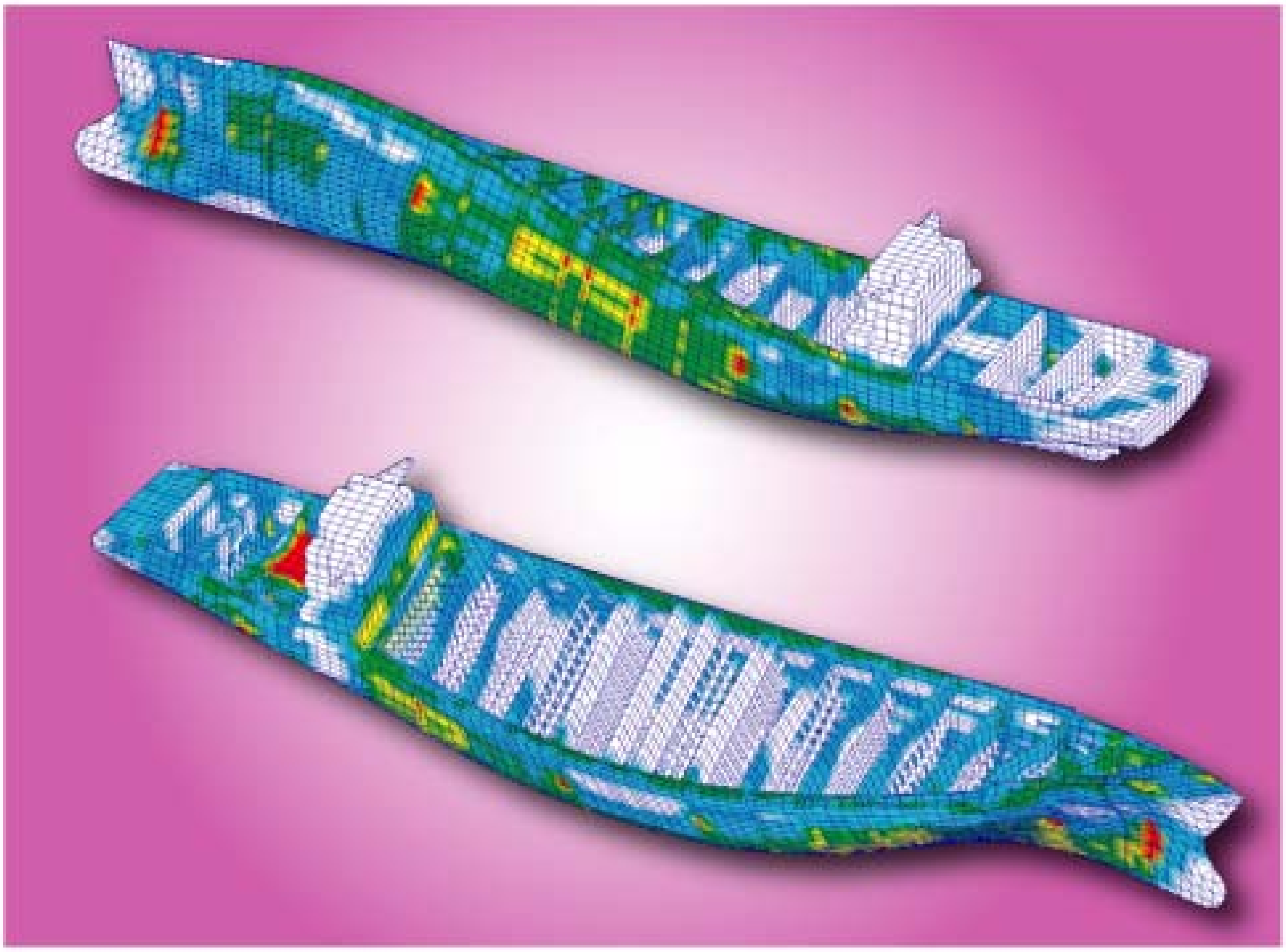
ClassNK

Guidelines for Hull Girder Torsional Strength Assessment

November 2003



Nippon Kaiji Kyokai

Guidelines for Hull Girder Torsional Strength Assessment

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Symbols

L	: Scantling length of ship	*m*
B	: Greatest moulded breadth of ship	*m*
D	: Moulded depth of ship	*m*
d_f	: Design moulded draught of ship	*m*
C_b	: Block coefficient corresponding to the design moulded draught of ship	-
C_w	: Water plane coefficient corresponding to the design moulded draught of ship	-
K	: Material Coefficient corresponding to the yielding strength of material K=1.0 for *MS* K=0.78 for *HT*32 K=0.72 for *HT*36	-
M_{WV}	: Wave-induced vertical bending moment	*kN-m*
M_{SV}	: Still water vertical bending moment	*kN-m*
M_{WH}	: Wave-induced horizontal bending moment	*kN-m*
M_{ST}	: Still water torsional moment	*kN-m*
M_{WT}	: Wave-induced torsional moment	*kN-m*
σ_{WV}	: Stress due to wave-induced vertical bending moment	N/mm^2
σ_{SV}	: Stress due to still water vertical bending moment	N/mm^2
σ_{WH}	: Stress due to wave-induced horizontal bending moment	N/mm^2
σ_{WT}	: Warping stress due to wave-induced torsional moment	N/mm^2
σ_{ST}	: Warping stress due to still water torsional moment	N/mm^2
σ_T	: Combined stress	N/mm^2

Guidelines for Hull Girder Torsional Strength Assessment

1 General

1.1 Application

-1. The hull girder torsional strength of container carriers, which comply with Chapter32, Part C of the Rules, can be assessed using these Guidelines.

-2. The strength of the cross deck box beam in way of transverse bulkhead or partial transverse bulkhead subjected to torsion of the hull can be assessed according to these Guidelines.

-3. The fatigue strength with respect to torsion of the hull can be assessed based on the separate publication titled "**Guidelines for Fatigue Strength Assessment**".

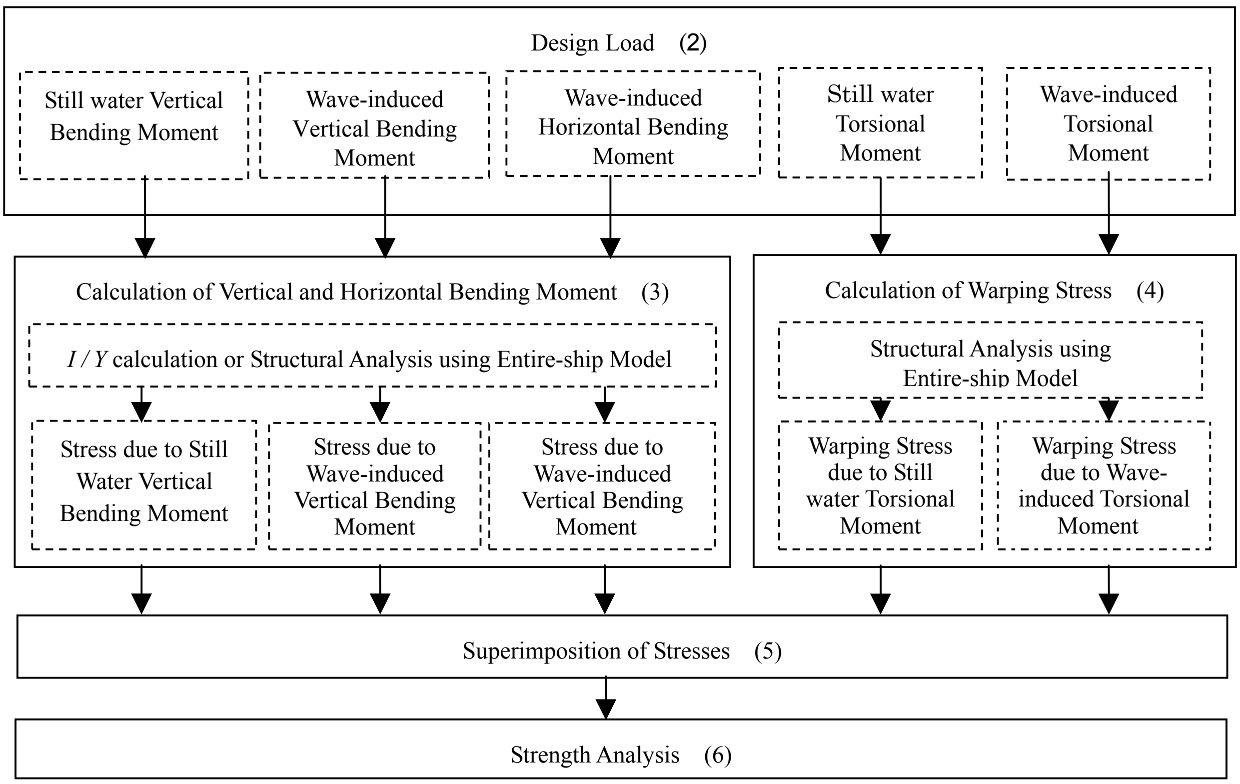
-4. A more advanced method may be used for the torsional strength evaluation of ships irrespective of the method specified in these Guidelines.

1.2 Members subject to Hull Girder Torsional Strength Assessment

The members subject to hull girder torsional strength assessment are the longitudinal strength members in the cargo hold area between the forward bulkhead of the engine room and the collision bulkhead.

1.3 Procedures for Evaluation

An overview of the procedure for evaluation is given in Fig.1.1.



NOTE: Numbers within parentheses indicate chapter numbers.

Fig. 1.1 Procedure for Torsional Strength Evaluation

2 Design Loads

2.1 General

The vertical bending moment and the torsional moment due to unbalanced loading of containers in still water are to be considered as the hull girder moment in still water, while the vertical bending moment, horizontal bending moment and torsional moment in waves are to be considered as the hull girder moment in waves during torsional strength assessment.

2.2 Vertical Bending Moment

2.2.1 Still Water Vertical Bending Moment

The vertical bending moment in still water, M_{SV}, corresponding to the severest condition from among the loading conditions mentioned in the Loading Manual is calculated. The sign convention of the vertical bending moment is depicted in Fig. 2.1.

2.2.2 Wave-induced Vertical Bending Moment

Wave-induced vertical bending moment M_{WV} can be determined from the following equation.

$M_{WV} = +0.19 C_1 C_2 L^2 B C_b'$ (*kN-m*) in the hogging condition

$M_{WV} = -0.11 C_1 C_2 L^2 B (C_b' + 0.7)$ (*kN-m*) in the sagging condition

However, M_{WV} is selected such that its sign is the same as that of M_{SV}.

C_1 : As given by the following formulae :

$10.75 - \left(\frac{300 - L}{100}\right)^{1.5}$ for $L \le 300$ (m)

10.75 for $300 < L \le 350$ (m)

$10.75 - \left(\frac{L - 350}{150}\right)^{1.5}$ for $350 < L$ (m)

C_2 : Coefficient in the longitudinal direction of the longitudinal bending moment, determined according to the position of the considered cross section and the values of K_v and K_f, which are obtained from the equations given below. C_2 is taken as the larger of the values determined by linear interpolation of Tables 1.1 and 1.2. However, Table 1.2 is used only for the sagging condition.

$K_v = 0.2V / \sqrt{L}$

$K_f = (A_d - A_w) / L h_B$

A_d : Projected area onto a horizontal plane of exposed deck from the fore end extending to $0.2L$ aft of fore end including the part forward of fore end (m^2)

A_w : Area of the waterplane (m^2) forward of $0.2L$ from the front end at the design load line

h_B : Vertical distance from the design load line to the exposed deck at the side of forward end (m)

Table 1.1 Coefficient C_2

K_v	x				
	AP	0.40L	0.65L	0.75L	FP
0.28 and under	0.0	1.0	1.0	5/7	0.0
0.32 and over	0.0	1.0	1.0	0.8	0.0

Table 1.2 Coefficient C_2

K_v+K_f	x				
	AP	0.40L	0.65L	0.75L	FP
0.40 and under	0.0	1.0	1.0	5/7	0.0
0.50 and over	0.0	1.0	1.0	0.8	0.0

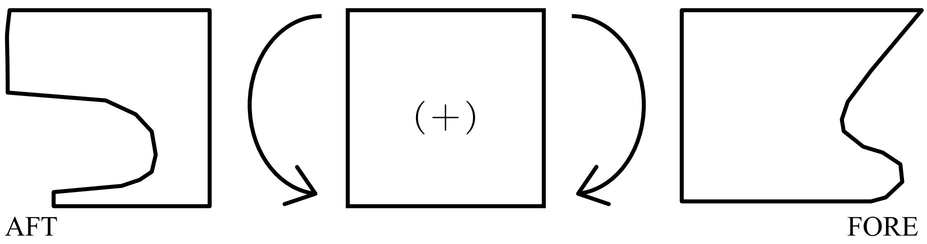


Fig. 2.1 Sign Convention of Vertical Bending Moment

2.3 Horizontal Bending Moment

Horizontal bending moment M_{WH} can be determined from the equation given below.

$$M_{WH} = 0.32 C_1 C_3 L^2 d_f \sqrt{\frac{L-35}{L}} \quad (kN\text{-}m)$$

C_1 : As specified in 2.2.2

C_3 : Distribution coefficient of the horizontal bending moment in the length direction of the ship, which is determined by linear interpolation using the equation given below according to the position of the considered cross section.

C_3 = 0 at A.P.

= 1.0 at 0.35L – 0.65L

= 0 at F.P.

2.4 Torsional Moment

2.4.1 Still Water Torsional Moment

The torsional moment in still water, M_{ST}, due to unbalanced loading of containers is estimated using the equation given below as a standard. The distribution of the torsional moment in the longitudinal direction of the ship is to be taken similar to the distribution in waves as given in 2.4.2.

$$M_{ST} = 0.23 L N_R W_C \quad (kN\text{-}m)$$

N_R : Maximum number of rows of cargo containers loaded in the cargo hold

W_C : Mean weight of a 20*ft* container to be loaded. Usually taken as 100*kN*

2.4.2 Wave-induced Torsional Moment

Wave-induced torsional moment can be determined from the equation given below.

$$M_{WT1} = M_{WT} \cdot C_{T1}$$

$$M_{WT2} = M_{WT} \cdot C_{T2}$$

$$M_{WT} = 1.3 C_1 L d_f C_b \cdot (0.65 d_f + e) + 0.2 C_1 L B^2 C_w$$

$$e = e_1 - \frac{d_0}{2}$$

$$e_1 = \frac{(3D_1 - d_1) d_1 t_d + (D_1 - d_1)^2 t_s}{3 d_1 t_d + 2(D_1 - d_1) t_s + B_1 t_b / 3}$$

d_0 : Height of double bottom (*m*)

d_1 : Breadth of double side (*m*)

$$D_1 = D_S - \frac{d_0}{2}$$

$$B_1 = B - d_1$$

t_d, t_s, t_b : Mean thickness of deck, side shell and bottom shell plating (*m*) respectively. The range of each is given in Fig. 2.2. The mean plating thickness may also be determined after including the longitudinal strength members within each range.

Figure 2.3 shows the distributions of C_{T1} and C_{T2}. However, the distributions may also be calculated using the equation given below.

$$C_{T1} = 1.0 \left[\sin\left(2\pi \frac{x}{L}\right) + 0.1 \sin^2\left(\pi \frac{x}{L}\right) \right] \exp\left(-0.35 \frac{x}{L}\right) \exp\left(-8 \left(\frac{x/L - 0.5}{0.5}\right)^{10}\right)$$

$$C_{T2} = 0.5 \left[-\sin\left(3\pi \frac{x}{L}\right) + 0.65 \sin^3\left(\pi \frac{x}{L}\right) \right] \exp\left(-0.4 \frac{x}{L}\right) \exp\left(-8 \left(\frac{x/L - 0.5}{0.5}\right)^{10}\right)$$

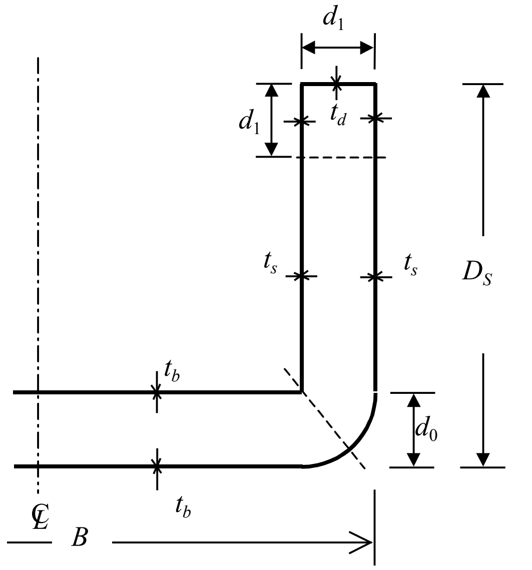


Fig. 2.2 The range of the thickness for deciding the coefficient *e*

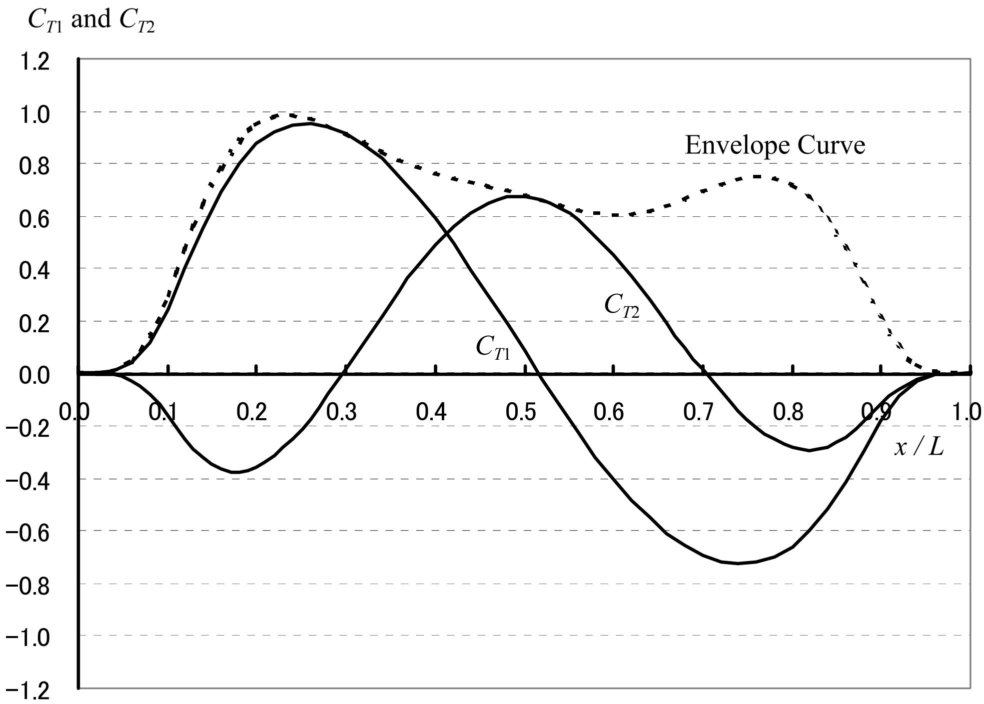


Fig. 2.3 Distribution of Torsional Moment

3 Stresses due to Bending Moment

3.1 General

The stresses due to vertical and horizontal bending moments are calculated by applying the beam theory. However, the stresses may also be calculated by direct structural analysis using an entire-ship model. In this case, the effects of local bending may be included at the position to be evaluated, and such effects should be eliminated by extrapolating the stress in the longitudinal direction of the ship.

3.2 Stress due to Vertical Bending Moment

Stress due to still water vertical bending moment, σ_{SV}, and wave-induced vertical bending moment, σ_{WV}, are given by the following equation.

$$\sigma_{SV} = \frac{M_{SV}}{I_V} \cdot f_V \times 10^5 \quad (N/mm^2)$$

$$\sigma_{WV} = \frac{M_{WV}}{I_V} \cdot f_V \times 10^5 \quad (N/mm^2)$$

M_{SV} : Still water vertical bending moment at the considered section (*kN-m*)

M_{WV} : Wave-induced vertical bending moment at the considered section (*kN-m*)

I_V : Moment of inertia of the transverse cross section about the horizontal neutral axis (cm^4)

f_V : Vertical distance from the horizontal neutral axis to the evaluation position (*m*)

3.3 Stress due to Horizontal Bending Moment

Stress due to horizontal bending moment, σ_{WH}, can be determined from the following equation.

$$\sigma_{WH} = \frac{M_{WH}}{I_H} \cdot f_H \times 10^5 \quad (N/mm^2)$$

M_{WH} : Wave-induced horizontal bending moment at the considered section (*kN-m*)

I_H : Moment of inertia of the transverse cross section about the vertical neutral axis (cm^4)

f_H : Horizontal distance from the neutral axis to the evaluation position (*m*)

4 Warping Stress due to Torsional Moment

4.1 General

-1. The warping stress is determined by applying the torsional moment given in 2.4.2 on the structural model using the three-dimensional Finite Element Method (FEM).

-2. The analysis programs are to have a sufficient accuracy. If deemed necessary, the Society may require submission of the details of the analysis methods, verification of accuracy, etc.

4.2 Structural Model

4.2.1 Extent of the Modeling

An entire-ship model is to be used for analysis. Either full-breadth or half-breadth model may be used.

4.2.2 Members Considered

All longitudinal members, such as primary strength members and stiffeners are to be included in the model

4.2.3 Mesh Size

To determine the warping stress , membrane elements or shell elements may be used to represent plate members in the model. The size of the mesh should be appropriately selected considering the stress condition in the model. The distance between the centers of girders and floors is taken as the standard length of one side of the element. Elemtnts with large aspect ratios shall be avoided. Use equivalent beam elements in the model for stiffeners so that the same rigidity is obtained in the cross section of each structural part. Several small stiffeners may be considered into one equivalent element for modeling purposes. Gross scantlings given in the plans are to be used for modeling. Fig. 4.1 shows examples of the analysis models.

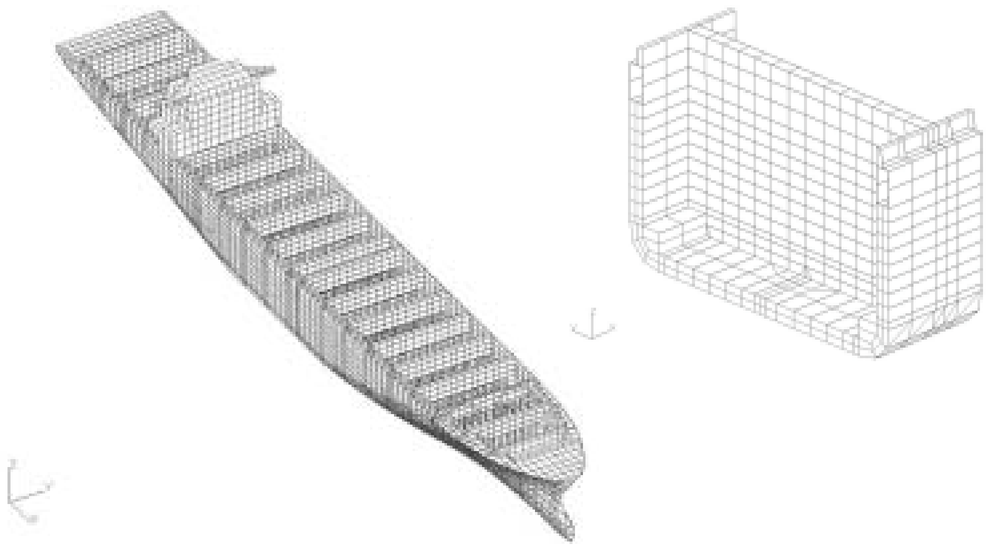


Fig. 4.1 Example of Entire-ship Model and Part Model

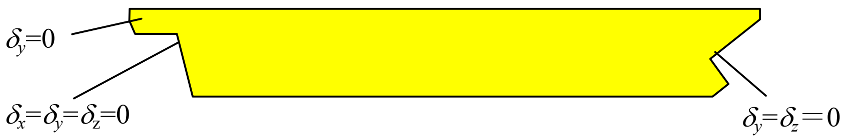
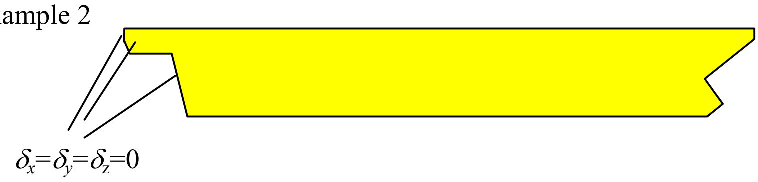
4.2.4 Confirming the Validity of the Structural Model

The validity of the structural model is verified by comparing the results of analysis(of the beam theory). That is, the stress corresponding to a unit vertical bending moment is confirmed to be equivalent to the value obtained by dividing the vertical bending moment by I_V / f_V. Similarly, a unit horizontal bending moment is applied and the resulting stress is confirmed to be equivalent to the value obtained by dividing the horizontal bending moment by I_H / f_H. Here, I_V, f_V, I_H, f_H are defined in Chapter 3.

4.3 Boundary Conditions

To determine the warping stress by entire-ship analysis, a combination of support conditions that constrain the translational and rotational deflections of the structure is applied at locations where the reaction forced are considered to be small. Table 4.1 shows examples of combinations of appropriate support conditions for a full-breadth model. For a half-breadth model, anti-symmetric conditions ($\delta_x = \delta_z = \delta_{\theta y} = 0$) are applied along the center line over the entire length.

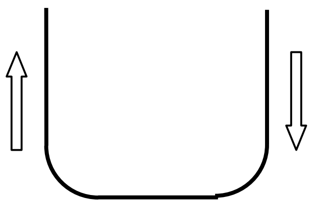
Table 4.1 Examples of Support Conditions for Torsional Analysis by FEM

Full-breadth model	Example 1 
	Example 2 

4.4 Loading Method

The equivalent load is applied such that it faithfully represents the actual load so that the stress at the referenced location is not affected. Table 4.2 shows an example of the loading method.

Table 4.2 An Example of the Loading Method

	The difference in torsional moment at a cross section is taken at the bulkhead, and an equivalent shear load is applied on both sides.

4.5 Calculation of Warping Stress

The warping stress corresponding to the torsional load is calculated by first calculating the warping stresses for each of the two torsional moments M_{WT1} and M_{WT2} given in 2.4.2 and then combining them using the equation given below.

$$\sigma_{WT} = \sqrt{{\sigma_{WT1}}^2 + {\sigma_{WT2}}^2}$$

σ_{WT1} : Warping stress when the torsional moment M_{WT1} is applied.

σ_{WT2} : Warping stress when the torsional moment M_{WT2} is applied.

5 Superimposition of Stresses

The total hull girder stress σ_T is obtained by superimposing the stress components using the equations given below. The absolute value of each stress component is to be used for the calculation.

$$\sigma_T = \sqrt{\sigma_{WV}^2 + (\sigma_{WH}^2 + \sigma_{WT}^2 + 2C_{COR}\sigma_{WH}\sigma_{WT})} + \sigma_{SV} + \sigma_{ST} \quad \text{for upper deck side}$$

$$\sigma_T = \sqrt{\sigma_{WV}^2 + (\sigma_{WH}^2 + \sigma_{WT}^2 - 2C_{COR}\sigma_{WH}\sigma_{WT})} + \sigma_{SV} + \sigma_{ST} \quad \text{for bottom side}$$

C_{COR} is according to Fig. 5.1 and Table 5.1, depending on the position of the transverse section being considered. For intermediate values of x, C_{COR} is to be obtained by linear interpolation.

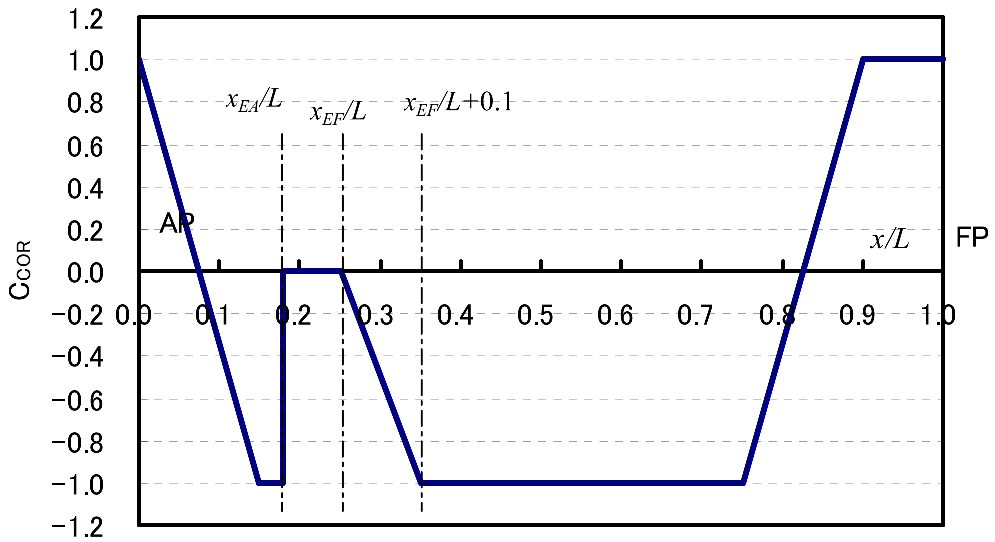


Fig. 5.1 Distribution of C_{COR}

Table 5.1 Coefficient C_{COR}

x	AP	$0.15L$	x_{EA}	x_{EF}	$x_{EF}+0.1L$	$0.75L$	$0.9L$	FP
C_{COR}	1.0	-1.0	-1.0 / 0.0	0.0	-1.0	-1.0	1.0	1.0

Here, x_{EA} and x_{EF} indicate the positions of the aft end and forward end of the engine room respectively.

6 Evaluation of Strength

The following conditon is to be satisfied for both upper deck and bottom sides at any transverse section. At any positions of both these transverse sections, confirm that the conditions below are satisfied.

$$\sigma_T \leq 185/K \quad (N/mm^2)$$

The bottom shell should have adequate buckling strength to resist the total hull girder stress.

7 Strength Assessment of the Cross Deck Box Beam Structure in way of Transverse Bulkhead or Partial Transverse Bulkhead

7.1 Reference Stress

The reference stress is calculated by first calculating the warping stress for each of the two torsional moments M_{WT1} and M_{WT2} given in 2.4.2 and then calculating it using the following equation. The Mises' equivalent stress is used for shell elements and membrane elements, while the axial stress is used for rod elements.

$$\sigma_{WT} = C_4 \sqrt{{\sigma_{WT1}}^2 + {\sigma_{WT2}}^2}$$

C_4 : Correction coefficient considering stress increment due to corrosion; taken as 1.1

σ_{WT1} : Warping stress when the torsional moment M_{WT1} is applied.

σ_{WT2} : Warping stress when the torsional moment M_{WT2} is applied.

7.2 Consideration for Yielding Strength

Confirm that the reference stresses are less than the allowable stress of $215/K$ (N/mm^2).

7.3 Consideration for Buckling Strength

-1. Buckling strength assessment is to be performed according to "**Evaluation of Buckling Strength**" given in the "**Guidelines for Direct Strength Analysis**".

-2. The values of corrosion deduction are determined according to "**Guidelines for Direct Strength Analysis**"

-3. The buckling strength criterion is taken as 1.0.