given in Table 9.1.1.

9.1.3 while assessing plate buckling .bi-directional axial compressing stress and shear stress are to be considered，and the stress at the mid surface of the plate is generally applied for buckling check.

9.1.4 While determining buckling safety factor. boundary constraint coefficient “C” as defined in paragraph 2.2.7，Part two of the Rules，is taken into consideration.

9.1.5 The required minimum buckling safety coefficient A given in Table 9.1.2 should be satisfied for buckling check.

Standard Thickness Deduction for Calculation of Critical Buckling Stress Table 9.1.1

Location		Thickness deduction (mm)
Within 1.5 m weather deck	Deck and side plating	1.0
	Longitudinal bulkhead and inner shell	2.0
	Inner structure including transverse bulkhead，see Note 1	2.0
Other areas	Side plating	1.0
	Longitudinal bulkhead and inner shell	1 0
	Inner structure including transverse bulkhead，see Note 1	1.0
Note： 1. 1mm more deduction for plate thickness is required for tanks without coating if no inert gas system is fitted.		

Required Safety Factor *A* for Plate Buckling Table 9.1.2

Structure	Buckling safety factor *A*
Double bottom girder	1 .1
Single bottom girder	1.0
Deck，side，inner bottom，longitudinal and transverse bulkhead plating，etc.	1. 0
Web of transverse members，such as midship flames，webs of horizontal and vertical bulkhead stiffeners	1.1
Symbol	
λ =critical buckling stress/applied stress	

9.2 Methods for buckling assessment

Either of the following methods may by applied：

9.2.1 Method 1：Finite Element Method

(1) Modeling

When addressing the issue of stability based on net scantlings，the thickness of the panel selected for buckling is deduced as specified in Table 9.1.1.1he requirements of meshing are not less than 8 meshes at each side，preferably in square shape.

(2) Loads and boundary conditions

Loads：the results of σ_x，σ_y，τ_{xy} (i.e. applied stress) for stresses at mid surface of the panel，as calculated by means of FE model. are taken according to the selected condition and multiplied respecttively by the thickness before deduction to get corresponding pressure.

$$N_x = \sigma_x \times t_o$$

$$N_y = \sigma_y \times t_o$$

$$N_{xy} = \tau_{xy} \times t_o$$

where：

to is original plate thickness.

These loads are to be applied on relevant boundaries

Where compressive stresses being significantly variable between plate panels，they may be applied as linearly distributed load，and mean value of shear stress full depth of the web for girders and floors is to be taken.

Boundary conditions：

The displacements in x-direction at the midpoints of longitudinal boundaries and in y-direction at the midpoints of transverse boundaries should be constrained. The displacement in z—direction at the 4 sides boundaries should be constrained，as shown in Figures 9.2.1 and 9.2.2.

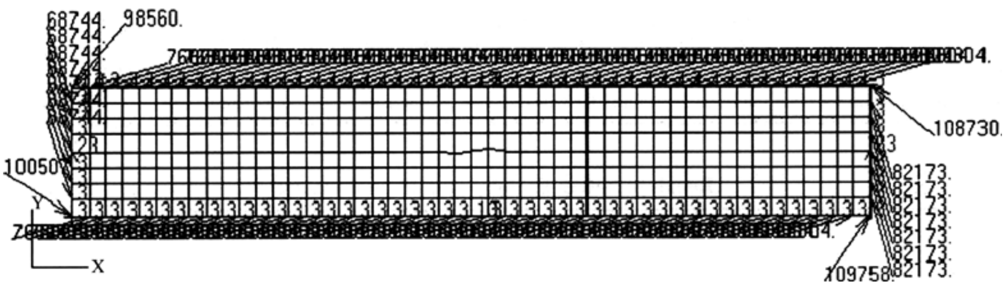


Figure 9.2.1 Model where bi—directional pressure and shear force are applied

Notes：1. Boundary constraint as shown in both Figure 9.2.1 and Figure 9.2.2 are acceptable.

2. Figure 9.2.1 indicates the nodal pressure for boundary load type，and Figure 9.2.2 indicates boundary pressure of that type.

(3) Buckling assessment

The factor shown in finite element analysis reprocessing is the critical buckling factor λ .The results can be obtained by multiplying with the boundary constraint coefficient as defined in 9.1.4 according to boundary constraint conditions. and should not be less than the values of safety factor in Table 9.1.2.

9.2.2 Method 2：Simply method

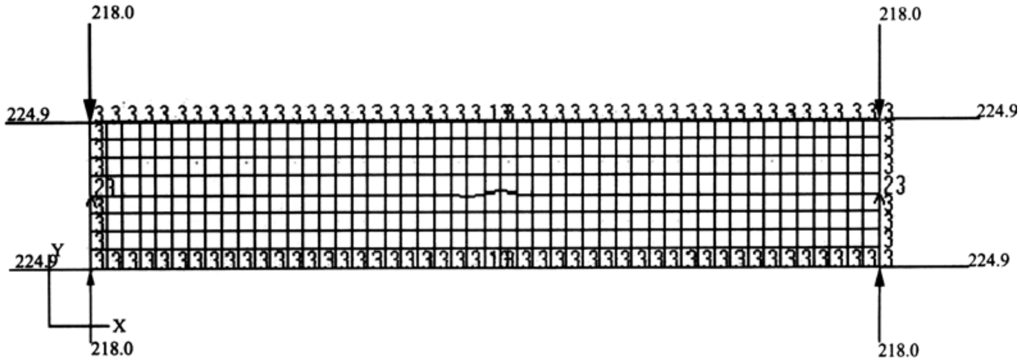


Figure 9.2.2 Model where bi –directional pressure is applied

(1 The stresses at the mid. surface by FE method, are corrected by the standard thickness deduction given in Table 9.1.1:

$$\sigma_A = \sigma_t /(t - t_r)$$

where: σ_A ——working stress in buckling calculation;

σ ——stress obtained by finite element calculation;

t—— original plate thickness used in finite element calculation;

t_r .——standard thickness deduction as given in Table 9.1.1.

(2) Critical buckling stress and elasticity correction

① The elastic critical buckling stress σ_{xcr-e} of the plate panel, of which the shorter side is subjected to compression, is defined as follows:

$$\sigma_{xcr-e} = k_x C_1 \frac{\pi^2 E}{12(1-v^2)} (\frac{t}{s})^2 \qquad \text{N/mm}^2$$

where:

k_x ——buckling coefficient for shorter side subjected to compression and bending, calculated according to Table 9.2.1:

C_1 ——boundary constraint coefficient, obtained from Table 9.2.2;

t ——thickness of plate panel, in m;

s ——length of shorter side of plate panel, in mm9taken as spacing of longitudinals or stiffeners;

x ——defined as axial direction of longer side of plate panel.

② The elastic critical buckling stress σ_{ycr-e} 。 of the plate panel, of which the longer side is subjected to compression, is defined as follows:

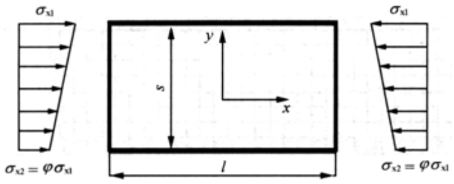
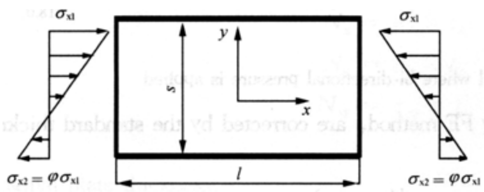
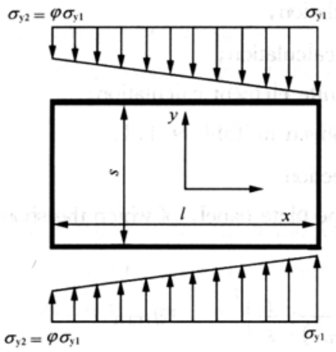
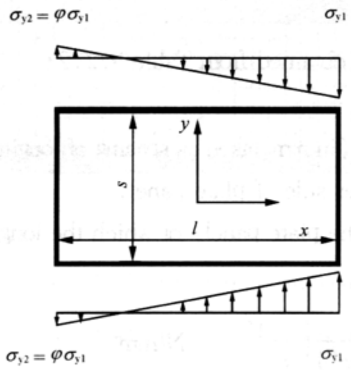
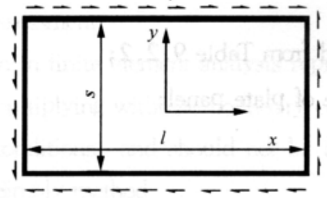
$$\sigma_{ycr-e} = k_y C_2 \frac{\pi^2 E}{12(1-v^2)} (\frac{t}{s})^2 \qquad \text{N/mm}^2$$

where: K_y ——buckling coefficient for longer side subjected to compression and bending, determined by Table 9.2.1:

C_2 ——boundary restraint coefficient, obtained from Table 9.2.2;

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

Buckling coefficients of plate panel Table 9.2.2

Mechanical model of plate panel subjected to compression ,bending and shearing		Buckling coefficients
Pressure on shorter side	 where : $0 \le \varphi \le 0$	$k_x = \frac{8.4}{\varphi + 1.1}$
	 where : $-1 \le \varphi < 0$	$k_x = 7.6 - 6.4\varphi + 10\varphi^2$
Compression on longer side	 where : $0 \le \varphi \le 0$	$k_y = [1 + (\frac{s}{l})^2]^2 \frac{2.1}{\varphi + 1.1}$
	 where : $-1 \le \varphi \prec 0$	$ky = 1.909(1+\varphi)[1 + (\frac{s}{l})^2]^2 - p\varphi + 10_{\varphi}$ $(1+\varphi)(\frac{s}{l})^2$ where: $k_p \begin{cases} 24(\frac{s}{l})^2 & \frac{l}{s} \le \frac{3}{2} \\ 2 + 16(\frac{s}{l})^2 + 8(\frac{s}{l})^4 & \frac{l}{s} > \frac{3}{2} \end{cases}$
Shearing on side		$k_t = 5.34 + 4(\frac{s}{l})^2$

Boundary constraint Coefficients C_1 and C_2 of Plate Table 9.2.2

Boundary	C_1	C_2	
		Within double bottom or double hull	Other locations
Angel or T-bar	1.1	1.3	1.2
Flat plate or bulb bar	1.0	1.2	1.1

Others are the san2.e as those in ①.

③ The elastic critical buckling stress τ_{cr-e} of the plate panel，which is subjected to shearing，is defined as follows：

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

where：K_t——shear buckling coefficient，determined by Table 9.2.1；

Others are the same as those in ① and ②.

④ The elastic critical buckling stress of plate panel is to be corrected as follows：

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

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

where：σ_{xcr-e}，σ_{ycr-e}，τ_{cr-e} ——elastic critical buckling compressive stress and critical buckling shear stress of plate panel along axes X and Y respectively，refer to ①，② and ③；

σ_s——yielding stress, in N/mm^2;

τ_s——$\frac{\sigma_s}{\sqrt{3}}$

(3) Buckling strength check

① The ratio λ of the critical buckling stress of plate panel under composite stress to the calculated actual compressive stress，determined by Table 9.2.3，is riot to be less than the safety factor given in Table 9.1.2.

λ Calculation Table 9.2.3

Stress status \ Ratio of plate panel	$1\le\frac{l}{s}\le\sqrt{2}$	$\sqrt{2}<\frac{1}{s}\le 8$
Bi-directional compression	$\frac{1}{(1+k_1)}\frac{\sigma_{xcr}}{\sigma_x}$	$\frac{1}{\sqrt{1+k_l^2}}\frac{\sigma_{xcr}}{\sigma_x}$

Compression along axis X+ shear	$\frac{1}{\sqrt{1+k_2^2}}\frac{\sigma_{xcr}}{\sigma_x}$
Compression along axis Y+ shear	$\frac{1}{\sqrt{1+k_3^2}}\frac{\sigma_{ycr}}{\sigma_y}$
Bi-directional compression +shear	$\frac{1}{\sqrt{1+k_l^2+k_2^2}}\frac{\sigma_{xcr}}{\sigma_x}$

② The absolute values of σ_x, σ_y and τ_{xy} are applied for the assessment and the ape taken as zero, when the working stress along axis x or y is tensile stress，such stress component is taken as zero。

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

Notes：① σ_{x1} and σ_{y1} are greater values of Working stresses acting on sides of plate pant along axes X and Y； σ_{x2} and σ_{y2} are the smaller values of such stresses，and σ_x and σ_y are taken as average values of σ_{x1}， σ_{x2} and σ_{y1}， σ_{y2} respectively； τ_{xy} is average shear stress.

$\sigma_{x1}, \sigma_{x2}, \sigma_{y1}, \sigma_{y2}$ and τ_{xy}, as shown in Table 9.2.1.

② σ_{xcr}， σ_{ycr} and τ_{cr} are the elastically corrected critical buckling compressive stress mad critical buckling shear stress of plate panel along axes X an Y respectively.