Chapter 5 Earth Pressure and Water Pressure

Public Notice

Earth Pressure and Water Pressure

Article 14

1 Earth pressure shall be set appropriately based on the ground conditions in consideration of the structure of the facilities concerned, imposed loads, the action of earthquake ground motions, and others.

2 Residual water pressure shall be set appropriately in consideration of the structure of the facilities concerned, the surrounding ground conditions, tide levels, and others.

3 Dynamic water pressure shall be set appropriately in consideration of the structure of the facilities concerned, the action of earthquake ground motions, and others.

[Technical Note]

1 Earth Pressure

1.1 General

The behavior of soil varies with physical conditions such as grain size, void ratio and water content, and with stress history and boundary conditions, which also affect earth pressure. The earth pressure discussed in this chapter is the pressure by ordinary soil. The earth pressure generated by improved soil and reinforced soil will require separate consideration. The earth pressure during an earthquake for design mentioned herein, is based on the concept of the seismic coefficient method and is different from the actual earth pressure generated during an earthquake caused by dynamic interaction between structures, soil and water. However, this earth pressure can generally be used in performance verifications as revealed by analyses of past damage due to earth pressures during earthquakes. The hydrostatic pressure and dynamic water pressure acting on a structure should be calculated separately.

(1) Earth Pressure (Relating to Item 1 of the Public Notice Above)
In setting earth pressure, appropriate consideration should be given to the earth pressure state, namely whether it is an active or a passive earth as a result of structure behavior etc., and the design situation, in accordance with the type of soil quality such as sandy or cohesive soil and the structural characteristics of the subject facility.

(2) Residual Water Pressure (Relating to Item 2 of the Public Notice Above)
Residual water pressure mentioned herein refers to the water pressure arising from the difference in water levels on the front side and rear side of the facility. This difference must be given due consideration in setting residual water pressure.

(3) Dynamic Water Pressure (Relating to Item 3 of the Public Notice Above)
In verifying the performance of facilities subject to the technical standard, proper consideration should be given, as required, to the effect of dynamic water pressure.

(4) Other
In verifying the performance of facilities subject to the technical standard, buoyancy should be considered, as required, in addition to these settings.

1.2 Earth Pressure at Permanent Situation

1.2.1 Earth Pressure of Sandy Soil

(1) The earth pressure of sandy soil acting on the backface wall of structure and the angle of sliding surface shall be calculated by the following equations:

① Active earth pressure and the angle of failure surface

$$p_{ai} = K_{ai}\left[\sum \gamma_i h_i + \frac{\omega \cos\psi}{\cos(\psi - \beta)}\right]\cos\psi \tag{1.2.1}$$

$$\cot(\zeta_i - \beta) = -\tan(\phi_i + \delta + \psi - \beta) + \sec(\phi_i + \delta + \psi - \beta)\sqrt{\frac{\cos(\psi+\delta)\sin(\phi_i+\delta)}{\cos(\psi-\beta)\sin(\phi_i-\beta)}} \tag{1.2.2}$$

where

$$K_{ai} = \frac{\cos^2(\phi_i - \psi)}{\cos^2\psi\cos(\delta+\psi)\left[1+\sqrt{\frac{\sin(\phi_i+\delta)\sin(\phi_i-\beta)}{\cos(\delta+\psi)\cos(\psi-\beta)}}\right]^2}$$

② Passive earth pressure and the angle of failure surface.

$$p_{pi} = K_{pi}\left[\sum\gamma_i h_i + \frac{\omega\cos\psi}{\cos(\psi-\beta)}\right]\cos\psi \qquad (1.2.3)$$

$$\cot(\zeta_i - \beta) = \tan(\phi_i - \delta - \psi + \beta) + \sec(\phi_i - \delta - \psi + \beta)\sqrt{\frac{\cos(\psi+\delta)\sin(\phi_i-\delta)}{\cos(\psi-\beta)\sin(\phi_i+\beta)}} \qquad (1.2.4)$$

where

$$K_{pi} = \frac{\cos^2(\phi_i + \psi)}{\cos^2\psi\cos(\delta+\psi)\left[1-\sqrt{\frac{\sin(\phi_i-\delta)\sin(\phi_i+\beta)}{\cos(\delta+\psi)\cos(\psi-\beta)}}\right]^2}$$

with

p_{ai}, p_{pi} : active and passive earth pressures, respectively, acting on the backface of the wall at the bottom level of the i-th soil layer (kN/m^2)
ϕ_i : angle of internal friction of the i-th soil layer (°)
γ_i : unit weight of the i-th soil layer (kN/m^3)
h_i : thickness of the i-th soil layer (m)
K_{ai}, K_{pi} : coefficients of active and passive earth pressures, respectively, in the i-th soil layer
ψ : angle of batter of backface wall from vertical line (°)
β : angle of backfill ground surface from horizontal line (°)
δ : angle of friction between backfilling material and backface wall (°)
ζ_i : angle of failure surface of the i-th soil layer (°)
ω : uniformly distributed surcharge on the ground surface (kN/m^2)

(2) The earth pressure at permanent situation is based on Coulomb's earth pressure theory.

(3) Earth pressure at rest as expressed by equation **(1.2.5)** may be used when there is little displacement because of the wall being confined.

$$p = K_0\sum\gamma_i h_i \qquad (1.2.5)$$

where

K_0 : coefficient of earth pressure at rest

(4) Angle of Internal Friction of Soil
The angle of internal friction of backfill soil normally has a value of 30°. In case of especially good backfilling material, it can be set as large as 40°. It is possible to use the results of soil tests and /or to estimate the angle of internal friction of soil by reliable estimation formulas.

(5) Angle of Friction between Backfilling Material and Backface Wall
The angle of friction between backfilling material and backface wall normally has a value of ±15–20°. It may be estimated as one-half of the angle of internal friction of backfilling material.

(6) Unit Weight of Soil.
The unit weight of soil normally has a value of 18 kN/m^3 as unsaturated soil such as a soil above the residual water level, and 10 kN/m^3 as saturated soil below it.

(7) Calculation Formula for Resultant Force of Earth Pressure
The resultant force of earth pressure is calculated at each layer. The objective force for the i-th layer can be calculated using equation **(1.2.6)**.

$$P_i = \frac{p_{i-1}+p_i}{2}\frac{h_1}{\cos\psi} \qquad (1.2.6)$$

Moreover, the horizontal and vertical components of the resultant force of earth pressure can be calculated using equations **(1.2.7)** and **(1.2.8)**.

$$P_{ih} = P_i\cos(\psi+\delta) \qquad (1.2.7)$$

$$P_{iv} = P_i \sin(\psi + \delta) \tag{1.2.8}$$

where

P_{ih}: horizontal component of the resultant force of earth pressure

P_{iv}: vertical component of the resultant force of earth pressure

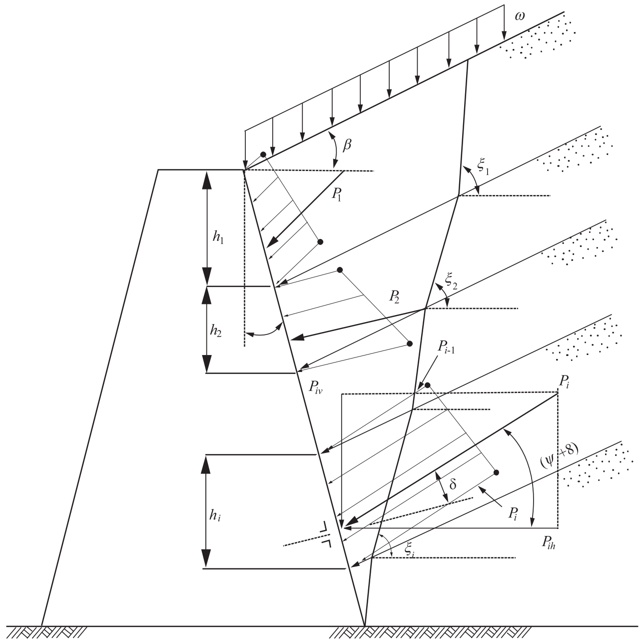

Fig. 1.2.1 Schematic Diagram of Earth Pressure Acting on Retaining Wall

1.2.2 Earth Pressure of Cohesive Soil

(1) The earth pressure of cohesive soil acting on the backface wall of structure shall generally be calculated by following equations:

① Active Earth Pressure

$$p_a = \sum \gamma_i h_i + \omega - 2c \tag{1.2.9}$$

② Passive Earth Pressure

$$p_p = \sum \gamma_i h_i + \omega + 2c \tag{1.2.10}$$

where

p_a : active earth pressure acting on the bottom level of the *i*-th soil layer (kN/m^2)

p_p : passive earth pressure acts on the bottom level of the *i*-th soil layer (kN/m^2)

γ_i : unit weight of the *i*-th soil layer (kN/m^3)

h_i : thickness of the *i*-th soil layer (m)

ω : uniformly distributed surcharge on the ground surface (kN/m^2)

c : cohesion of soil (kN/m^2)

(2) The earth pressure of cohesive soil is very complex. The equations above are based on expedient calculation methods and must be applied with care.

(3) Active earth pressure can be calculated using equation **(1.2.9)**. If a negative earth pressure is obtained by calculation, the pressure should be assumed to be zero down to the depth where positive earth pressure exerts.

(4) Equation **(1.2.11)** may be used for earth pressure at rest.

$$p = K_0 \sum \gamma_i h_i \tag{1.2.11}$$

where

K_0 : coefficient of earth pressure at rest

(5) Cohesion of Soil

Cohesion of soil should be determined using an appropriate method, refer to **Chapter 3, 2.3.3 Shear Characteristics**. For example, equation **(1.2.12)** should be used when using results of unconfined compression tests.

$$c = \frac{q_u}{2} \tag{1.2.12}$$

where

q_u : unconfined compressive strength (kN/m²)

(6) Angle of Friction between Backfilling Material and Backface Wall

In case of cohesive soil, the cohesion between backfill and backface wall should be ignored.

(7) Unit Weight of Cohesive Soil

The unit weight of cohesive soil should be estimated by soil test. The wet unit weight γ_t should be used for soils above the residual water level, and the submerged unit weight γ' be used for soils below the residual water level.

1.3 Earth Pressure during Earthquake

1.3.1 Earth Pressure of Sandy Soil

The earth pressure of sandy soil acting on a backface wall of structure during an earthquake and the angle of failure surface shall be calculated by following equations:

(1) Active Earth Pressure and the Angle of Failure Surface from the Horizontal Surface

$$p_{ai} = K_{ai}\left[\sum \gamma_i h_i + \frac{\omega\cos\psi}{\cos(\psi-\beta)}\right]\cos\psi \tag{1.3.1}$$

$$\cot(\zeta_i - \beta) = -\tan(\phi_i + \delta + \psi - \beta) + \sec(\phi_i + \delta + \psi - \beta)\sqrt{\frac{\cos(\psi+\delta+\theta)\sin(\phi_i+\delta)}{\cos(\psi-\beta)\sin(\phi_i-\beta-\theta)}} \tag{1.3.2}$$

where

$$K_{ai} = \frac{\cos^2(\phi_i - \psi - \theta)}{\cos\theta\cos^2\psi\cos(\delta+\psi+\theta)\left[1+\sqrt{\dfrac{\sin(\phi_i+\delta)\sin(\phi_i-\beta-\theta)}{\cos(\delta+\psi+\theta)\cos(\psi-\beta)}}\right]^2}$$

(2) Passive Earth Pressure and the Angle of Failure Surface from the Horizontal Surface

$$p_{pi} = K_{pi}\left[\sum \gamma_i h_i + \frac{\omega\cos\psi}{\cos(\psi-\beta)}\right]\cos\psi \tag{1.3.3}$$

$$\cot(\zeta_i - \beta) = \tan(\phi_i - \delta - \psi + \beta) + \sec(\phi_i - \delta - \psi + \beta)\sqrt{\frac{\cos(\psi+\delta-\theta)\sin(\phi_i-\delta)}{\cos(\psi-\beta)\sin(\phi_i+\beta-\theta)}} \tag{1.3.4}$$

where

$$K_{pi} = \frac{\cos^2(\phi_i + \psi - \theta)}{\cos\theta\cos^2\psi\cos(\delta+\psi-\theta)\left[1-\sqrt{\dfrac{\sin(\phi_i-\delta)\sin(\phi_i+\beta-\theta)}{\cos(\delta+\psi-\theta)\cos(\psi-\beta)}}\right]^2}$$

The notations p_{ai}, p_{pi}, K_{ai}, K_{pi}, ζ_i, ω, γ_i, h_i, ψ, β, δ and ϕ_i, are the same as those defined in **1.2 Earth Pressure at Permanent Situation,** equation **(1.2.1)** to **(1.2.4)**. Also, θ is defined as follows.

θ : composite seismic angle (º) shown as following (a) or (b):

(a) $\theta = \tan^{-1} k$

(b) $\theta = \tan^{-1} k'$

where

k and k' are as shown below;

k : seismic coefficient

k' : apparent seismic coefficient

(3) Apparent seismic coefficient shall be in accordance with **1.3.3 Apparent Seismic Coefficient.**

(4) Earth pressure during an earthquake is based on the theories proposed by Mononobe [1)] and Okabe.[2)]

(5) Angle of Friction Between Backfilling Material and Backface Wall
Angle of friction between backfilling material and backface wall normally has a value of ± 15and below. It may be estimated as one-half of the angle of internal friction of backfilling material.

(6) Earth Pressure below Residual Water Level
Generally, the earth pressure distribution above the residual water level and below the residual water level should be determined by using the seismic coefficient in air and the apparent seismic coefficient shown in **1.3.3 Apparent Seismic Coefficient** respectively. The composite seismic angle k is used for soils above the residual water level, and k' is used below it.

(7) Coefficient of Earth Pressure
The coefficient of earth pressure and angle of failure surface can be obtained from the diagrams in **Fig. 1.3.1**.

(8) The earth pressure theory assumes that the soil and the pore water behave integrally. Thus the equations mentioned above cannot be applied to liquefied soil. It is necessary for liquefied soil to evaluate the seismic stability of the ground and structures with dynamic effective stress analysis or model tests.

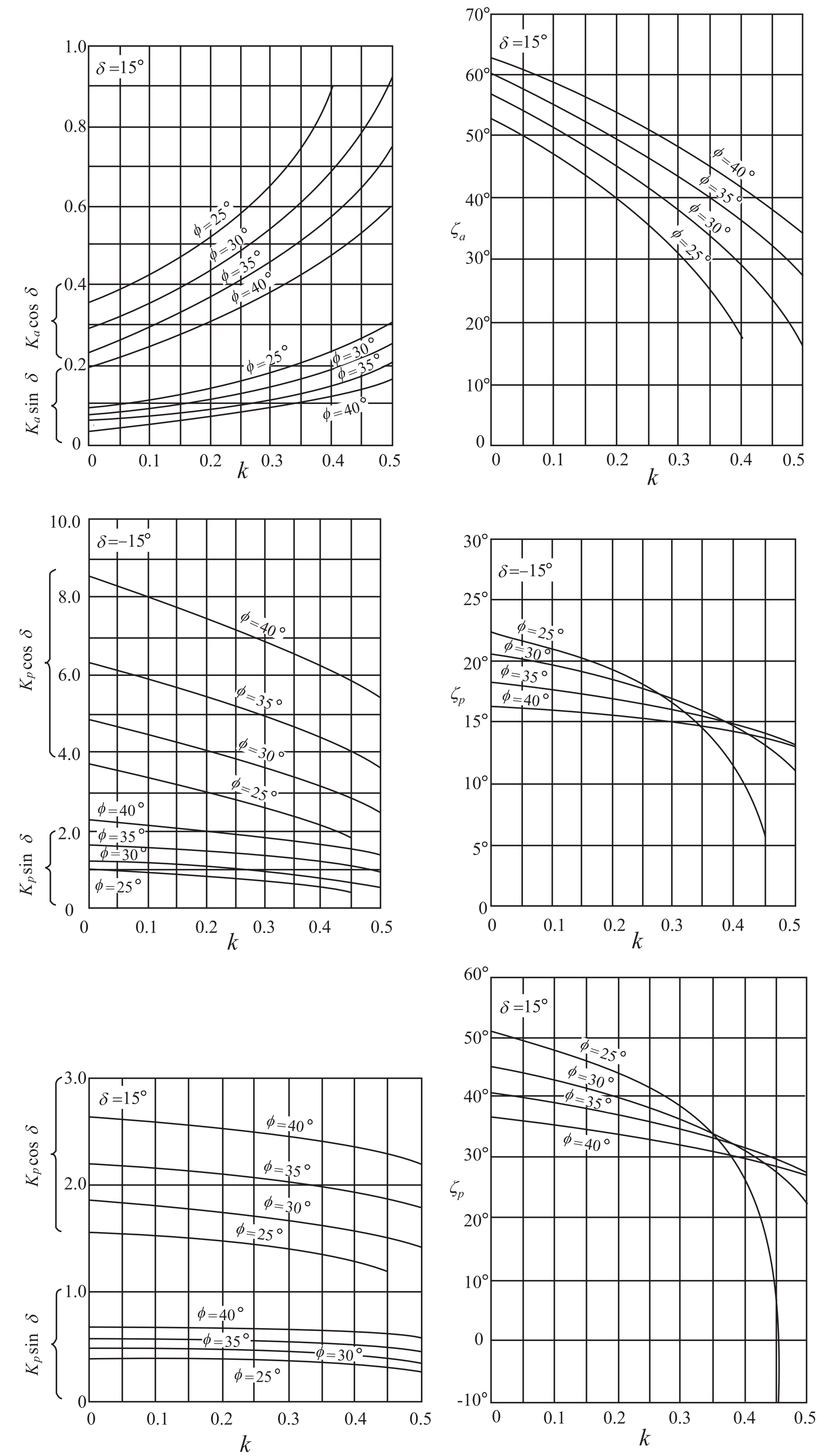

Fig. 1.3.1 Coefficient of Earth Pressure and Failure Angle

1.3.2 Earth Pressure of Cohesive Soil

The earth pressure of cohesive soil acting on a wall of the structure during an earthquake and the angle of the failure surface against the horizontal surface shall generally be calculated as follows:

(1) Active Earth Pressure
Active earth pressure shall be calculated using an appropriate earth pressure formula which takes the seismic coefficient into account so that the structural stability will be secured during an earthquake. Generally, the active earth pressure can be calculated using equation **(1.3.5)** and the angle of failure surface using equation **(1.3.6)**.

$$p_a = \frac{\left(\sum \gamma_i h_i + \omega\right)\sin\left(\zeta_a + \theta\right)}{\cos\theta \sin\zeta_a} - \frac{c}{\cos\zeta_a \sin\zeta_a} \tag{1.3.5}$$

$$\zeta_a = \tan^{-1}\sqrt{1 - \left(\frac{\sum \gamma_i h_i + 2\omega}{2c}\right)\tan\theta} \tag{1.3.6}$$

where

p_a : characteristic value of the active earth pressure (kN/m2)
γ_i : unit weight of the soil (kN/m3)
h_i : thickness of the soil layer (m)
ω : surcharge load per horizontal surface area (kN/m2)
c : cohesion of the soil (kN/m2)
θ : expressed as composite seismic angle $\theta = \tan^{-1} k$ (°) or $\theta = \tan^{-1} k'$ (°).
k : seismic coefficient
k' : apparent seismic coefficient
ζ_a : angle of the failure surface (°)

(2) Passive Earth Pressure
Passive earth pressure shall be calculated using an appropriate earth pressure formula so that the structural stability will be secured during an earthquake.
There are many unknown factors concerning the method for determining the passive earth pressure of cohesive soil during an earthquake. Conventionally, however, equation **(1.2.10)** in **1.2.2 Earth Pressure of Cohesive Soil** for obtaining the earth pressure of cohesive soil is used in line with methods for earth pressure calculation at Permanent situation. At present, equation **(1.2.10)** can be used as an expedient method.

(3) The apparent seismic coefficient should be used to calculate the earth pressure of cohesive soil down to the sea bottom during an earthquake. The apparent seismic coefficient may be set as zero when calculating the earth pressure at the depth of 10 m from the sea bottom or deeper. However, if the earth pressure at the depth of 10 m below the sea bottom becomes less than the earth pressure at the sea bottom, the latter should be applied.

1.3.3 Apparent Seismic Coefficient

(1) The earth pressure acting on the soil below the water level during an earthquake can be calculated according to the procedures outlined in **1.3.1 Earth Pressure of Sandy Soil** and **1.3.2 Earth Pressure of Cohesive Soil**, by using the apparent seismic coefficient which is generally determined by the following equation:

$$k' = \frac{2\left(\sum \gamma_t h_i + \sum \gamma h_j + \omega\right) + \gamma h}{2\left\{\sum \gamma_t h_i + \sum\left(\gamma - 10\right)h_j + \omega\right\} + \left(\gamma - 10\right)h} k \tag{1.3.7}$$

where

k' : apparent seismic coefficient
γ_t : unit weight of soil layer above the residual water level (kN/m3)
h_i : thickness of the i-th soil layer above the residual water level (m)
γ : unit weight in the air of saturated soil layer (kN/m3)
h_j : thickness of the j-th soil layer above the layer for which earth pressure is being calculated below the residual water level (m)
ω : surcharge load per unit area of the ground surface (kN/m2)
h : thickness of soil layer for which earth pressure is being calculated below the residual water level (m)
k : seismic coefficient

(2) Presently, equation **(1.3.7)** [3] is generally used for calculating earth pressure during an earthquake, as it can be applied to light-weight filling material and other new materials, and is believed to be the most rational method.

(3) On the assumption that soil grain and water move in an integrated manner with respect to soil under the water level during an earthquake, the force of the ground motion acting on the soil would be the product of the soil's saturated weight multiplied by the seismic coefficient. Moreover, since the soil under the water level is endowed with buoyancy, the vertical force acting on the soil is the soil's under-water weight. Therefore, the resultant force on the soil under the water level during an earthquake would be different from that in the air. When calculating earth pressure during an earthquake, the equation for determining earth pressure during an earthquake for soil in the air can also be used with soil under water by applying apparent seismic coefficient deduced from the composite seismic angle.

The vertical force acting on soil under water includes the weight of the soil layers above the layer for which earth pressure is being calculated as well as the surcharge load. Hence apparent seismic coefficient is affected by these factors.

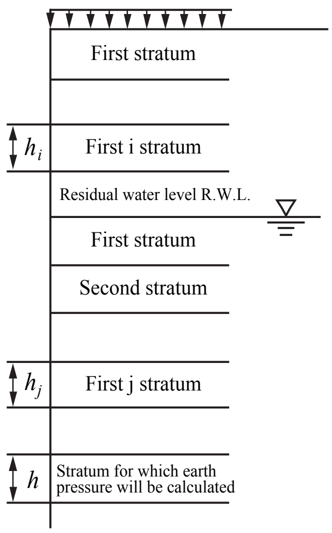

Fig. 1.3.2 Symbols for Apparent Seismic Coefficients

References

1) Mononobe, N.: Seismic Civil Engineering, Riko-Tosho Publishing, 1952
2) Okabe, S.: General Theory on Earth Pressure and Seismic Stability of Retaining Wall and Dam, Journal of JSCE Vol. 10, No. 6, p.1277, 1924
3) Arai, H. and T. Yokoi : Study on the characteristics of earthquake-resistance of sheet pile wall (Third Report)Proceedings of 3rd conference of PHRI, Vol. 1l4 No 4, 1975

2 Water Pressure

2.1 Residual Water Pressure

(1) When mooring facilities etc. have watertight structures or when backfilling material and backfilling soil (hereinafter referred to in this paragraph as "backfilling") have low permeability, there is a time delay in the water level changes in the backfilling as opposed to the water level at the front and the difference of water level appears. When carrying out performance verifications on mooring facilities etc., what needs to be checked is the conditions that develop when the water level in the backfilling is higher than that at the front and when that difference is at its greatest. Residual water pressure refers to the water pressure acting on the mooring facilities etc. under this condition.

The magnitude of the residual water-level difference varies depending on the permeability of the walls and surrounding materials making up the mooring facility etc. as well as the tidal range. The general values for residual water-level difference by structural type are shown in sections relating to performance verification of the respective facilities. Values other than these general values may be used when determining residual water-level difference from surveys conducted on similar structures nearby or from permeability checks carried out on the walls and surrounding ground.

(2) The residual water pressure caused by the time delay of water level changes between the sea level and the residual water level can be calculated using the following equation:

① When y is less than h_w

$$p_{w_k} = \rho_w g y \tag{2.1.1}$$

② When y is equal to or greater than h_w

$$p_{w_k} = \rho_w g h_w \tag{2.1.2}$$

where

p_w : residual water pressure (kN/m²)
$\rho_w g$: unit weight of seawater (kN/m³)
y : depth of soil layer from the residual water level (m)
h_w : water level difference between the water level in front and behind the facility (m)

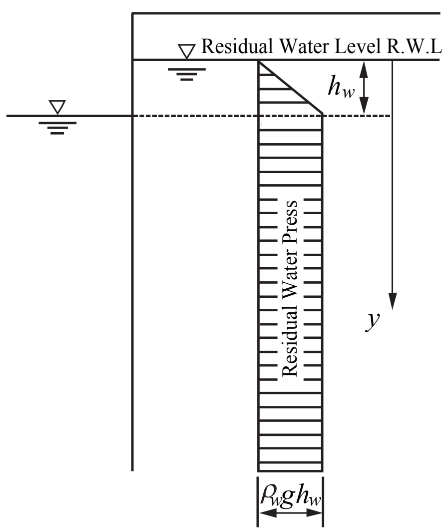

Fig. 2.1.1 Schematic Diagram of the Residual Water Pressure

(3) The residual water level is determined in consideration of factors such as permeability of backfill soil, and tidal range. Normally the height h_w will be 1/3 - 2/3 of the tidal range.

(4) After a facility is completed, the permeability of its walls and surrounding materials may diminish with time. Therefore, when the anterior tidal range is sizeable, it would be preferable to take that into consideration in determining residual water-level difference.

2.2 Dynamic Water Pressure

(1) Items (2) through (8) below should be followed when using performance verification equations that make use of characteristic values of dynamic water pressure whereas item (9) should be followed in performing verifications that use techniques such as the finite element method for taking the effects of dynamic water pressure into consideration.

(2) Normally, methods based on the dynamic water pressure on steady oscillation [1] are used for calculating the characteristic values of the dynamic water pressure. However, in view of the phase relationship of other actions, when a particular need arises, the dynamic water pressure on irregular oscillation should be calculated.

Also, if a liquid occupies spaces inside the facility, the dynamic pressure of the liquid must be taken into consideration. If dynamic water pressure is acting on both sides of the facility, the sum of the resultant force of the dynamic water pressure becomes two-fold. Dynamic water pressure needs not be considered in the following cases:

① When performance verifications can be performed without taking dynamic water pressure directly into consideration due to structural characteristics;

② When using verification methods that do not take dynamic water pressure directly into account. This would require sufficient records of results.

More specifically, this would be in the following cases:

(a) Dynamic water pressure of pore water in the caisson filling

(b) Dynamic water pressure of pore water in backfilling materials and backfilling soil of mooring quaywalls etc.

(c) Dynamic water pressure for the bottom slab reinforcement design of caisson

(3) The dynamic water pressure during an earthquake for structures in water and facilities with interior spaces that are partially or fully filled with water can be calculated using the following equation:

$$p_{dw} = \pm \frac{7}{8} k_h \rho_w g \sqrt{Hy} \tag{2.2.1}$$

where

p_{dw} : dynamic water pressure (kN/m2)
k_h : seismic coefficient
γw : unit weight of water (kN/m3)
H : height of structure below the still water level (m)
y : depth of the dynamic water pressure calculation level from the still water level (m)

The resultant force of dynamic water pressure and its acting height can be calculated by the following equation:

$$\begin{aligned} p_{dw_k} &= \pm \frac{7}{12} k_h \rho_w g H^2 \\ h_{dw} &= \frac{3}{5} H \end{aligned} \tag{2.2.2}$$

Here, P_{dw} and h_{dw} are the following values and k_h, pw and H are equal to the values of k_h, p_w and H in item (3) above respectively.

p_{dw_k} : resultant force of dynamic water pressure (kN/m)
h_{dw} : depth of the acting point of the dynamic water pressure resultant force from the still water level (m)

(4) The action of the dynamic water pressure both in the front and the back of the wall is directed towards the sea.

(5) In the case of structures using **1.3.3 Apparent Seismic Coefficient** (equation **(1.3.7)**), the dynamic water pressure acting on the front side of the wall should be directed seawards, and dynamic water pressure on the rear side of the wall needs not be considered.

(6) Where the wall is inclined, the dynamic water pressure acting on that surface is smaller than that acting on a vertical wall. This is because, the direction of motion of the water particles are diverted diagonally upwards along the inclined surface. Dynamic water pressure in this case can be calculated using the method proposed by Zanger [2] et al.

References

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Chapter 6 Ground Liquefaction

Public Notice

Ground Liquefaction

Article 17

The possibility and extent of ground liquefaction shall be assessed with appropriate methods based on the ground conditions and by taking account of the actions from earthquake ground motions.

[Commentary]

(1) Effects of Liquefaction in the Case of Level 1 Earthquake Ground Motions
As for the consideration of liquefaction in the case of level 2 earthquake ground motions, measures against liquefaction are taken to protect the ground concerned when liquefaction is predicted and judged to occur, taking account of the effects of liquefaction on structures and the surrounding situations of the facilities concerned.

(2) Effects of Liquefaction in the Case of Level 2 Earthquake Ground Motions
As for the consideration of liquefaction in the case of Level 2 earthquake ground motions, the methods of taking measures against liquefaction and the necessity of their implementation are determined based on a comprehensive evaluation of the situations of the facilities concerned.

[Technical Note]

1 General

The subjects described in this Chapter may refer to **Handbook of Liquefaction Measures for Reclaimed Land (Revised Edition)**.[1)]

The following methods are for the study of ground liquefaction in the case of Level 1 earthquake ground motions.

As for the consideration of liquefaction in the case of Level 2 earthquake ground motions, the methods of taking measures against ground liquefaction and the necessity of their implementation shall be determined based on a comprehensive evaluation of the situations of the facilities concerned. Refer to **Chapter 4 Earthquakes** of this Part Ⅱ and the description on the performance verification of facilities in Part 3 for the evaluation.

2 Prediction and Judgment of Liquefaction

(1) The prediction and judgment of whether or not the ground is liquefied are generally performed by proper methods using grain sizes and standard penetration test values or the results of cyclic triaxial tests.

(2) Methods of Prediction and Judgment of Liquefaction
Liquefaction prediction and judgment methods include the method using grain sizes and N values or that using the results of cyclic triaxial tests. The method using grain sizes and N values is simple and easy and can be generally used for predicting and judging liquefaction. The method using the results of cyclic triaxial tests is more detailed and can be used when the prediction and judgment using grain sizes and N values have been found difficult and more detailed approaches are needed.

(3) Prediction and Judgment of Liquefaction Using Grain size and *N*-values.[2)]

① Judgment based on grain size
The subsoils should be classified according to grain size, by referring to **Fig.2.1**, to which application depends on the value of the uniformity coefficient. The threshold value of the uniformity coefficient ($U_c = D_{60} / D_{10}$) is 3.5, where U_c is the uniformity coefficient, and D_{60} and D_{10} denote the grain sizes corresponding to 60% and 10% passing, respectively. Soil is judged not to liquefy when the grain size distribution curve is not included in the range “possibility of liquefaction” in **Fig. 2.1**.

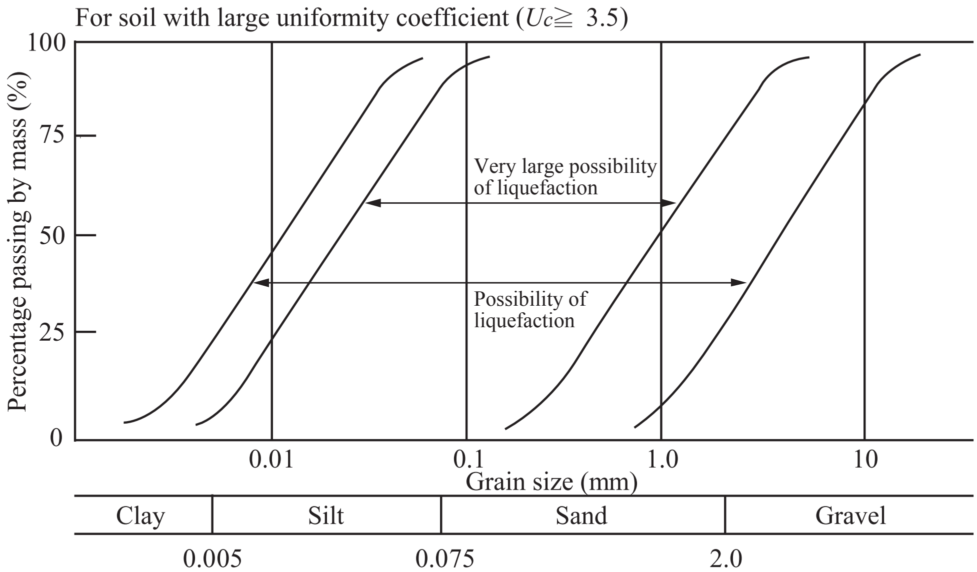

Fig. 2.1(a) Range of Possible Liquefaction ($U_c \geqq 3.5$)

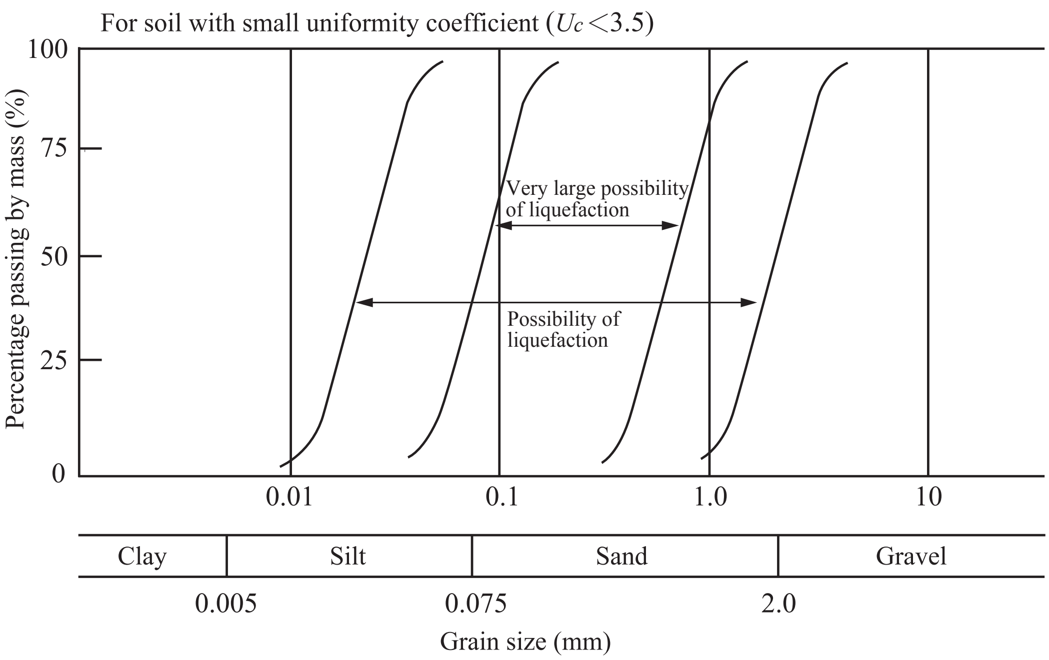

Fig. 2.1(b) Range of Possible Liquefaction ($U_c < 3.5$)

When the grain size distribution curve spans the "possibility of liquefaction" range, a suitable approach is required to examine the possibility of liquefaction. For soil with a large portion of fine grain size distribution, a cyclic triaxial test should be carried out. For soil with a large gravel portion, the soil is determined not to liquefy when the coefficient of permeability is 3 cm/s or greater. When there are subsoils with poor permeability such as clay or silt on top of the target subsoil in this case, however, it should be treated as soil that falls within the range of "possibility of liquefaction".

A permeability test for the soil with the permeability of larger than 3cm/s shall be a special method.[3)] A method of indirect estimation of permeability is available when the permeability measurement is difficult. However, care about the soil characteristics, such as content of fine particles shall be paid to apply the indirect estimation method.

② Prediction and judgment of liquefaction using equivalent *N*-values and equivalent acceleration
For the subsoil with a grain size that falls within the range "possibility of liquefaction" shown in **Fig. 2.1**, further investigations should be carried by the descriptions below.

(a) Equivalent *N*-value

The equivalent *N*-value should be calculated from equation **(2.1)**.

$$(N)_{65} = \frac{N - 0.019(\sigma_v' - 65)}{0.0041(\sigma_v' - 65) + 1.0} \tag{2.1}$$

where

$(N)_{65}$: equivalent *N*-value

N : *N*-value of the subsoil

σ_v' : effective overburden pressure of the subsoil (kN/m²)
(The effective overburden pressure used here should be calculated with respect to the ground elevation at the time of the standard penetration test.)

Fig. 2.2 shows the relationship given by equation **(2.1)**. When using equation **(2.3)** described below, the N values themselves of the soil layer are assumed to be equivalent N values.

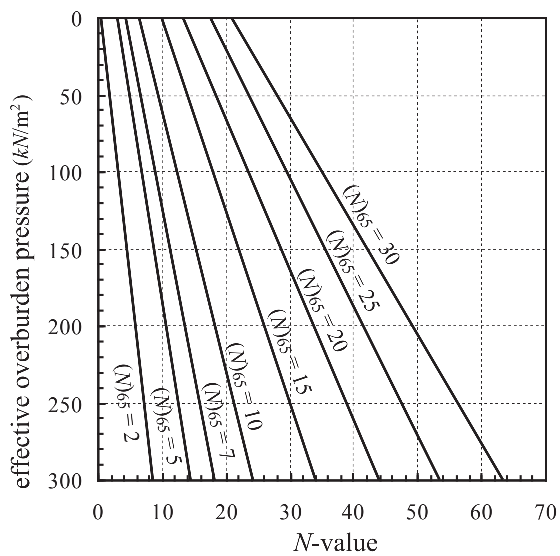

Fig. 2.2 Calculation Chart for Equivalent N-value, the Straight Lines show the Relationship between N-values and Effective Overburden Pressures when Relative Densities are Constant

(b) Equivalent accelerations

Equivalent accelerations are calculated from equation **(2.2)**. They are calculated for each soil layer using the maximum shear stresses obtained from the results of the seismic response analyses of the ground.

$$\alpha_{eq} = 0.7 \frac{\tau_{\max}}{\sigma_V'} g \tag{2.2}$$

where

α_{eq} : equivalent acceleration (Gal)

$\tau_{\max}$: maximum shear stress (kN/m²)

σ_V' : effective overburden pressure (kN/m²) (Note that the effective overburden pressures used for calculating equivalent accelerations are obtained based on the ground heights at the time of earthquakes.)

g : gravitational acceleration (980 Gal)

(c) Predictions and judgment using the equivalent N-value and equivalent acceleration

The subject soil layer should be classified according to the ranges labeled I – IV in **Fig. 2.3**, using the equivalent N-value and the equivalent acceleration of the soil layer.

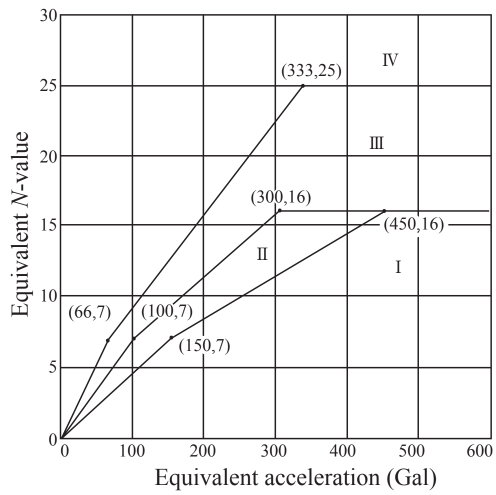

Fig. 2.3 Classification of Soil Layer with Equivalent N-Value and Equivalent Acceleration

③ Prediction, judgment and correction of N-values when the fraction of fines content is relatively large.

(a) When the fines content, grain size of 75 μm or less, is 5% or greater, the equivalent N-value should be corrected before applying **Fig. 2.3**, then the subject soil should be evaluated to which range of I to IV in **Fig. 2.3** it falls. Corrections of the equivalent N-value are divided into the following three cases.

(b) Case 1: when the plasticity index is less than 10 or cannot be determined, or when the fines content is less than 15%;

The equivalent N-value, after correction, should be set as $(N)_{65}/c_N$. The correction factor c_N is given in **Fig. 2.4**. The equivalent N-value, after correction, and the equivalent acceleration are used to determine the range in **Fig. 2.4**.

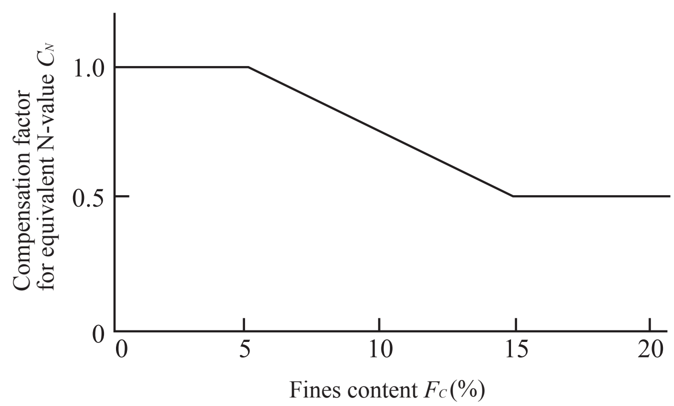

Fig. 2.4 Correction Factor of Equivalent N-Value Corresponding to Fine Contents

(c) Case 2: when the plasticity index is greater than 10 but less than 20, and the fines content is 15% or higher; The equivalent N-value, after correction, should be set as both $(N)_{65}/0.5$ and $N + \Delta N$, and the range should be determined according to the following situations, where the value for ΔN is given by the following equation:

$$\Delta N = 8 + 0.4\left(I_p - 10\right) \tag{2.3}$$

1) when $N + \Delta N$ falls within the range I, use range I.
2) when $N + \Delta N$ falls within the range II, use range II.
3) when $N + \Delta N$ falls within the range III or IV and $(N)_{65}/0.5$ is within range I, II or III, use range III.
4) when $N + \Delta N$ falls within range III or IV and $(N)_{65}/0.5$ is within range IV, use range IV.

(d) Case 3: when the plasticity index is 20 or greater, and the fines content is 15% or higher;

The equivalent *N*-value, after correction, should be set as $N + \Delta N$. The range should be determined according to the equivalent *N*-value, after correction, and the equivalent acceleration.

(e) **Fig. 2.5** shows the relationship between fines content and plasticity index which is described above (b), (c) and (d).

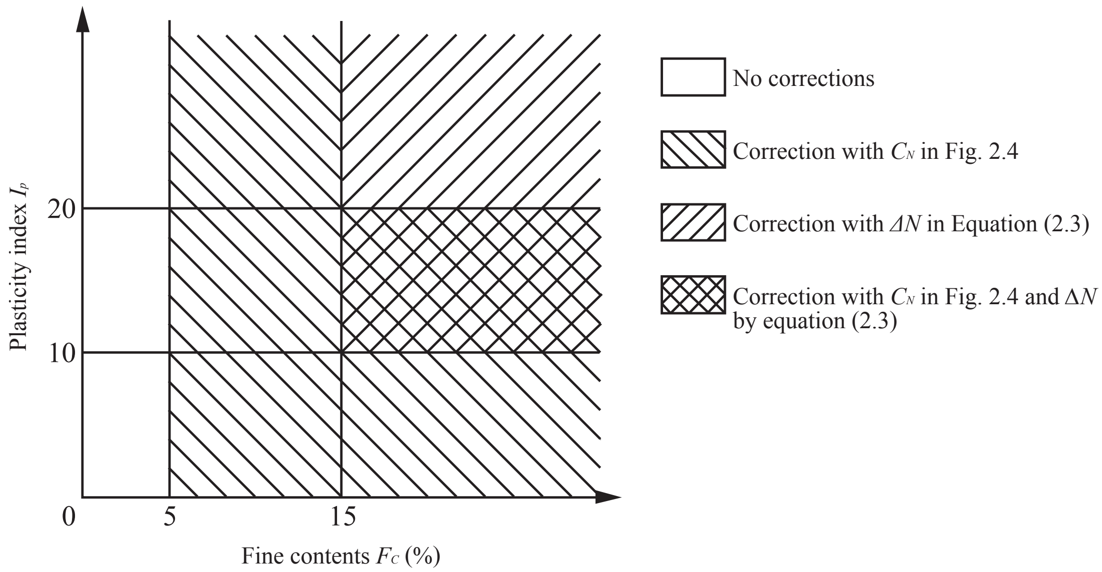

Fig. 2.5 N-Value Correction Methods by Fine Contents and Plasticity Index

④ Prediction and judgment of liquefaction
Since liquefaction predictions must also consider the factors other than physical phenomena such as what degree of safety should be maintained in the structures, it is not possible to unconditionally establish any criterion for judgments regarding various prediction results. **Table 2.1** shows the judgment that is considered as standard.

In this table the term "prediction of liquefaction" refers to the high or low possibility of liquefaction as a physical phenomenon. In contrast, the term "judgment of liquefaction" refers to the consideration of the high or low possibility of liquefaction and determination of whether or not the ground will liquefy.

Table 2.1 Prediction and Judgment of Liquefaction for Soil Layer According to Ranges I to IV

Range shown in **Fig. 2.3**	Prediction of liquefaction	Judgment of liquefaction
I	Possibility of liquefaction occurrence is very high	Liquefaction will occur
II	Possibility of liquefaction occurrence is high	Either to judge that liquefaction will occur or to conduct further evaluation based on cyclic triaxial tests.
III	Possibility of liquefaction is low	Either to judge that liquefaction will not occur or to conduct further evaluation based on cyclic triaxial tests. For a very important structure, either to judge that liquefaction will occur or to conduct further evaluation based upon cyclic triaxial tests.
IV	Possibility of liquefaction is very low	Liquefaction will not occur

(4) Prediction and Judgment Based on the Results of Cyclic Triaxial Tests

① When it may be difficult to predict and judge the possibility of subsoil liquefaction of the subject ground from the results of grain size and *N*-values, the prediction and the judgment for subsoil liquefaction should be made with the results of a seismic response analysis and cyclic triaxial tests conducted on undisturbed soil samples.

② The proper consideration of the stress state in the ground and the irregularity of the actions caused by ground motions is important for the results of the seismic response analyses of the ground and those of cyclic triaxial tests to show actual phenomena in the ground.

(5) Judgment of Overall Liquefaction
In the judgment of overall subsoil liquefaction for a site consisting of soil layers, the comprehensive decision should be made based on a judgment for each layer of subsoil.

(6) Liquefaction Prediction and Judgment in the Case of Long-duration Ground Motions
The liquefaction prediction and judgment method using grain sizes and N-values is an empirical approach for the cases of ground motions whose principal motions have duration of about 20 seconds. It should be noted that this

method is likely to give prediction and judgment results on the danger side in the cases where the ground motions concerned have long duration.

(7) Liquefaction Prediction and Judgment in the Cases of Long-period Ground Motions
The liquefaction prediction and judgment method using grain sizes and N-values is an empirical approach for the cases of ground motions whose principal motions have a period of about one second. It should be noted that this method is likely to give prediction and judgment results on the danger side for cohesive soil in the cases where the ground motions concerned have a long period.

References

1) Coastal Development Institute of Technology (CDIT): Handbook of liquefaction of reclaimed land (Revised Edition), 1997
2) Yamazaki, H., K. Zen and F. Koike Study of the Liquefaction Prediction Based on the Grain Distribution and the SPT N-value, Technical Note of PHRI, No.914,1998
3) The Japan Geotechnical Society: Soil Testing Methods and Commentary, pp.271-288,2000
4) Japan Geotechnical Society: Geotechnical Engineering Handbook, pp.16-20,1999

Chapter 7 Ground Subsidence

Public Notice

Ground Subsidence

Article 15
Influence of ground subsidence shall be assessed with appropriated methods based on the ground conditions in consideration of the structures of the facilities, imposed load, and the surrounding situations of the facilities concerned.

[Technical Note]

1.1.1 Ground Subsidence

Ground subsidence includes immediate settlement, consolidation settlement, uneven settlement, lateral displacement etc. The effects of ground subsidence shall be evaluated based on ground conditions using proper methods and properly taking account of the structures of the facilities concerned, surcharges, and the actions caused by ground motions. The evaluation of ground subsidence may refer to **Chapter 3 Geotechnical Conditions** of **Part II** and **2.5 Settlement of Foundation in Chapter 2 of Part III.**

Chapter 8 Ships

Public Notice

Dimensions of Design Ships and Related Matters

Article 18

1 The dimensions of design ships (hereinafter refers to the ships used as the input data in the performance verification of the facilities subject to the Technical Standards) shall be set according to the methods provided in the subsequent items:

(1) In the case where design ships are identifiable, their dimensions shall be used.

(2) In the case where design ships are unidentifiable, the dimensions shall be properly set based on the statistical analyses of the dimensions of ships in operation.

2 The actions from ship berthing, ship movements, and the traction by ships shall be set according to the methods provided in the subsequent items corresponding to a single action or the combinations of two or more actions to be considered in the performance criteria and the performance verification of the facilities concerned:

(1) The actions from ship berthing shall be set with appropriate methods by taking account of the dimensions of design ships, the structures of the facilities concerned, berthing methods, berthing velocities, and/or others.

(2) The actions from ship movements shall be set with appropriate methods by taking account of the dimensions of design ships, the structures of the facilities concerned, mooring methods, characteristics of mooring system, and the winds, waves, water currents, and/or others acting on design ships.

(3) The actions from the traction by ships shall be set with appropriate methods by taking account of the dimensions of design ships, mooring methods, and the winds, waves, water currents, and/or others acting on design ships.

[Commentary]

(1) Principal Dimensions of Design Ships
Design ships are those, among the ships using the facilities concerned, which are assumed to have the most significant effects on the performance verification of the facilities. It should be noted that design ships vary depending on performance criteria to be applied even for the same facilities and that they are not always the ships with the largest gross tonnage.

(2) Actions due to Ship Berthing and the Traction by Ships

① Actions caused by ship berthing
The actions caused by ship berthing to mooring facilities shall be properly considered. In setting the actions caused by ship berthing, ship berthing energy can be calculated using proper methods based on ship masses, ship berthing velocities, virtual mass factors, eccentricity factors, flexibility factors, and the berth configuration factors.

② Actions caused by ship movements
The actions caused by ship motions to mooring facilities shall be properly determined. Methods to be considered are oscillation calculation etc.

③ Actions due to the traction by ships
The traction caused by ships to mooring facilities shall be properly determined. The setting of the traction by ships properly takes account of the actions caused by moored and berthed ships.

[Technical Note]

1 Principal Dimensions of Design Ships

(1) Design ships are those, among the ships expecting to use the facilities concerned, which are assumed to have the most significant effects on the performance verification of the facilities. Therefore, in the case where design ships are identifiable, their principal dimensions may be used.

(2) In the case where design ships are unidentifiable in advance such case as the public port facilities, the standardized values of tonnages, lengths overall, lengths between perpendiculars, molded breadths, and full load drafts by ship type shown in **Table 1.1** may be used for the designs. The standard values in **Table 1.1** are prepared based on the statistical analysis of the dimensions of the existing ships with a coverage ratio of 75% for each tonnage category. The data on the dimensions of small cargo vessels used for the standard values vary widely, hence the dimensions of small cargo vessels should be set using the values in **Table 1.2** as references and taking into consideration the trends of ships in ports. The gross tonnage, GT, given in **Table 1.1** basically means international gross tonnage, but in some cases it refers to domestic gross tonnage depending on the characteristics of the data used for setting the standard values. Such cases, where the gross tonnage, means the domestic gross tonnage, are clearly indicated in **Table 1.1**. The table uses the commonly used tonnage, gross tonnage or dead weight tonnage, of each ship type as the representative index. **Fig. 1.1** shows the principal dimensions used in the tables.

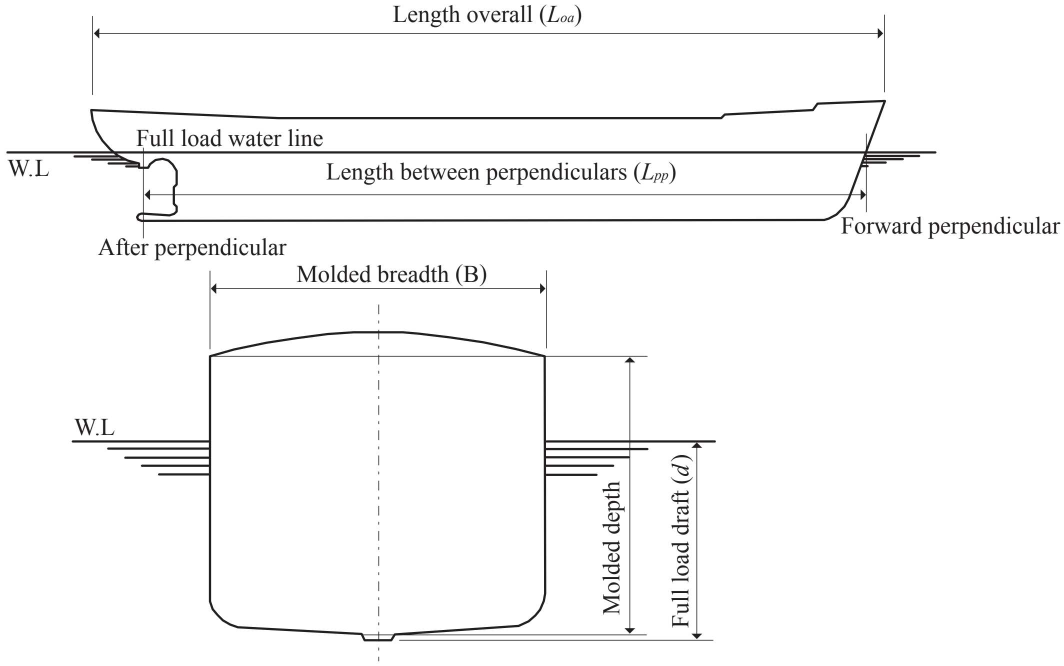

Fig. 1.1 Principal Dimensions of Ships

Table 1.1 Standard Values of the Principal Dimensions of Design Ships

1 General cargo ships

Dead Weight Tonnage *DWT* (t)	Length overall L_{oa} (m)	Length between perpendiculars L_{pp} (m)	Molded breadth B (m)	Full load draft d (m)
1,000	67	61	10.7	3.8
2,000	82	75	13.1	4.8
3,000	92	85	14.7	5.5
5,000	107	99	17	6.4
10,000	132	123	20.7	8.1
12,000	139	130	21.8	8.6
18,000	156	147	24.4	9.8
30,000	182	171	28.3	10.5
40,000	198	187	30.7	11.5
55,000	217	206	32.3	12.8
70,000	233	222	32.3	13.8
90,000	251	239	38.7	15
120,000	274	261	42	16.5
150,000	292	279	44.7	17.7

2 Container ships

Dead Weight Tonnage DWT (t)	Length overall L_{oa} (m)	Length between perpendiculars L_{pp} (m)	Molded breadth B (m)	Full load draft d (m)	Reference: Container carrying capacity (TEU)
10,000	139	129	22.0	7.9	500 – 890
20,000	177	165	27.1	9.9	1,300 – 1,600
30,000	203	191	30.6	11.2	2,000 – 2,400
40,000	241	226	32.3	12.1	2,800 – 3,200
50,000	274	258	32.3	12.7	3,500 – 3,900
60,000	294	279	35.9	13.4	4,300 – 4,700
100,000	350	335	42.8	14.7	7,300 – 7,700

3 Tankers

Dead Weight Tonnage DWT (t)	Length overall L_{oa} (m)	Length between perpendiculars L_{pp} (m)	Molded breadth B (m)	Full load draft d (m)
1,000	63	57	11.0	4.0
2,000	77	72	13.2	4.9
3,000	86	82	14.7	5.5
5,000	100	97	16.7	6.4
10,000	139	131	20.6	7.6
15,000	154	146	23.4	8.6
20,000	166	157	25.6	9.3
30,000	184	175	29.1	10.4
50,000	209	199	34.3	12.0
70,000	228	217	38.1	12.9
90,000	243	232	41.3	14.2
100,000	250	238	42.7	14.8
150,000	277	265	48.6	17.2
300,000	334	321	59.4	22.4

4 Roll-On Roll-Off (RORO) ships

Gross Tonnage GT (t)	Length overall L_{oa} (m)	Length between perpendiculars L_{pp} (m)	Molded breadth B (m)	Full load draft d (m)
3,000	120	110	18.9	5.8
5,000	140	130	21.4	6.5
10,000	172	162	25.3	7.7
20,000	189	174	28.0	8.7
40,000	194	174	32.3	9.7
60,000	208	189	32.3	9.7

(3,000, 5,000, and 10,000 GT are in Japanese gross tonnage)

5 Pure Car Carrier (PCC) ships

Gross Tonnage GT (t)	Length overall L_{oa} (m)	Length between perpendiculars L_{pp} (m)	Molded breadth B (m)	Full load draft d (m)
3,000	112	103	18.2	5.5
5,000	130	119	20.6	6.2
12,000	135	123	21.8	6.8
20,000	158	150	24.4	7.9
30,000	179	175	26.7	8.8
40,000	185	175	31.9	9.3
60,000	203	194	32.3	10.4

(3,000 and 5,000 GT are in Japaese gross tonnage)

6 Liquefied Petroleum Gas (LPG) carriers

Gross Tonnage GT (t)	Length overall L_{oa} (m)	Length between perpendiculars L_{pp} (m)	Molded breadth B (m)	Full load draft d (m)
3,000	98	92	16.1	6.3
5,000	116	109	18.6	7.3
10,000	144	136	22.7	8.9
20,000	179	170	27.7	10.8
30,000	204	193	31.1	12.1
40,000	223	212	33.8	13.1
50,000	240	228	36.0	14.0

7 Liquefied Natural Gas (LNG) carriers

Gross Tonnage GT (t)	Length overall L_{oa} (m)	Length between perpendiculars L_{pp} (m)	Molded breadth B (m)	Full load draft d (m)
20,000	174	164	27.8	8.4
30,000	199	188	31.4	9.2
50,000	235	223	36.7	10.4
80,000	274	260	42.4	11.5
100,000	294	281	45.4	12.1

8 Passenger ships

Gross Tonnage GT (t)	Length overall L_{oa} (m)	Length between perpendiculars L_{pp} (m)	Molded breadth B (m)	Full load draft d (m)
3,000	97	88	16.5	4.3
5,000	115	104	18.6	5.0
10,000	146	131	21.8	6.4
20,000	186	165	25.7	7.8
30,000	214	189	28.2	7.8
50,000	255	224	32.3	7.8
70,000	286	250	32.3	8.1
100,000	324	281	32.3	8.1

9 Ferries

9-1 Short-to-medium distance ferries (navigation distance of less than 300 km in Japan)

Gross Tonnage GT (t)	Length overall L_{oa} (m)	Length between perpendiculars L_{pp} (m)	Molded breadth B (m)	Full load draft d (m)
400	56	47	11.6	2.8
700	70	60	13.2	3.2
1,000	80	71	14.4	3.5
3,000	124	116	18.6	4.6
7,000	141	130	22.7	5.7
10,000	166	155	24.6	6.2
13,000	194	179	26.2	6.7

(All are in domestic gross tonnage)

9-2 Long distance ferries (navigation distance of 300 km or more in Japan)

Gross Tonnage GT (t)	Length overall L_{oa} (m)	Length between perpendiculars L_{pp} (m)	Molded breadth B (m)	Full load draft d (m)
6,000	147	135	22	6.3
10,000	172	159	25.1	6.3
15,000	197	183	28.2	6.9
20,000	197	183	28.2	6.9

(All are in domestic gross tonnage)

Table 1.2 Reference Values of the Principal Dimensions of Design Ships

10 Small cargo vessels

Dead Weight Tonnage DWT (t)	Length overall L_{oa} (m)	Length between perpendiculars L_{pp} (m)	Molded breadth B (m)	Full load draft d (m)
500	53	47	9.4	3.3
700	58	53	9.5	3.3

(3) The table for the standard values of the principal dimensions of design ships shows the principal dimensions of ships for stepwise tonnage categories. These dimensions are obtained from statistical analyses by Takahashi et al.[1), 2)] with overall coverage ratio of 75%. Some ships therefore have larger dimensions than those of the same tonnage category ships given in the table, and some other ships with the tonnage category larger than that set for design ships have dimensions smaller than those given in the table.

(4) The data of "LMIU Shipping Data (2004.1)" [3)] and "Japanese Register of Ships (2004)" [4)] are used for determining the principal dimensions of design ships.

(5) Tonnage [5)]

The definitions of the various types of tonnage are as follows:

① Gross Tonnage

The measurement tonnage of sealed compartments of a ship, as stipulated in the "**Law Concerning the Measurement of the Tonnage of Ships**".

② Dead Weight Tonnage

The maximum weight, expressed in tons, of cargo that can be loaded onto a ship.

③ Displacement Tonnage

The amount of water, expressed in tons, displaced by a ship when it is floating at rest.

(6) The regression equations for gross tonnages, GT, and displacement tonnages, DSP, are shown in **Tables 1.3** and **1.4**, [1), 2), 6)] respectively. They are applicable on the condition that the coefficients of determination R^2 and the standard deviations σ around the regression equations are taken into consideration. The regression equations

for each ship type in the tables are applicable within the range of the tonnages shown in **Table 1.1**.

(7) The container ships of under-panamax, panamax, and over-panamax types have characteristic dimensions peculiar to each type, and hence the setting of their dimensions may refer to **Tables 1.5** to **1.9**. The setting of the dimensions of very large crude oil carrier may refer to **Table 1.10**.

(8) The heights of the ships differ considerably even in case of the same type and the same tonnage. The performance verification of bridges and other structures crossing waterways should therefore take account of the heights of design ships from the sea surface to the highest points. The heights of ships can refer to the findings of the study by Takahashi et al.[7), 8)].

Table 1.3 Regression Equations for Dead Weight Tonnages (DWT) and Gross Tonnages (GT) [1), 2)]

Ship type		Regression equation	Coefficient of determination R^2	Standard deviation σ (t)
General cargo ship		$GT = 0.529DWT$	0.988	2,202
Container ship		$GT = 0.882DWT$	0.971	3,735
Tanker		$GT = 0.535DWT$	0.992	4,276
RORO ship	International Gross tonnage	$GT = 1.780DWT$	0.752	7,262
	Domestic Gross tonnage	$GT = 1.409DWT$	0.825	1,528
Pure car carrier (PCC)	International Gross tonnage	$GT = 2.721DWT$	0.826	7,655
	Domestic Gross tonnage	$GT = 1.241DWT$	0.781	676
LPG carrier		$GT = 0.845DWT$	0.988	1,513
LNG carrier		$GT = 1.370DWT$	0.819	12,439
Passenger ship		$GT = 8.939DWT$	0.862	12,285
Medium distance ferry		$GT = 2.146DWT$	0.833	1,251
Long distance ferry		$GT = 2.352DWT$	0.816	1,988

Table 1.4 Regression Equations for Dead Weight Tonnages (DWT) or Gross Tonnages (GT) and Displacement Tonnages (DSP) [6)]

Ship type	Regression equation	Standard deviation σ
General cargo ship	$DSP = 1.139DWT$	$0.052DWT$
Container ship	$DSP = 1.344DWT$	$0.060DWT$
Tanker	$DSP = 1.138DWT$	$0.145DWT$
RORO ship (International Gross Tonnage)*	$DSP = 0.880GT$	$0.211\ GT$
Pure car carrier (PCC) (International Gross Tonnage)*	$DSP = 0.652GT$	$0.147\ GT$
LPG carrier	$DSP = 1.114GT$	$0.425\ GT$
LNG carrier	$DSP = 1.015GT$	$0.154\ GT$
Passenger ship	$DSP = 0.522GT$	$0.076\ GT$
Medium distance ferry	$DSP = 1.052GT$	$0.337\ GT$
Long distance ferry	$DSP = 1.150GT$	$0.135\ GT$

* Only international gross tonnage values are shown.

Table 1.5 Principal Dimensions of Container Ships (under panamax) 1), 2)

Dead Weight Tonnage DWT (t)	Length overall L_{oa} (m)	Length between perpendiculars L_{pp} (m)	Molded breadth B (m)	Full load draft d (m)	Reference: Container carrying capacity (TEU)
5,000	109	101	17.9	6.3	300 – 500
10,000	139	129	22.0	7.9	630 – 850
20,000	177	165	27.0	10.0	1,300 – 1,500
30,000	203	191	30.4	11.4	2,000 – 2,200
40,000	225	211	30.6	12.5	2,600 – 2,900

Table 1.6 Principal Dimensions of Container Ships (panamax) 1), 2)

Dead Weight Tonnage DWT (t)	Length overall L_{oa} (m)	Length between perpendiculars L_{pp} (m)	Molded breadth B (m)	Full load draft d (m)	Reference: Container carrying capacity (TEU)
30,000	201	187	32.3	11.3	2,100 – 2,400
40,000	237	223	32.3	12.0	2,800 – 3,200
50,000	270	255	32.3	12.7	3,400 – 3,900
60,000	300	285	32.3	13.4	4,000 – 4,600

Table 1.7 Principal Dimensions of Container Ships (over panamax) 1), 2)

Dead Weight Tonnage DWT (t)	Length overall Loa (m)	Length between perpendiculars L_{pp} (m)	Molded breadth B (m)	Full load draft d (m)	Reference: Container carrying capacity (TEU)
60,000	275 / 285	260 / 268	37.2 / 40.0	12.7 / 13.8	4,300 – 5,400
70,000	276 / 280	263 / 266	40.0 / 40.0	14.0 / 14.0	5,300 – 5,600
80,000–100,000	300 / 304	285 / 292	40.0 / 42.8	13.5 / 14.5	6,300 – 6,700

* This table does not show the results of statistical analyses, but shows the 1/4th and 3/4th values in ascending order.

Table 1.8 Principal Dimensions of Container Ships Over 100,000 DWT

Dead Weight Tonnage DWT (t)	Length overall L_{oa} (m)	Length between perpendiculars L_{pp} (m)	Molded breadth B (m)	Full load draft d (m)	Reference: Container carrying capacity (TEU)
100,870	324.0	324.0	42.0	13.0	8,000
101,570	334.1	319.0	42.8	14.5	8,204
101,612	334.0	319.0	42.8	14.5	8,100
104,696	346.0	331.5	42.8	14.5	6,600
104,700	346.0	331.5	42.8	14.5	6,600
104,750	346.0	331.5	42.8	14.5	7,226
107,500	332.0	—	43.2	14.5	8,400
109,000	352.0	336.4	42.8	14.5	10,150
110,000	336.7	321	42.8	15.0	9,200
115,700	366.9	351.1	42.8	15.0	7,929
156,907	397.6	376.0	56.0	16.5	11,000

* This table is prepared based on "LMIU Shipping Data (2006.8)." As of August 2006, 100 container ships have a tonnage of over 100,000 DWT. In this table, each DWT category represents a case where there are three or more ships with the same DWT category, and shows the principal dimensions of the ship with the largest container carrying capacity among them except one ship of 156,907 DWT.

Table 1.9 Principal Dimensions of the Container Ships with a Container Carrying Capacity of Over 8,000 TEU

Container carrying capacity (TEU)	Length overall L_{oa} (m)	Length between perpendiculars L_{pp} (m)	Molded breadth B (m)	Full load draft d (m)	Reference: Self weight Tonnage DWT (t)
8,000	324.0	324.0	42.0	13.0	100,870
8,030	324.8	–	42.0	14.5	104,904
8,063	323.0	308.0	42.8	14.5	99,615
8,100	335.5	–	42.8	14.6	103,800
8,152	335.0	–	42.8	13.5	97,612
8,154	275.0	263.0	37.1	12.5	68,363
8,189	334.0	–	–	14.5	101,906
8,200	334.1	314.7	–	14.5	101,818
8,204	334.0	319.0	–	14.5	110,000
8,238	335.0	319.0	42.8	11.5	97,430
8,400	332.4	317.2	–	14.5	108,180
9,200	350.6	336.8	42.8	14.5	112,062
9,415	349.0	353.3	42.8	14.5	117,800
9,600	337.0	–	–	–	115,000
10,150	352.0	336.4	42.8	14.5	109,000
11,000	397.6	376.0	56.0	16.5	156,907

* This table is prepared based on “LMIU Shipping Data (2006.8).” As of August 2006, 90 container ships have a capacity of over 8,000 TEU. In this table, each TEU category represents a case where three or more ships with the same TEU capacity exist. The principal dimensions of the ship with the largest DWT among them are indicated in the table except the largest ship of 11,000 TEU ship.

Table 1.10 Principal Dimensions of Tankers Over 400,000 DWT

Dead Weight Tonnage DWT (t)	Length overall L_{oa} (m)	Length between perpendiculars L_{pp} (m)	Molded breadth B (m)	Full load draft d (m)
423,000	380	366	68.0	24.5
441,893	380	366	68.0	24.5
441,823	380	–	68.0	24.5
442,470	380	–	68.0	24.5

* This table shows the data of a particular ship.

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2) Lloyd’s Marine Intelligence Unite: LMIU Shipping Data (2004.1), 2004
3) Japan Shipping Exchange, Inc.: The Annual “Register of Ships” (SENPAKU MEISAISHO)2004, 2004
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2 Actions Caused by Ships

2.1 General

2.1.1 Ship Berthing

(1) The actions caused by berthing ships to mooring facilities shall be determined using appropriate methods, taking account of the dimensions of design ships, berthing methods, berthing velocities, the structures of mooring facilities, etc.

(2) The actions caused by berthing ships to mooring facilities shall include those by ship berthing. The performance verification of mooring facilities, in general, shall take account of the berthing forces by ships.

(3) The berthing forces caused by ships to mooring facilities can generally be calculated based on the berthing energy of ships using the displacement-restoring force characteristics of fender systems.

(4) In the normal performance verification of fender systems, in general, the berthing forces of ships are dominant actions. The types of design ships, berthing velocities, berthing methods etc. have significant effects on berthing forces, and hence it is preferable for the performance verification to thoroughly study the conditions of design ships.

(5) In general, the actions caused by ships rarely dominate in the performance verification of mooring facilities. In verifying the performance of offshore berths for mooring large tankers and large ore carriers, piled piers designed with small seismic actions and mooring facilities for ship refuge, however, the actions caused by ships sometimes dominate in designing the structure. Careful attention should be paid in these cases.

2.1.2 Ship Motions

(1) The actions caused by moored ships to mooring facilities shall be determined using appropriate methods, taking account of the dimensions of design ships, the structures of mooring facilities, mooring methods, the characteristics of mooring equipment, and the winds, waves and water current etc. acting on design ships.

(2) The actions caused by moored ships to mooring facilities shall include those by ship motions. The performance verification of mooring facilities, in general, shall take account of the impact forces and tractive forces on the mooring facilities caused by the motions of moored ships. The motions are generated by the action of the wave forces, wind pressure forces, and water current pressure forces on the ships. In the cases of the mooring facilities constructed at the port facing the open sea and expecting the invasion of long period waves, or constructed in the open sea or port entrance such as the offshore berths or constructed for ship refuge, the wave forces have a significant effects on moored ships. These effects shall be fully taken into consideration.

(3) The impact forces and tractive forces caused by the motions of moored ships can usually be obtained by motion simulation based on wave forces, wind pressure forces, water current pressure forces, and the characteristics of mooring equipment.

(4) The normal performance verification of fender systems shall take account of not only dominating berthing forces of ships but also the impact forces caused by the motions of moored ships. In the performance verification of mooring posts, the tractive forces due to the motions of moored ships caused by the wind pressure forces are important. The impact forces caused by the motions of moored ships are strongly affected by the types of design ships, wave characteristics, the displacement-restoring force characteristics of fender systems etc., and wind pressure forces are strongly affected by the types of design ships, hence it is preferable for the performance verification to thoroughly study the conditions of design ships, wave characteristics, the structures of quaywalls, the characteristics of mooring equipment etc.

2.2 Actions Caused by Ship Berthing

(1) Berthing Energy of Ship

① The actions caused by ship berthing are generally calculated from the berthing energy of ships. The berthing energy of a ship can be calculated from the following equation by using the mass of the ship, the berthing velocity of the ship, the eccentricity factor, the virtual mass factor, the flexibility factor, and the berth configuration factor. The subscript *k* in the equation refers to the characteristics value.

$$E_{f_k} = \frac{1}{2} M_{s_k} {V_{b_k}}^2 C_{m_k} C_{e_k} C_{s_k} C_{c_k} \qquad (2.2.1)$$

where

E_f : berthing energy of ship (kNm)
M_s : mass of ship (t)
V_b : berthing velocity of ship (m/s)
C_m : virtual mass factor
C_e : eccentricity factor
C_s : flexibility factor
C_c : berth configuration factor

② There are methods of estimating the berthing energy of ships such as statistical methods, methods using hydraulic model tests, and methods using fluid dynamics models in addition to kinetic energy of method.[1] However, regarding these alternative methods, the data necessary for design are insufficient and the values of the various factors used in the calculations may not appropriately properly given. Thus, the kinetic energy method is generally used.

③ If it is assumed that a berthing ship moves only in the abeam direction, then the kinetic energy E_s (kNm) becomes equal to $M_sV_b^2/2$. However, when a ship is berthing at a dolphin, a quaywall or a berthing beam equipped with fender systems, the energy absorbed by the fender systems, i.e., the berthing energy E_f of the ship, will become E_sf considering the various relevant factors, where $f = C_m\ C_e\ C_s\ C_c$

(2) Mass of Ship

The mass of ship in the calculation equation of the berthing energy of ships means the full load displacement of the ship. Equation **(2.2.2)** may also be used to show the relations between the characteristic values of the full load displacements (*DT)* and dead weight tonnages (*DWT)* or gross tonnages (*GT)* of ships. They were calculated as the regression equations covering 75% of the total statistical data of full load displacements (*DT)* with respect to dead weight tonnages (*DWT)* or gross tonnages (*GT)*, using the regression equations and standard deviations shown in **Table 1.4 Regression Equations for Dead Weight Tonnages (DWT) or Gross Tonnages (GT) and Displacement Tonnages (DSP)** in **1. Principal Dimensions of Design Ships.** These relations are applicable within the range of tonnage shown in **Table 1.1**. The subscript *k* in the equations refers to the characteristic values.

General cargo ships	$DT_k = 1.174DWT$
Container ships	$DT_k = 1.385DWT$
Tankers	$DT_k = 1.235DWT$
Roll-on roll-off (RORO) ships	$DT_k = 1.022GT$
Pure car carriers (PCC)	$DT_k = 0.751GT$
LPG carriers	$DT_k = 1.400GT$
LNG carriers	$DT_k = 1.118GT$
Passenger ships	$DT_k = 0.573GT$
Short-to-medium distance ferries (navigation distance of less than 300 km)	$DT_k = 1.279GT$
Long distance ferries (navigation distance of 300 km or more)	$DT_k = 1.240GT$

(2.2.2)

where

DT : full load displacement of ship (t)
GT : gross tonnage of ship (GT)
DWT : dead weight tonnage of ship (DWT)

(3) Berthing Velocity

① It is preferable to determine the characteristic values of the berthing velocities of ships based on actual measurements or references on the previous measurements of berthing velocities, taking account of the types of design ships, loaded conditions, the locations and structures of mooring facilities, meteorological phenomena and oceanographic phenomena, the usage of tugboat assistance and their sizes etc.

② When large general cargo ships or large oil tankers berth, they come to a standstill temporarily, lined up parallel to the quaywall at a certain distance away from it. They are then gently pushed by several tugboats until they come into contact with the quaywall. When there is a strong wind toward the quaywall, such ships may berth being pulled outwards against wind by the tugboats. When such a berthing method is adopted, it is common to use the berthing velocity of 10 to 15 cm/s based on the past design examples.

③ Special ships such as ferries and roll-on roll-off ships and small cargo ships often use berthing methods different from large ships, as such that they berth by themselves without using tugboats or they shift parallel to the face lines of quaywalls if they are equipped with bow or stern lamps. The berthing velocities hence shall be carefully determined based on actual measurements taking account of their berthing methods.

④ **Fig. 2.2.1** shows the relationship between the ship maneuvering conditions and berthing velocity by ship size. [2] It has been prepared based on the empirical data collected. This figure shows that the berthing velocity must be set high in such case that the mooring facilities are not sheltered by breakwaters and are being used by small ships.

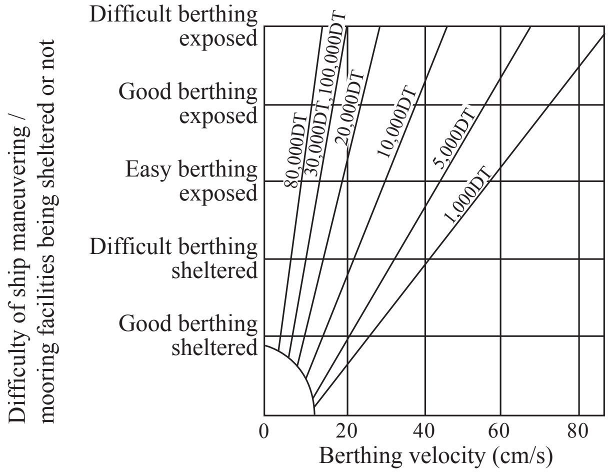

Fig. 2.2.1 Relationship between Ship Maneuvering Conditions and Berthing Velocity by Ship Size [2]

⑤ According to the study reports [3), 4)] on berthing velocity, the berthing velocity is usually less than 10 cm/s for general cargo ships, but only in a few cases are over 10 cm/s (see **Fig. 2.2.2**). The berthing velocity only occasionally exceeds 10 cm/s for large oil tankers that use offshore berths (see **Fig. 2.2.3**). Even for ferries which berth under their own power, the berthing velocity in many cases is less than 10 cm/s. Nevertheless, since there are a few cases in which the berthing velocity is over 15 cm/s, due care must be taken when verifying the performance of ferry quays (see **Fig. 2.2.4**). Based on the above-mentioned study reports, the cargo loading condition has a considerable influence on the berthing velocity. In other words, when a ship is fully loaded, which results in small under-keel clearance, the berthing velocity tends to be lower, whereas when it is lightly loaded, which results in a large under-keel clearance, the berthing velocity tends to be higher.

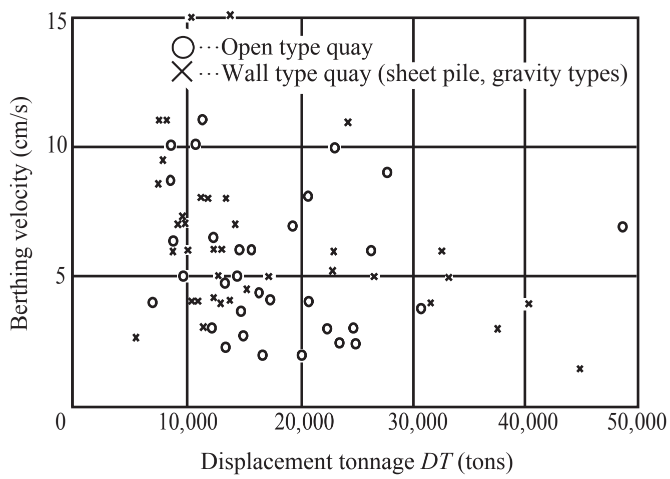

Fig. 2.2.2 Berthing Velocity and Displacement Tonnage for General Cargo Ships [3]

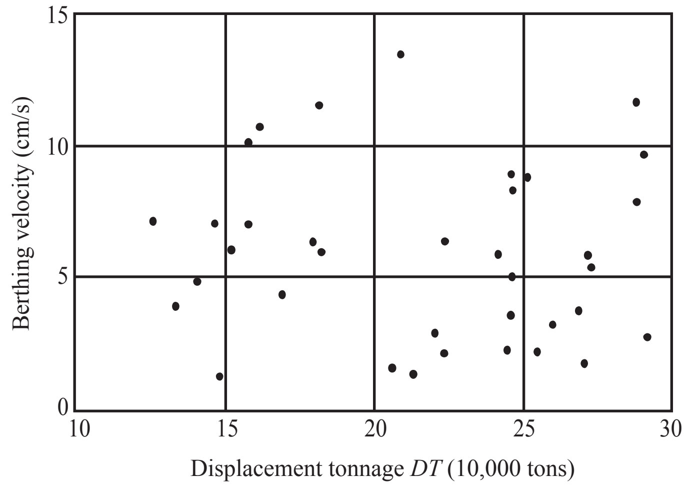

Fig. 2.2.3 Berthing Velocity and Displacement Tonnage for Large Oil Tankers [4)]

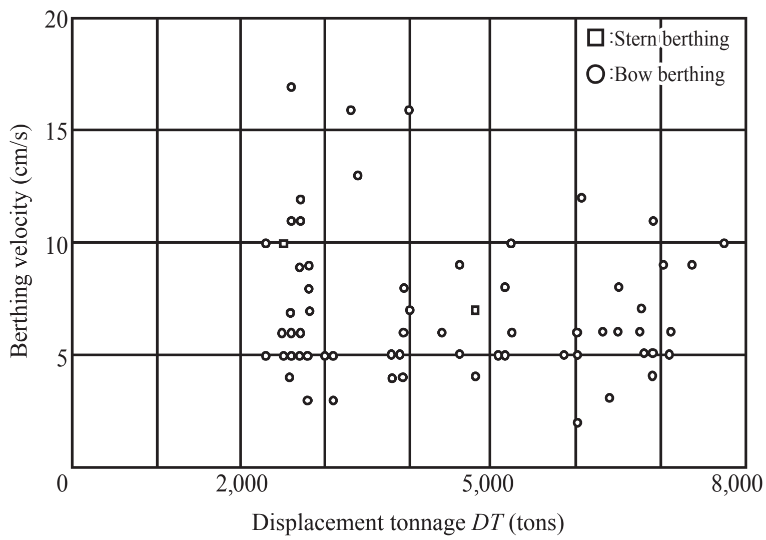

Fig. 2.2.4 Berthing Velocity and Displacement Tonnage for Longitudinal Berthing of Ferries [3)]

According to the survey by Moriya et al.[5)], the average berthing velocities for general cargo ships, container ships, and pure car carriers are as listed in **Table 2.2.1**. The relationship between the dead weight tonnage and berthing velocity is shown in **Fig. 2.2.5**. This survey also shows that the larger the ship, the lower the berthing velocity tends to be. The highest berthing velocities observed were about 15 cm/s for ships under 10,000 DWT and about 10 cm/s for ships of 10,000 DWT or over.

Table 2.2.1 Dead Weight Tonnage and Average Berthing Velocity [5)]

Dead Weight Tonnage (DWT)	Berthing velocity (cm/s)			
	General cargo ships	Container ships	Pure car carriers	All ships
1,000class	8.1	–	–	8.1
5,000class	6.7	7.8	–	7.2
10,000class	5.0	7.2	4.6	5.3
15,000class	4.5	4.9	4.7	4.6
30,000class	3.9	4.1	4.4	4.1
50,000class	3.5	3.4	–	3.4
All ships	5.2	5.0	4.6	5.0

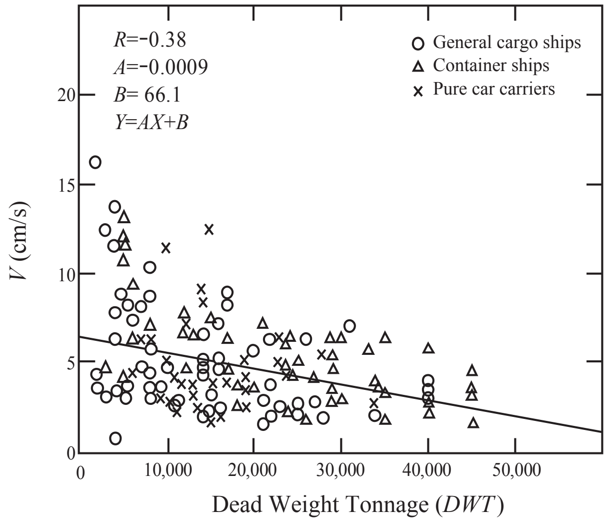

Fig. 2.2.5 Relationship between Dead Weight Tonnage and Berthing Velocity 5)

⑥ **Fig. 2.2.6** shows a berthing velocity frequency distribution obtained from actual measurement records of berthing velocities at offshore berths used by large oil tankers of around 200,000 DWT. It shows that the highest measured berthing velocity was 13 cm/s. If the data are assumed to follow a Weibull distribution, then the non-exceedence probability of the berthing velocity below the value of 13 cm/s would be 99.6%. The mean μ is 4.4cm/s and the standard deviation σ is 2.08 cm/s. Application of the Weibull distribution yields the probability density function $f(V_b)$ as expressed in equation **(2.2.3)**:

$$f\left(V_b\right)=\frac{V_b}{0.8}\exp\left(-V_b^{1.25}\right) \tag{2.2.3}$$

From this equation, the berthing velocity corresponding to the expected probability of 1/1000 becomes 14.5 cm/s. At the offshore berths where the berthing velocities were actually measured, a design berthing velocity was set at either 15 cm/s or 20 cm/s.6)

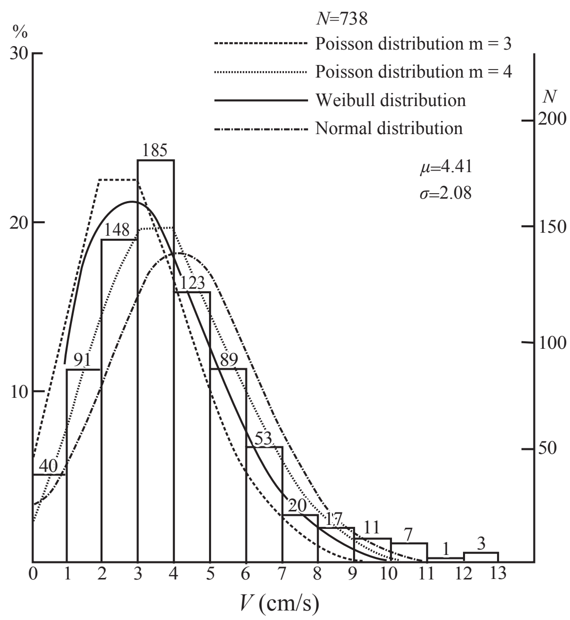

Fig. 2.2.6 Frequency Distribution of Berthing Velocity 6)

⑦ Small general cargo ships approach to berths by controlling their positions under their own power without assistance of tugboats. Consequently, the berthing velocity is generally higher than that of larger ships, and in some cases it may even exceed 30 cm/s. Hence, it is necessary to pay attention to this. For small ships in particular, it is necessary to carefully determine the berthing velocity based on actually measured data.

⑧ In cases where cautious berthing methods such as those described above are not taken, or in the case of berthing of small or medium-sized ships under influence of currents, it is necessary to determine the berthing velocity based on actually measured data considering the ship drift velocity by currents.

⑨ Some studies proposed the regression equations for the berthing velocities of ships with respect to daed weight tonnages.[7), 8)] Since the ranges of ship types and tonnages to which the regression equations of berthing velocities are applicable are limited, the results of the above studies should be carefully used.

(4) Virtual Mass Factors

① Virtual mass factors can be calculated from the following equations:

$$C_m = 1 + \frac{\pi}{2C_b}\frac{d}{B} \tag{2.2.4}$$

$$C_b = \frac{\nabla}{L_{pp}Bd} \tag{2.2.5}$$

where

C_b : block coefficient
∇ : displacement volume of ship (m^3)
L_{pp} : length between perpendiculars (m)
B : molded breadth (m)
d : full load draft (m)

The calculation requires the use of the lengths between perpendiculars L_{pp}, molded breadths B, and full load drafts d of design ships. The cases where design ships are of a standard ship type may use the values shown in **Table 1.1 Standard Values of the Principal Dimensions of Design Ships** included in Commentary.

② When a ship berths, the ship with mass of M_s and the water mass of M_w surrounding the ship simultaneously decelerate. Accordingly, the inertial force corresponding to the water mass is added to that of the ship itself. The virtual mass factor is thus defined as in equation **(2.2.6)**.

$$C_m = \frac{M_s + M_w}{M_s} \tag{2.2.6}$$

where

C_m : virtual mass factor
M_s : mass of ship (t)
M_w : mass of the water surrounding the ship, added mass (t)

Ueda [9)] proposed equation **(2.2.4)** based on the results of model tests and field measurements. The second term in equation **(2.2.4)** corresponds to M_w / M_s in equation **(2.2.6)**.

(5) Eccentricity Factor

① Eccentricity factors can be calculated from the following equation:

$$C_e = \frac{1}{1 + \left(\frac{\ell}{r}\right)^2} \tag{2.2.7}$$

where

l : distance from the ship's contact point to the center of gravity of the ship measured parallel to the face line of the mooring facility (m)
r : radius of rotation around the vertical axis passing through the center of gravity of the ship (m)

② During the berthing process, a ship is not aligned perfectly along the face line of the berth. This means that when the ship comes into contact with the fender systems, it starts yawing and rolling. This results in the loss of a part of the ship's kinetic energy. The amount of energy loss by rolling is negligibly small compared with that by yawing. Equation **(2.2.7)** thus only considers the amount of energy loss by yawing.

③ r/Lpp is a function of the block coefficient C_b of the ship and can be obtained from **Fig. 2.2.7.**[10)] Alternatively, one may use the linear approximation shown in equation (**2.2.8**).

$$r = (0.19C_b + 0.11)L_{pp} \tag{2.2.8}$$

where

- r : radius of rotation (radius of gyration); this is related to the moment of inertia I_z around the vertical axis of the ship by the relationship $I_z=M_s r^2$
- C_b : block coefficient
- L_{pp} : length between perpendiculars (m)

The calculation requires the use of the lengths between perpendiculars L_{pp} of design ships. The cases where design ships are of a standard ship type may use the values shown in **Table 1.1 Standard Values of the Principal Dimensions of Design Ships** included in Commentary.

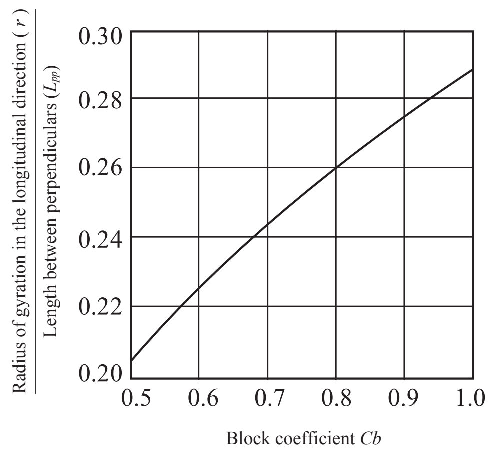

Fig. 2.2.7 Relationship between the Radius of Gyration around the Vertical Axis and the Block Coefficient [9)]

④ As shown in **Fig. 2.2.8**, when a ship comes into contact with the fenders F_1 and F_2 being the ship closest to the quaywall at point P, the distance l from the point of contact to the center of gravity of the ship as measured parallel to the mooring facilities is given by equation **(2.2.9)** or **(2.2.10)** [11)]; l is taken to be L_1 when k >0.5 and L_2 when k < 0.5. When k = 0.5, l is taken as whichever of L_1 or L_2 that gives the higher value of C_e in equation (**2.2.7**).

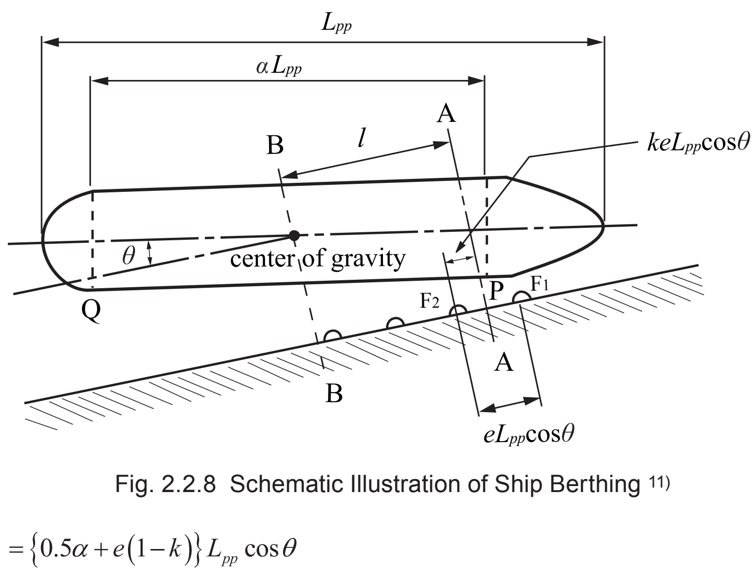

Fig. 2.2.8 Schematic Illustration of Ship Berthing [11)]

$$L_1 = \{0.5\alpha + e(1-k)\} L_{pp} \cos\theta \qquad (2.2.9)$$

$$L_2 = \{0.5\alpha - ek\} L_{pp} \cos\theta \qquad (2.2.10)$$

where

- L_1 : distance from the point of contact to the center of gravity of the ship as measured parallel to the mooring facilities when the ship contacts with fender F1 (m)
- L_2 : distance from the point of contact to the center of gravity of the ship as measured parallel to the mooring facilities when the ship contacts with fender F2 (m)
- θ• : berthing angle (the value of θ is given as a design condition; it is usually set somewhere in the range of 0 to 10°)

e : ratio of the distance between the fenders, as measured in the longitudinal direction of the ship, to the length between perpendiculars

α : ratio of the length of the parallel side of the ship at the height of the point of contact with the fender to the length between perpendiculars; this varies according to factors like the type of ship, and the block coefficient etc., but is generally in the range of 1/3 to 1/2.

k : parameter that represents the relative location of the point where the ship comes closest to the mooring facilities between the fenders F1 and F2 ; k varies $0<k<1$, but it is generally taken at $k = 0.5$.

(6) Flexibility Factor

The flexibility factor C_s is the ratio of the berthing energy absorbed by the deformation of ship hull to the berthing energy of the ship. The characteristic value of the flexibility factor C_{sk} may normally be set as $C_{sk} = 1.0$, assuming that there is no energy absorption by the deformation of ship hull.

(7) Berth Configuration Factor

The water mass compressed between berthing ship and mooring facility behave like a cushion and decrease the energy to be absorbed by fender systems. The berth configuration factor C_c needs to be determined taking account of this effect. This phenomenon is considered to relate to berthing angles, the shapes of ship hull, under-keel clearances, and berthing velocities, but only limited quantitative studies on the phenomenon have been made.

The characteristic value of berth configuration factor C_{ck} may normally be set as $C_{ck} = 1.0$.

2.3 Actions Caused by Ship Motions

(1) Motions of Moored Ships

① Actions caused by the motions of moored ships are generally calculated by motion calculation, by appropriately setting wave forces, wind pressure forces, and water current pressure forces.

② The ships moored to the mooring facilities constructed in the open sea or close to port entrances or in ports where long period waves invade and those moored in rough weather are possible to move by the actions of waves, winds, and water currents. The kinetic energy generated by the motions of moored ships sometimes exceeds the berthing energy. In such cases, it is preferable for the performance verification of mooring posts and fender systems to take account of the tractive forces and impact forces generated by the motions of moored ships.[12] In the ports facing the open sea in particular, it has been frequently reported that the long period oscillations of moored ships caused by the long period waves resulted in a difficulty with smooth cargo handling.[13), 14] Care should be taken in such ports.

③ As a general rule, the oscillations of a moored ship should be analyzed through numerical simulation in consideration of the random variations of the actions and the nonlinearity of the displacement-restoring force characteristics of the mooring system. However, when such a numerical simulation of ship motions is not possible, or when the ship is moored at a system that is considered to be more-or-less symmetrical, one may obtain the displacement of and loads on the mooring system either by using frequency response analysis for regular waves or by referring to the results of motion calculation on a floating body moored at a system that has displacement-restoring force characteristics of bilinear nature.[15]

④ The wave force acting on a ship consists of the wave-exciting force due to incident waves and the wave-making resistance force accompanied by the motions of the ship.[16] The wave-exciting force due to incident waves is the wave force calculated for the case that the motions of the ship are restrained. The wave-making resistance force is the wave force exerted on the ship when the ship undergoes a motion of unit amplitude for each mode of motions. The wave-making resistance force can be expressed as the summation of two factors, one is proportional to the acceleration of the ship and the other is proportional to the velocity. The former can be expressed as an added mass when it is divided by the acceleration, while the latter can be expressed as a damping coefficient when it is divided by the velocity.[17] In addition, the nonlinear fluid dynamic force that is proportional to the square of the wave height acts on the ship, see **4.9 Actions on Floating Body and its Motions** in **Chapter 2.**

⑤ For ships that have a block coefficient of 0.7 to 0.8 such as large oil tankers, the ship can be replaced with an elliptical cylinder for an approximate evaluation of the wave force.[18]

⑥ For box-shaped ships such as working crafts, the wave force can be obtained by assuming the ship to be either a floating body with a rectangular cross section or a rectangular prism.

(2) Wave Forces Acting on Ship

① The wave force acting on a moored ship shall be calculated using an appropriate method, considering the type of ship and the wave parameters.

② The wave force acting on a moored ship is calculated using appropriate analysis methods such as the strip method, the source distribution method, the boundary element method, or the finite element method; the most common method used for ships is the strip method.

③ Wave Forces by the Strip Method [15), 16), 17), 19)]

(a) Wave force of regular waves acting on the ship
The wave force acting on the ship is given by the summation of the Froude-Kriloff force and the diffraction force.

(b) Froude-Kriloff force
The Froude-Kriloff force is the force derived from the progressive waves around the ship. It is given by the summation of the force of the incident waves and the force of the reflected waves from the quaywall.

(c) Diffraction force
The diffraction force acting on a ship is the force that is generated by the change in the pressure field when incident waves are scattered by the ship. The diffraction force can be estimated by replacing this change in the pressure field with the radiation force, namely the wave-making resistance force when the ship moves at a certain velocity on a fluid at rest, for the case that the ship is moved relative to fluid. It is assumed that the velocity of the ship in this case is equal to the relative velocity of the ship to the water particles in the incident waves. This velocity is referred to as the equivalent relative velocity.

(d) Force acting on the ship as a whole
The wave force acting on the ship as a whole can be calculated by integrating the Froude-Kriloff force and the diffraction force acting on a cross section of the ship in the longitudinal direction from $x=-L_{pp}/2$ to $x=L_{pp}/2$

④ Wave forces by diffraction theory [18)]
In the case of very fat ship, i.e., it has a block coefficient C_b of 0.7 to 0.8, there are no reflecting structures such as quaywalls behind the ship, and the motions of the ship are considered to be very small, the wave force can be calculated using an equation based on a diffraction theory [18)] by replacing the ship with an elliptical cylinder.

(3) Wind Loads Acting on Ship

① The wind load acting on a moored ship shall be determined using an appropriate calculation formula.

② It is preferable to determine the wind load acting on a moored ship in consideration of the time fluctuation of the wind velocity and the characteristics of the wind drag coefficients in respect of the cross-sectional shape of the ship.

③ The wind loads acting on a ship are calculated from equations **(2.3.1)** to **(2.3.3)** using wind drag coefficients C_X and C_Y in the X and Y directions, respectively, and wind pressure moment coefficient C_M around the midship. The subscript k in the equations refers to the characteristic values.

$$R_{X_k} = \frac{1}{2}\rho_a U_k{}^2 A_T C_X \tag{2.3.1}$$

$$R_{Y_k} = \frac{1}{2}\rho_a U_k{}^2 A_L C_Y \tag{2.3.2}$$

$$R_{M_k} = \frac{1}{2}\rho_a U_k{}^2 A_L L_{pp} C_M \tag{2.3.3}$$

where

C_X : wind drag coefficient in the X direction (bow direction)
C_Y : wind drag coefficient in the Y direction (side direction)
C_M : wind pressure moment coefficient around midship
R_X : X-direction component of wind load resultant force (kN)
R_Y : Y-direction component of wind load resultant force (kN)
R_M : moment of wind load resultant force around midship (kNm)
ρ_a : air density, which may be set as $\rho_a = 1.23 \times 10^{-3}$ (t/m^3)
U : wind velocity (m/s)
A_T : above-water bow projected area (m^2)
A_L : above-water side projected area (m^2)
L_{pp} : length between perpendiculars (m)

④ It is preferable to determine the wind drag coefficients C_X, C_Y, and C_M through wind tunnel tests or water tank tests on design ships. However, since such tests require time and cost, it is acceptable to use the calculation equations for wind drag coefficients [21), 22)] that are based on wind tunnel tests [20)] or water tank tests that have been carried out in the past.

⑤ The maximum wind velocity, 10-minute average wind velocity, may be used as the wind velocity U.

⑥ Since the wind velocity varies both in time and space, it should be treated as fluctuating wind in the motion calculation of a moored ship. Davenport [23)] and Hino [24)] have proposed the frequency spectra for the time fluctuations of the wind velocity. The frequency spectra proposed by Davenport and Hino are given by equations **(2.3.4)** and **(2.3.5)**, respectively.

$$\left.\begin{aligned} fS_u(f) &= 4K_rU_{10}^2\frac{X^2}{\left(1+X^2\right)^{4/3}} \\ X &= 1200f/U_{10} \end{aligned}\right\} \tag{2.3.4}$$

$$\left.\begin{aligned} S_u(f) &= 2.856\frac{K_rU_{10}^2}{\beta}\left\{1+\left(\frac{f}{\beta}\right)^2\right\}^{-5/6} \\ \beta &= 1.169\times10^{-3}\frac{U_{10}\alpha}{\sqrt{K_r}}\left(\frac{z}{10}\right)^{2m\alpha-1} \end{aligned}\right\} \tag{2.3.5}$$

where

$S_u(f)$: frequency spectrum of wind velocity (m^2/s)
U_{10} : average wind velocity at the standard height of 10 m (m/s)
K_r : friction coefficient for the surface defined with the wind velocity at the standard height; on the sea , it is considered that $K_r = 0.003$ is appropriate.
α : power exponent when the vertical distribution of the wind velocity is expressed by a power law [$U \propto (Z/10)^{\alpha}$]
z : height above the surface of the ground or the water (m)
m : correction factor relating to the stability of the atmosphere; m is taken to be 2 in case of a storm.

(4) Water Current Pressure Forces Acting on Ship

① The current pressure force due to water currents acting on a ship shall be determined using an appropriate calculation formula.

② Current pressure force caused by currents from the bow
The current pressure force developed between a ship and currents from the bow can be calculated from equation **(2.3.6)**.
The subscript k in the equation refers to the characteristic value.

$$R_{f_k} = 0.0014SV_k^{\ 2} \tag{2.3.6}$$

where

R_f : current pressure force (kN)
S : submerged surface area (m^2)
V : current velocity (m/s)

③ Current pressure force caused by currents from the side
The current pressure force caused by currents from the side can be calculated from equation **(2.3.7)**.
The subscript k in the equation refers to the characteristic value.

$$R_k = 0.5\rho_0CV_k^{\ 2}B \tag{2.3.7}$$

where

R : current pressure force (kN)
ρ_o : density of seawater (t/m^3)
C : current pressure coefficient
V : current velocity (m/s)
B : under-water side projected area of ship (m^2)

④ Water current pressure force consists of frictional resistance and pressure resistance. The currents from the bow and the side mostly generate frictional and pressure resistances, respectively, but these two resistances cannot be rigorously distinguished. Equation **(2.3.6)** is a simplified one substituting ρ_o = 1.025 t/m^3, t = 15°C, and ρ_o = 0.14 into equation **(2.3.8)** called Froude's formula. The subscript k in the equation refers to the characteristic value.

$$R_{f_k} = \rho_0 g \lambda \left\{ \frac{1 + 0.0043(15 - t)}{1000} \right\} S V_k^{1.825} \qquad (2.3.8)$$

where

R_f : current pressure force (kN)
$\rho_0 g$: unit weight of seawater (kN/m^3)
t : temperature (°C)
S : submerged surface area (m^2)
V : current velocity (m/s)
λ : coefficient, which can be set as λ = 0.14741 for a length overall of 30 m and λ = 0.13783 for a length overall of 250 m.

⑤ The current pressure coefficient C varies according to the relative current direction θ ; the values obtained from **Fig. 2.3.1** may be used as a reference.

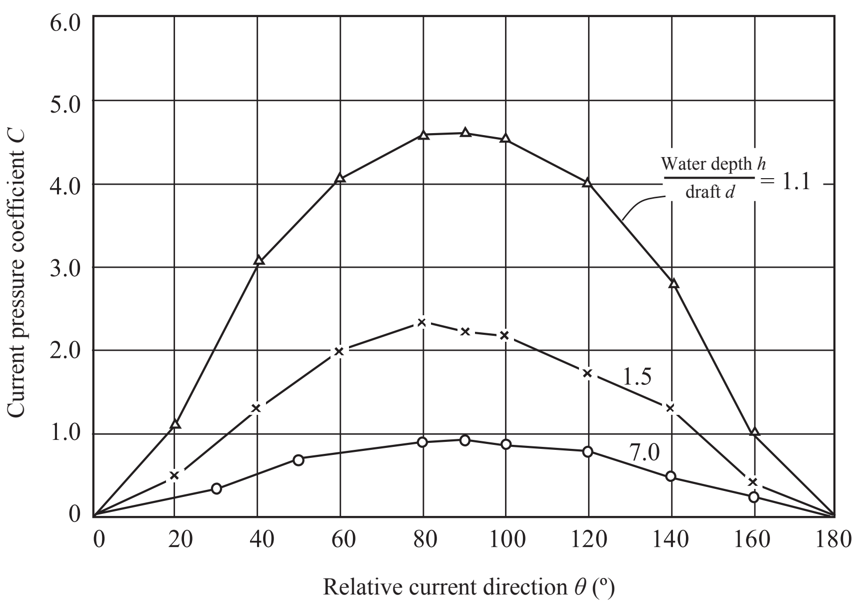

Fig. 2.3.1 Current Pressure Coefficient *C*

(5) Characteristics of Mooring System

① For the motion calculation of a moored ship, the displacement-restoring force characteristics of the mooring system such as mooring ropes and fenders shall be modeled appropriately.

② The displacement-restoring force characteristics of the mooring system such as mooring ropes and fenders is generally nonlinear. Moreover, the displacement-restoring force characteristics of fenders may possess hysterisis nature. In that case, it is preferable to model these characteristics appropriately for the motion calculation of a moored ship.[25)]

2.4 Actions due to Traction by Ships

(1) The values given in **Table 2.4.1** shall generally be used for the standard values of the tractive forces caused by ships to mooring posts and bollards.

(2) In case of the mooring post, it shall be assumed that the tractive forces by ships specified in the Item (1) act in the horizontal direction, and the half of the tractive forces act in the vertical direction at the same time.

(3) In case of the bollard, it shall be assumed that the tractive forces by ships specified in the Item (1) act in all directions.

Table 2.4.1 Standard Values of Tractive Forces by Ships

Gross tonnage of ship (t)	Tractive force acting on mooring post (kN)	Tractive force acting on bollard (kN)
Over 200 and not more than 500	150	150
Over 500 and not more than 1,000	250	250
Over 1,000 and not more than 2,000	350	250
Over 2,000 and not more than 3,000	350	350
Over 3,000 and not more than 5,000	500	350
Over 5,000 and not more than 10,000	700	500
Over 10,000 and not more than 20,000	1,000	700
Over 20,000 and not more than 50,000	1,500	1,000
Over 50,000 and not more than 100,000	2,000	1,000

(4) Mooring posts are installed away from the face line of quaywall, around the both ends of a berth so that they may be used for mooring a ship in a storm. Bollards, on the other hand, are installed close to the face line of the mooring facilities so that they may be used for mooring, berthing, or unberthing a ship in normal operations.

(5) Regarding the layout and names of mooring ropes of a ship, **2.1.1 (1) Dimensions of Wharves** in **Part III, Chapter 5** may be referred.

(6) Regarding the layout and structure of mooring posts and bollards, see **9.1 Mooring Posts and Mooring Rings** in **Part III, Chapter 5.**

(7) It is preferable to calculate the tractive forces acting on mooring posts and bollards based on the breaking loads of the mooring ropes of design ships, meteorological and oceanographic conditions at the installation places of mooring facilities, ship dimensions etc., taking account as necessary of the forces caused by berthing ships, the wind pressure forces acting on moored ships, and the forces caused by the ship motions.[9), 15)] The tractive forces may also be determined according to the following Items (8) to (12).

(8) In case that the gross tonnage of a ship exceeds 5,000 tons and there is no risk of more than one mooring rope being attached to a bollard that is used for spring lines at the middle of mooring facilities for which the berthing ships are designated, the tractive force acting on a bollard may be taken as one half of the value listed in **Table 2.4.1**.

(9) The tractive forces by the ships of a gross tonnage of less than 200 tons or more than 100,000 tons, which are not given in **Table 2.4.1**, those applied to the mooring facilities capable of mooring ships in rough weather, and those applied to the mooring facilities installed in the open sea area where meteorological and oceanographic conditions are rough need to be determined, taking account of meteorological and oceanographic conditions, the structures of mooring facilities, measurement records of tractive forces, etc.

(10) The tractive force acting on a mooring post has been determined based on the wind pressure force acting on

a ship in such a way that a lightly loaded ship should be able to be moored safely even when the wind velocity is 25 to 30 m/s, with the assumption that the mooring posts are installed at the place away from the face line of the quaywall by a ship's width and that the breast lines are stretched in a direction of 45º to the ship's longitudinal axis. [26), 27)] The tractive force so obtained corresponds to the breaking strength of one to two mooring ropes, where the breaking strength of a mooring rope is evaluated according to **the Steel Ship Regulations by the Nippon Kaiji Kyokai**. For a small ship of gross tonnage up to 1,000 tons, the mooring posts can withstand the tractive force under the wind velocity of up to 35 m/s.

The tractive force acting on a bollard has been determined based on the wind pressure force acting on a ship in such a way that even a lightly loaded ship should be able to be moored using only bollards under the wind velocity of up to 15 m/s, with the assumption that the ropes at the bow and stern are stretched in a direction at least 25º to the ship's axis. The tractive force so obtained corresponds to the breaking strengths of one mooring rope for a ship of gross tonnage up to 5,000 tons and two mooring ropes for a ship of gross tonnage over 5,000 tons, where the breaking strength of a mooring rope is evaluated according to **the Steel Ship Regulations by the Nippon Kaiji Kyokai**.

The tractive force for a bollard that is used for spring lines and is installed at the middle of a berth, for which the berthing ships are designated, corresponds to the breaking strength of one mooring rope, where the breaking strength of a mooring rope is evaluated according to **the Steel Ship Regulations by the Nippon Kaiji Kyokai**.

In the above-mentioned tractive force calculations, in addition to the wind pressure force, it has been assumed that there are water currents of 2 kt in the longitudinal direction and 0.6 kt in the transverse direction.

(11) When determining the tractive force of a small ship of gross tonnage up to 200 tons, it is preferable to consider the type of ship, the berthing situation, the structure of the mooring facilities, etc.[28)] For the performance verification of mooring posts and bollards for ships of gross tonnage up to 200 tons, it is common to take the tractive force acting on a mooring post to be 150 kN and the tractive force acting on a bollard to be 50 kN.

(12) When calculating the tractive force in case of ships such as ferries, container ships, or passenger ships, caution should be taken in using **Table 2.4.1**, because the wind pressure-receiving areas of such ships are large.

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Chapter 9 Environmental Actions

Public Notice

Environmental Influences

Article 19
Environmental influences shall be assessed with appropriate methods by taking account of the design working life of the facilities, material characteristics, environmental conditions, maintenance methods, and the conditions to which the facilities concerned are subjected.

[Technical Note]

The evaluation of the effects of environmental actions may refer to **Part I, Chapter 2, 3 Maintenance of Facilities Subject to the Technical Standards** and **Chapter 11, 2.3 Corrosion Protection** for steel and **Part III, Chapter 2, 1.1 General** for concrete.