Chapter 3 Waterways and Basins

1 General

[Ministerial Ordinance] (General Provisions)

Article 8

1 Waterways and basins shall be located appropriately in light of geotechnical characteristics, meteorological characteristics, sea states and other environmental conditions, as well as navigation channels and other usage conditions of water area around the facilities.

2 In waterways and basins where it is necessary to maintain the calmness of water area, measures shall be taken to mitigate the effects of waves, water currents, winds, etc.

3 In waterways and basins in which there is a risk of siltation by sediments, etc. measures shall be taken to prevent the occurrence thereof.

[Ministerial Ordinance] (Necessary Items concerning Waterways and Basins)

Article 12

The necessary matters for the enforcement of the requirements as specified in this chapter by the Minister of Land, Infrastructure, Transport and Tourism and other performance requirements for waterways and basins shall be provided by the Public Notice.

[Public Notice] (Waterways and Basins)

Article 29

The items to be specified by the Public Notices under Article 12 of the Ministerial Ordinance concerning the performance requirements of waterways and basins shall be as provided in the following Article through Article 32.

(1) In selecting the locations for basins or small craft basins exclusively used by hazardous cargo ships, the following should be considered: minimize encounters with general ships, especially passenger ships; isolate them from the facilities of which the surrounding environment should be protected, such as residential areas, schools and hospitals; and promptly deal with accidents including spills of hazardous cargo.

(2) For ensuring safety and efficiency in navigation and cargo handling, it is preferable to separate the basins and small craft basins for passenger ships, ferries and fishing boats from those for other types of ships.

(3) In principle, it is preferable to allocate specialized terminals for timber handling which are isolated from other general facilities.

(4) Measures to maintain the calmness of basins and small craft basins include protective facilities for harbors such as breakwater, and the installation of wave-dissipating work as well as alongshore wave protection work.

(5) Measures to prevent siltation due to sediment include the following:

① Installation of protective facilities for harbors such as sediment control groins and training jetties as well as other equivalent facilities

② Sediment control for facilities such as sand pockets by spot dredging around waterways and basins

③ Installation of facilities such as waterway revetments for slope protection

④ Excessive dredging

2 Navigation Channels

[Ministerial Ordinance] (Performance Requirements for Navigation Channels)

Article 9

The performance requirements for navigation channels shall be such that the requirements specified by the Minister of Land, Infrastructure, Transport and Tourism are satisfied in light of geotechnical characteristics, waves, water currents and wind conditions, as well as the usage conditions of the surrounding water areas so as to secure safe and smooth navigations by ships.

[Public Notice] (Performance Criteria of Navigation Channels)

Article 30

The performance criteria of navigation channels shall be as prescribed respectively in the following items:

(1) Navigation channels shall have appropriate width that are equal to or greater than the lengths of the design ships in navigation channels where there is a possibility of ships passing each other or width that are equal to or greater than half of the length of the design ships in navigation channels where there is no possibility of ships passing each other, in light of the length and width of the design ship, the traffic volume of ships, the conditions of geotechnical characteristics, waves, water currents and winds, as well as the usage conditions of the surrounding water areas. Provided, however, that in cases where the mode of navigation is special, the width of the navigation channels can be reduced to the width that does not hinder the safe navigation of ships.

(2) Navigation channels shall have appropriate depths greater than the drafts of the design ships in consideration of the trim and the degree of ship motions of the design ship due to waves, water currents, winds, etc.

(3) Directions of navigation channels shall be such that safe ship navigation is not hindered, in light of the geotechnical conditions, waves, water currents and winds, as well as the usage conditions of the surrounding water areas.

(4) If navigation channels is remarkably congested, navigation channels shall be provided with lanes separated depending on the direction of movement or the sizes of ships.

[Interpretation]

9. Waterways and Basins

(1) Performance Criteria of Navigation Channels (Article 9 of the Ministerial Ordinance and the interpretation related to Article 30 of the Public Notice)

① The required performance of navigation channels shall be serviceability. Here, serviceability means the performance of navigation channels which enables ships to navigate safely and smoothly.

② **Widths of navigation channels**

Cases where the modes of navigation are special include navigation channels which require consideration for the use of tug boats or installation of water areas for refugees and navigation channels which have significantly shorter distances. The term “significantly shorter distances” can be applied to both the entire lengths of the navigation channels and their partial lengths.

③ **Directions of navigation channels**

The conditions of geotechnical characteristics are the ground and underground phenomena closely related to earthquakes, volcanic activities, uplift and settlement of ground, and the weather.

2.1 General

(1) Concept of Navigation Channels

Navigation channels are considered to be water areas, such as entrance and passage channels in shallow water areas, whose existence is clearly marked with buoys or other navigation aids so as to enable navigators to perform safe and smooth navigation of ships.

(2) Items to be Considered

The performance verification of navigation channels shall be carried out with due consideration to the design ships and navigation environment, particularly the depths, widths and alignments (bend sections) of navigation channels.

(3) Classification of Verification Methods

The verification methods for navigation channels can be classified as follows depending on whether or not design ships and navigation environment are specified. Because the Class 2 method below allows the navigation environment to be designated and changed, the method can be applied to cases for determining whether or not to allow ships to enter the existing navigation channels.

(a) Class 1: Cases where the design ship and navigation environment are not specified.

(b) Class 2: Cases where the design ship and navigation environment are specified.

(4) The performance verification of navigation channels can be based on the methods described in 1) and 2) below from **Part III, Chapter 3, 2.2 Depths of Navigation Channels** to **2.4 Alignment of Navigation Channels (Bends)**, which are proposed by the Japan Institute of Navigation Standard Committee and the Port and Harbor Department of the National Institute for Land and Infrastructure Management, the Ministry of Land, Infrastructure, Transport and Tourism.

(5) Performance Criteria of Navigation Channels

① **Depths of navigation channels (serviceability)**

(a) Cases where the design ship and navigation environment cannot be specified

For the performance verification of navigation channels in cases where the design ship and navigation environment are not specified, the following values can be used as appropriate depths greater than the maximum drafts of the design ships.

- In navigation channels inside harbors where the effects of waves such as swells are negligible: 1.10 times the maximum draft.
- In navigation channels outside harbors where the effects of waves such as swells are expected: 1.15 times the maximum draft.
- In navigation channels in the open sea where the effects of waves such as strong swells are expected: 1.20 times the maximum draft.

(b) Cases where the design ship and navigation environment are specified

In setting the water depths of navigation channels for performance verification of navigation channels in cases where the design ship and navigation environment are specified, appropriate consideration shall be given to the maximum drafts of the design ships, ship squatting due to ship waves or swells, and keel clearances.

(c) Cases where the modes of navigation are special

In setting the water depths for performance verification of navigation channels used for special modes of navigation such as navigation channels accommodating ships entering or leaving dry docks, or ships unloading at multiple ports during single voyages as part of normal operation, notwithstanding the items mentioned in (a) and (b) above, the water depths shall be set appropriately in consideration of the anticipated conditions of use of the navigation channels concerned. For example, when ships are expected to enter a port in significantly light load conditions, it is preferable to identify the design ships and navigation environment and evaluate the effects of waves such as swells on ship squatting. In such cases, the literature 3) can be used as a reference.

② **Widths of navigation channels (serviceability)**

(a) Cases where the design ship and navigation environment are not specified

1) Appropriate widths of navigation channels where it is possible for ships to pass each other

In the performance verification of navigation channels where it is possible for ships to pass each other in cases where the design ships and navigation environment cannot be designated, the following values can be used as appropriate widths greater than the lengths overall of the design ships.

- For comparatively long navigation channels: 1.5 times the lengths overall of the design ships.

- For navigation channels with design ships frequently passing each other during their navigation: 1.5 times the lengths overall of the design ships.
- For comparatively long navigation channels with design ships frequently passing each other during their navigation: 2.0 times the lengths overall of the design ships.

2) Appropriate widths of navigation channels where there is no possibility for ships to pass each other

In the performance verification of navigation channels where there is no possibility for ships to pass each other in cases where the design ships and navigation environment are not designated, the appropriate widths shall be 0.5 times the lengths overall of the design ships or greater. Provided, however, that in cases where the widths of the navigation channels are less than the lengths overall of the design ships, adequate countermeasures to ensure safe navigation, such as the provision of facilities to support ship navigation, shall be examined.

(b) Cases where the design ship and navigation environment are specified

When setting the widths of navigation channels in the performance verification of navigation channels in cases where the design ships and navigation environment are specified, appropriate consideration shall be given to the basic ship maneuvering widths and the widths necessary to cope with the effects of the side walls of the navigation channels, ships passing each other and ships overtaking other ships.

(c) Cases with special modes of navigation

Cases where there are special modes of navigation include navigation channels which require consideration for the use of tug boats or installation of water areas for refugees and navigation channels with significantly shorter distances. The term “significantly shorter distances” can be applied to both the entire lengths and the partial lengths (subject to examination) of navigation channels.

③ Directions of navigation channels (serviceability)

(a) Whenever possible, the directions of navigation channels shall be straight, provided, however, that in cases where bends are required in navigation channels, the intersection angles of the centerlines of the navigation channels at the bends shall not exceed roughly 30°.

(b) Cases where the intersection angles of the centerlines of the navigation channels at bends exceed 30°

1) Cases where the design ship and navigation environment such as rudder angles are not specified

In the performance verification of navigation channels in cases where the intersection angles of the centerlines of the navigation channels at bends exceed 30° and the design ships and features of the navigation environment such as rudder angles are not designated, the inner side of the bends shall be provided with appropriate corner cutoffs and the curvature radius of the centerlines of the navigation channels at the bends set to roughly 4 times the lengths between perpendiculars of the design ships or greater.

2) Cases where the design ship and navigation environment such as rudder angles are specified

In the performance verification of navigation channels in cases where the intersection angles of the centerlines of the navigation channels at bends exceed 30° and the design ships and features of the navigation environment such as rudder angles are designated, the inner side of the bends shall be provided with appropriate corner cutoffs and the curvature radius of the centerlines of the navigation channels at the bends set appropriately in consideration of turning performance factors considering the turning characteristics of design ships.

(c) When expanding the widths of navigation channels at bends, the planar shapes of the inner sides of the bends can be curved, except for corner cutoffs, in consideration of the installation of buoys.

2.2 Depths of Navigation Channels

2.2.1 Fundamentals of Performance Verification

(1) The following values can be used as the required water depths for Class 1 navigation channels.

①Navigation channel in a port where waves including swell does not affect ship motion : $D = 1.10\,d$
②Navigation channel out of a port where waves including swells affect ship motion : $D = 1.15\,d$
③Navigation channel in open water where waves including swells exist : $D = 1.20\,d$ **(2.2.1)**

where

D : depth of the navigation channel (m);

d : maximum draft of a moored design ship in still water (m);

(2) The required water depths for Class 2 navigation channels can be calculated by **equation (2.2.2)**.

$$D = d + D_1 + \max(D_2, D_3) + D_4 \quad \textbf{(2.2.2)}$$

where

D : depth of the navigation channel (m);

d : maximum draft of a moored design ship in still water (m);

D_1 : bow sinkage during navigation (m);

D_2 : bow sinkage due to heaving and pitching motions (additional item in the case of $\lambda > 0.45\,L_{pp}$) (m);

D_3 : bilge keel sinkage due to heaving and rolling (as shown in **Fig. 2.2.1**) (additional item in the case of $TR \approx TE$) (m);

D_4 : underkeel clearance (m);

λ : length of the wave such as the swell (m);

L_{pp} : length between perpendiculars (m);

TR : natural rolling period of the design ship (s);

TE : encounter period of the design ship and design wave such as the swell (s).

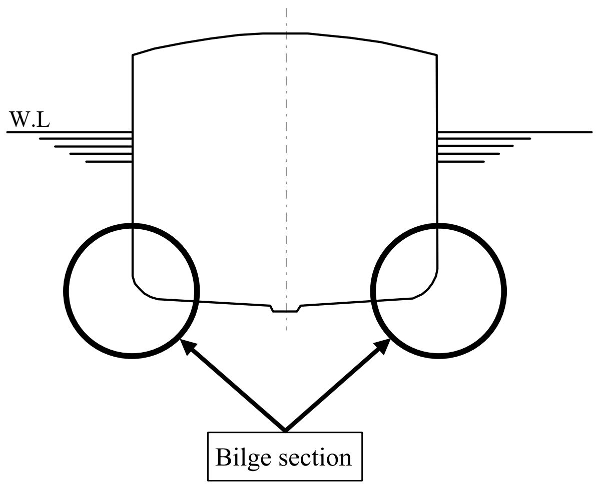


Fig. 2.2.1 Bilge Section

(3) Common items

① Swells subject to performance verification is determined by the relationship between the lengths overall of the design ships and the wavelengths in the water areas concerned.

② The maximum drafts d of maximum draft of a moored design ship in still water (m) is deemed to be, in the maximum, $d = d_0$ (d_0: full load draft), however, it can be $d < d_0$ depending on the operational condition concerned.

③ The following items can be considered when setting the depths D of the navigation channels:

(a) Tide levels: Tide levels during navigation are generally above the lowest astronomical tide and the difference between the tidal levels and the lowest astronomical tide can be considered as a factor which increases the actual water depths of the navigation channels. When considering the tide levels in the water depths of the navigation channels, it is necessary to ensure that tide levels are sufficiently high as per the consideration. The literature 4) introduces the actual situation of the use of tide levels with items to be considered in the implementation of their use.

(b) Accuracy of water depths: Errors in bathymetric data in the nautical charts may pose a danger to navigation, but in general, the actual water depths are deeper than the planning depths when dredging is implemented. Thus, excessive water depths below the planning depths can also be considered as a factor which increases the actual water depths of the navigation channels, provided, however, that such excessive water depths are confirmed through sufficient bathymetric surveys.

(c) Other: It is preferable to consider atmospheric pressure, bottom sediment, obstructions at the seabed, the specific gravity of seawater, etc., as needed. In the case of the existence of a soft clay layer with high water content close to the seafloor, it is necessary to pay attention to a possible discrepancy between the measurement results when using echo sounders and the measurement results when using sounding lead, which causes the underestimation of the depth measurement results when using echo sounders.[5) 6)]

2.2.2 Performance Verification of Class 2 Navigation Channels

(1) The required depths of Class 2 navigation channels can be calculated using the following methods.

① The bow sinkage D_1 during navigation can be calculated by **equation (2.2.3)** proposed by Yoshimura.[7)]

$$\left.\begin{aligned} D_1 &= \left(0.7 + 1.5\frac{d}{D}\right)\left(\frac{C_b}{L_{pp}/B}\right)\frac{U^2}{g} + 15\frac{d}{D}\left(\frac{C_b}{L_{pp}/B}\right)^3\frac{U^2}{g} \\ C_b &= DT/(L_{pp}\,B_d\gamma) \end{aligned}\right\} \qquad \textbf{(2.2.3)}$$

where

D : depth of the navigation channel (m);

d : maximum draft of a moored design ship in still water (m);

L_{pp} : length between perpendiculars (m);

B : molded breadth (m);

C_b : block coefficient;

DT : displacement tonnage of the design ship (t);

γ : density of seawater (t/m^3);

U : ship speed (m/s);

g : gravitational acceleration (m/s^2).

When block coefficients C_b (representing the degree of fatness or slenderness of the hulls) are unknown, the values in **Table 2.2.1** can be used.[8)]

Table 2.2.1 Block Coefficient C_b[8)]

Design ship	50% value	Standard deviation
Cargo ship	0.804	0.0712
Container ship	0.668	0.0472
Tanker	0.824	0.0381
Roll on/roll off (RORO) vessel	0.667	0.0939
Pure Car Carrier (PCC) ship	0.594	0.0665
LPG ship	0.737	0.0620
LNG ship	0.716	0.0399
Passenger ship	0.591	0.0595
Short-to-medium distance ferry	0.548	0.0452
Long distance ferry	0.516	0.0295

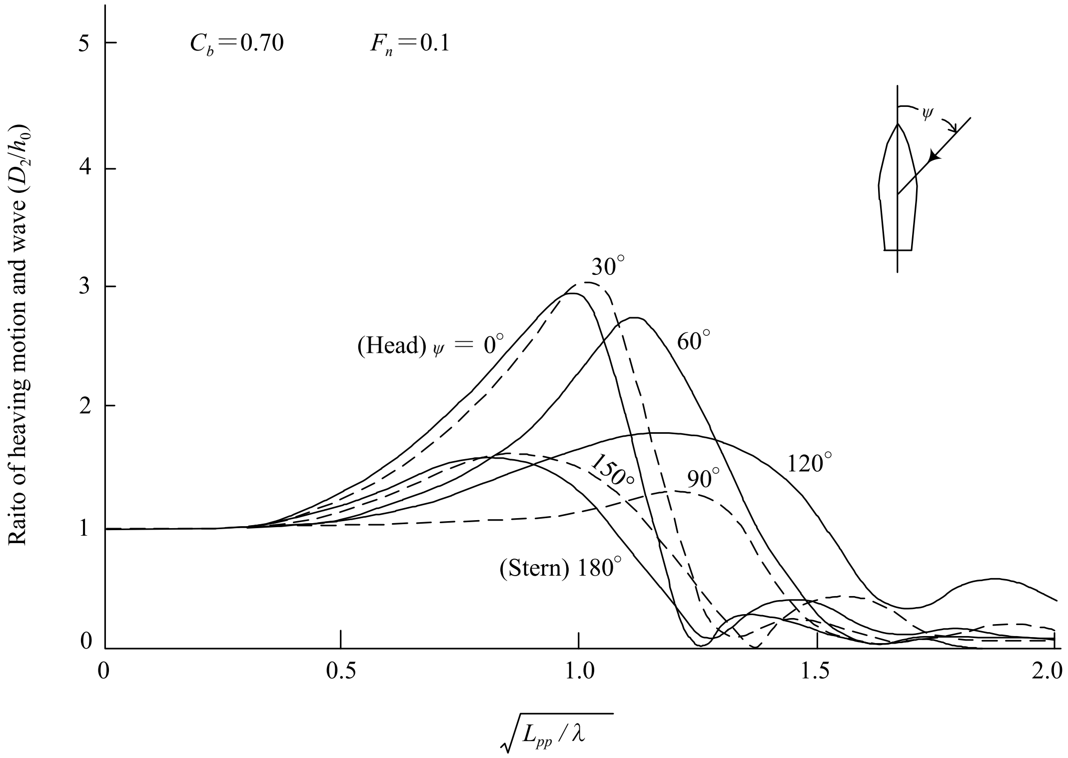
② The maximum value D_2 of bow sinkage due to heaving and pitching motions and the maximum value D_3 of bilge keel sinkage due to heaving and rolling do not occur at the same time. Therefore, as expressed by max (D_2, D_3) in **equation (2.2.2)**, D_2 or D_3, whichever is greater, shall be used.

where

D_2 : bow sinkage due to heaving and pitching motions (additional item in the case of $\lambda > 0.45\ L_{pp}$) (m);

D_3 : bilge keel sinkage due to heaving and rolling (additional item in the case of $TR \approx TE$) (m).

(a) In the case of $\lambda > 0.45\ L_{pp}$, D_2 can be calculated by the value of D_2/h_0 taken from **Fig. 2.2.2**.



Note: The figure above shows a case where C_b = 0.7 and F_n = 0.1 only. However, because the case represents phenomena in deep water areas which have larger values than shallow water areas (safer values for shallow water areas), the relationship can be applied to all cases regardless of the values of C_b and F_n (Froude number: $F_n = U/(L_{pp}g)^{0.5}$).

Fig. 2.2.2 Relationship between Heaving and Pitching Motions and Encounter Waves [9)]

where

λ : length of the wave such as the swell (m);

h_0 : amplitude of the wave such as the swell ($h_0 = H/2$) (m);

H : height of the wave such as the swell ($H = 0.7\ H_{1/3}$) (m);

$H_{1/3}$: significant height of the wave such as the swell (m);

L_{pp} : length between perpendiculars (m);

ψ : encounter angle (°) between the moving direction of the ship and the propagation direction of the design wave such as the swell.

(b) In cases where the natural rolling periods *TR* of design ships are almost equal to the encounter periods *TE* of design ships with design waves such as swells, D_3 can be calculated by **equation (2.2.4).**[10)]

$$\left.\begin{aligned} & D_3 = 0.7\left(\frac{H_{1/3}}{2}\right) + \left(\frac{B}{2}\right)\sin\Theta \\ & \text{provided that} \\ & \Theta = \mu\gamma\Phi \\ & \Phi = 360(0.35H_{1/3}/\lambda)\sin\psi \end{aligned}\right\} \quad \textbf{(2.2.4)}$$

where

D_3 : bilge keel sinkage due to heaving and rolling (additional item in the case of $TR \approx TE$) (m);

$H_{1/3}$: significant height of the wave such as the swell (m);

B : molded breadth (m);

Θ : maximum rolling angle of the design ship (°);

μ : rolling amplitude in regular waves

γ : effective wave slope coefficient;

Φ : maximum inclination angle of the surface wave (°) with respect to the line perpendicular to the fore and aft direction;

λ : length of the wave such as the swell (m);

ψ : encounter angle (°) between the moving direction of the ship and the propagation direction of the design wave such as the swell.

Here, $\mu\gamma$ can generally be a value up to 3.5 in the maximum.[11)]

1) *TR* and *TE* can be calculated by **equation (2.2.5)**.

$$\begin{aligned} & TR = 0.8B/(GM)^{0.5} \\ & TE = \lambda/(\lambda/TW + U\cos\psi) \end{aligned} \quad \textbf{(2.2.5)}$$

where

TR : natural rolling period of the design ship (s);

TE : encounter period of the design ship and the design wave such as the swell (s);

B : molded breadth (m);

GM : distance between the gravity center and metacenter of the ship (m);

TW : period of the wave such as the swell (s);

λ : length of the wave such as the swell (m);

U : ship speed (m/s);

ψ : encounter angle (°) between the moving direction of the ship and the propagation direction of the design wave such as the swell.

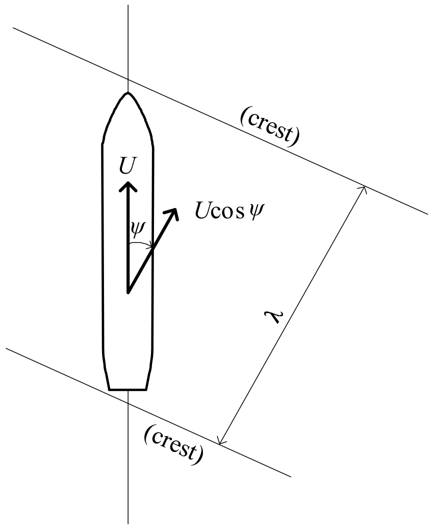


Fig. 2.2.3 Setting Method of ψ

2) It is considered appropriate to calculate the distance GM between the gravity center and metacenter of a ship by $GM = B/25$. However, considering that the actual GM varies, GM can be set with reference to the value calculated by **equation (2.2.6)**.

$$GM = a\left(B/25\right) \quad \textbf{(2.2.6)}$$

where

GM : distance between the gravity center and metacenter of the ship (m);

B : molded breadth (m);

a : 0.5 to 2.0.

③ D_4 is allowance for sinkage due to hull inclination when the ship is steered and can be calculated by **equation (2.2.7)**.

$$\left.\begin{array}{ll} D_4 = 0.5 \ \text{(m)} & d \le 10\text{m} \\ D_4 = 0.05d \ \text{(m)} & d > 10\text{m} \end{array}\right\} \quad \textbf{(2.2.7)}$$

where

D_4 : allowance in under keel clearance (m);

d : maximum draft of a moored design ship in still water (m).

(2) Convergence Calculation for the Design Depths of Newly Planned Navigation Channels

The depth of a navigation channel D needs to be input into **equation (2.2.3)** to calculate a bow sinkage during navigation D_1, which is the basic element to calculate the depth of a navigation channel D. Thus, in calculating the depth of a newly planned navigation channel, it is necessary to repeat convergence calculation until the initially set depth of the navigation channel D becomes equal to the depth of the navigation channel D calculated by **equation (2.2.8)**.

$$D = d + D_1 + \max\left(D_2, D_3\right) + D_4 \quad \textbf{(2.2.8)}$$

(3) Application to the Design Changes of Existing Navigation Channels

In cases involving a design change of the design ships and navigation environment of existing navigation channels, the depths of these channels can be the depths of navigation channels D to be input into **equation (2.2.3)** to calculate bow sinkage during navigation D_1. Then, the calculated depths of navigation channels D can be evaluated by **equation (2.2.9)**.

$$D \text{ (depth of an existing navigation channel)} \geq D \text{ (calculated depth of a navigation channel)} \qquad \textbf{(2.2.9)}$$

In cases where the above equation cannot be satisfied, the design changes need to be reviewed or the design depths need to be deepened to the depths obtained through the convergence calculation as is the case for new navigation channels.

2.3 Performance Verification of the Widths of Navigation Channels

2.3.1 Fundamentals of Performance Verification

(1) Generally, the following values can be used as the required widths of Class 1 navigation channels.

① In the cases of navigation channels which do not allow ships to pass each other, the appropriate widths can generally be set at 0.5 L_{oa} or more. For widths less than 1.0 L_{oa}, it is advisable to take adequate safety measures such as the installation of navigation aids.

② In the cases of navigation channels which allow ships to pass each other, the appropriate widths can generally be set at 1.0 L_{oa} or more, provided, however, that:

(a) those navigation channels which have comparatively long lengths : $W = 1.5L_{oa}$

(b) those navigation channels which have frequent navigation of design ships passing each other : $W = 1.5L_{oa}$ **(2.3.1)**

(c) those navigation channels which have comparatively long lengths and frequent navigation of design ships passing each other : $W = 2.0L_{oa}$

where

W : width of the navigation channel (m);

L_{oa} : length overall of the design ship (m).

(2) The values calculated by the following equation can be used as the required widths of Class 2 navigation channels.

① Navigation channels without accounting for two-ship interaction in passing (**Fig. 2.3.1** One-Way Navigation Channels)

$$W = W_{b1} + W_{m0} + W_{b2} \qquad \textbf{(2.3.2)}$$

② Navigation channels with accounting for two-ship interaction in passing (**Fig. 2.3.2** Two-Way Navigation Channels)

$$W = W_{b1} + W_{m1} + W_c + W_{m2} + W_{b2} \qquad \textbf{(2.3.3)}$$

③ Navigation channels with accounting for two-ship interaction in both passing and overtaking (**Fig. 2.3.3** Two-Way Navigation Channels That Allow Ships to Overtake Other Ships)

$$W = W_{b1} + W_{m1-1} + W_{ov1} + W_{m1-2} + W_c + W_{m2-1} + W_{ov2} + W_{m2-2} + W_{b2} \qquad \textbf{(2.3.4)}$$

where

W : width of the navigation channel (m);

W_{mi} : width of basic or fundamental ship maneuvering lane (m);

W_{bi} : additional width to account for bank effect (m);

W_c : additional width to account for two-ship interaction in passing (m);

W_{ovi} : additional width to account for two-ship interaction in overtaking (m).

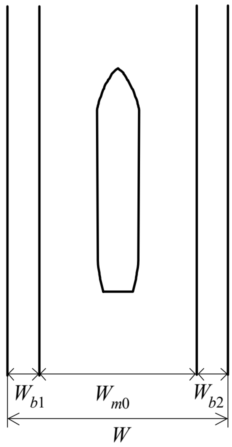


Fig. 2.3.1 One-Way Navigation Channels

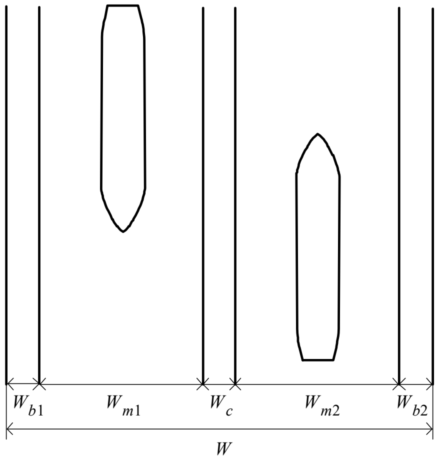


Fig. 2.3.2 Two-Way Navigation Channels

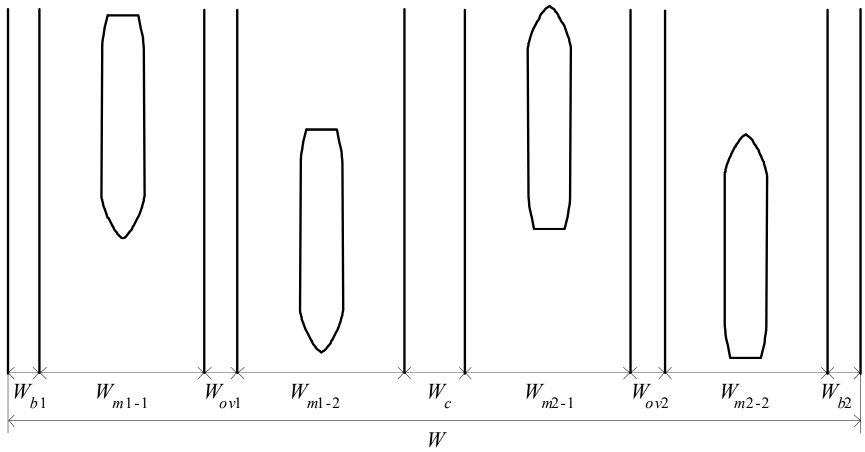


Fig. 2.3.3 Two-Way Navigation Channels to Account for Two-Ship Interaction in Overtaking

2.3.2 Performance Verification of Class 2 Navigation Channels

(1) The required widths of Class 2 navigation channels can be calculated by the following methods.

① Width of basic ship maneuvering lane W_{mi} can be obtained from the following two elements:

1) $W_m(\beta, y)$: additional widths to account for wind forces, current forces and yawing motion; and

2) $W_m(S)$: additional width to account for drift detection.

Here, the width of basic ship maneuvering lane W_{mi} can be calculated by **equation (2.3.5)** in the form of the maximum widths measured from the centerline to either edge.

$$0.5W_{mi} = W_m(S) + 0.5W_m(\beta, y) \quad \textbf{(2.3.5)}$$

Therefore, the width of basic ship maneuvering lane W_{mi} can be calculated by **equation (2.3.6)**.

$$W_{mi} = 2W_m(S) + W_m(\beta, y) \quad \textbf{(2.3.6)}$$

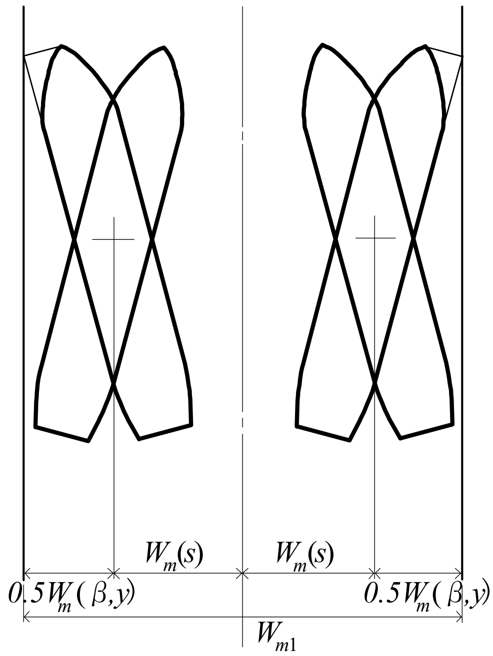


Fig. 2.3.4 Concept of Basic Ship Maneuvering Width

(a) The additional widths W_m (β, y) to account for wind forces, current forces and yawing motion can be calculated by the following procedure.

1) Basic concept of calculation

i. Calculate rudder angles δ to compensate for the effects of winds and drift angles β based on the design ships and navigation environment conditions. Note, however, that the rudder angles shall be up to 15° to compensate for the effects of winds. In cases where the check rudder angles exceed 15°, it is necessary to revise the setting of the maximum wind speed as one of the port call conditions. In addition, the drift angles to compensate for the effects of tidal currents need to be calculated based on the tidal component whose direction is perpendicular to the centerlines of the navigation channels as one of the navigation environmental conditions.

ii. The required widths of the navigation channels to cope with the effects of winds and tidal currents can be calculated from the drift angles obtained as a result of combining the drift angles to compensate for the effects of winds and tidal currents, respectively. Then, the required widths to cope with the effects of winds, tidal currents and yawing can be calculated by adding the widths required to compensate for meandering due to yawing to the above drift angles.

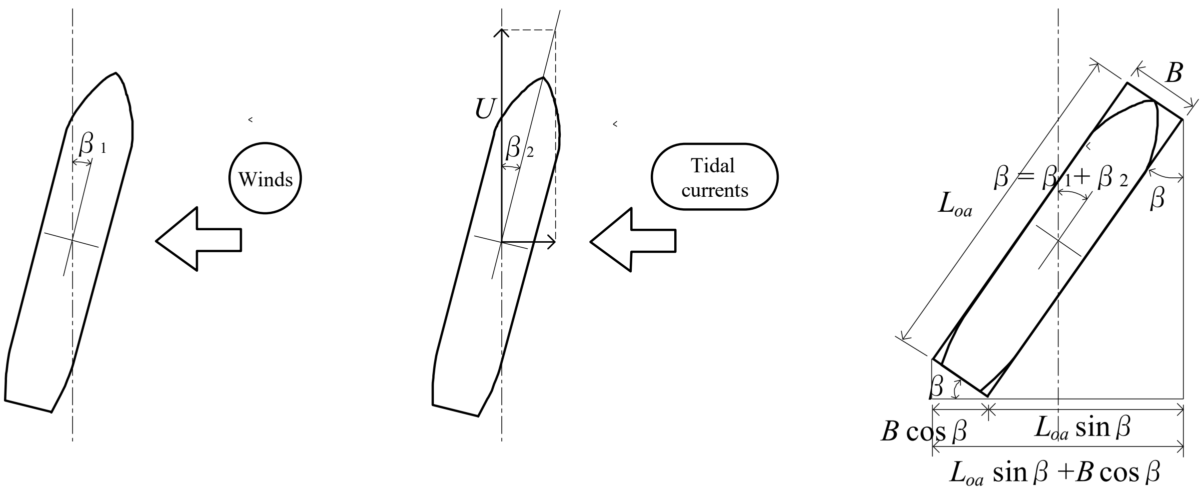


Fig. 2.3.5 Concept of Drift Angles to Cope with the Effects of Winds and Tidal Currents

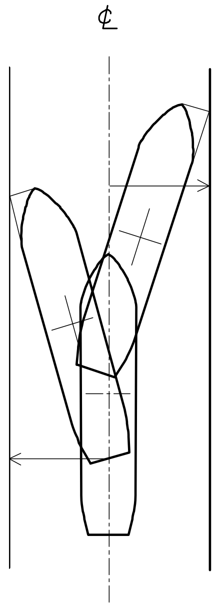


Fig. 2.3.6 Meandering Width Due to Yawing

2) Standard calculation method and calculation equation

i. Calculation of drift angles β_1 due to the effects of winds

Generally, the drift angles due to the effects of winds can be calculated by the following phased calculation method.

Setting of design ship dimensions, ship speeds and navigation environment conditions such as anticipated natural conditions

↓

Calculation of the coefficients of fluid dynamic forces

↓

Calculation of the coefficients of wind pressure resistance and wind pressure moment

↓

Calculation of rudder and drift angles based on the motion equation in an equilibrium situation

Fig. 2.3.7 Calculation of Drift Angle β_1 Due to the Effects of Winds

ii. Calculation of the coefficients of fluid dynamic forces

a) The coefficients of fluid dynamic forces with respect to ships can be calculated by **equation (2.3.7)**[1] based on the equation proposed by Hirano et al.[12] in consideration of the stabilization effects of rudders.

$$Y'_\beta = \frac{\pi}{2}\frac{k}{\frac{d}{2D}k + \left\{\frac{\pi d}{2D}\cot\left(\frac{\pi d}{2D}\right)\right\}^{2.3}} + 1.4C_b\frac{B}{L} - 0.4Y'_\delta$$

$$N'_\beta = \frac{k}{\frac{d}{2D}k + \left\{\frac{\pi d}{2D}\cot\left(\frac{\pi d}{2D}\right)\right\}^{1.7}} + 0.49\left(0.4Y'_\delta\right)$$

provided that

$$k = \frac{2d}{L} \qquad \textbf{(2.3.7)}$$

where

Y'_β : dimensionless value of the coefficient Y_β for the reaction force in a transverse direction from a fluid when a ship diagonally navigates with a drift angle β;

N'_β : dimensionless value of the coefficient N_β for the turning reaction moment from a fluid when a ship diagonally navigates with a drift angle β;

D : depth of the navigation channel (m);

d : maximum draft of a moored design ship in still water (m);

L : length between perpendiculars (= L_{pp}) (m);

B : molded breadth (m);

Y'_δ : dimensionless value of a transverse force coefficient Y_δ generated by a rudder set at rudder angle δ;

C_b : block coefficient, $C_b = DT/(L_{pp}Bd\gamma)$;

DT : displacement tonnage of the design ship;

γ : density of seawater (t/m^3).

b) The coefficients of fluid dynamic forces with respect to the rudder force corresponding to the respective combinations of the number of propellers and shafts can be calculated by **equations (2.3.8)**[1] and **(2.3.9)**[1] based on the equations proposed by Fujii et al.[13] in consideration of the hull wake and propeller slip effects.

(When 1 shaft and 1 propeller, or 2 shafts and 2 propellers)

$$\left.\begin{aligned} Y'_\delta &= -\frac{6.13\lambda_a}{(\lambda_a + 2.25)}\frac{A_R}{L_{pp}d}(1 + a_H)1.1 \\ N'_\delta &= -0.5Y'_\delta \end{aligned}\right\} \qquad \textbf{(2.3.8)}$$

(When 2 shafts and 1 propeller)

$$\left.\begin{aligned} Y'_\delta &= -\frac{6.13\lambda_a}{(\lambda_a + 2.25)}\frac{A_R}{L_{pp}d}(1 + a_H)0.7 \\ N'_\delta &= -0.5Y'_\delta \end{aligned}\right\} \qquad \textbf{(2.3.9)}$$

where

Y'_δ : dimensionless value of the coefficient Y_δ for the lateral force generated by a rudder at rudder angle;

N'_δ : dimensionless value of the coefficient N_δ for the rudder force moment generated by a rudder at rudder angle;

λ_a : effective aspect ratio of the rudder (a ratio b/c of a vertical length b and a lateral length c of the rudder);

A_R : rudder area (m^2), where A_R shall be doubled in the case of 2 rudders;

$A_R/(L_{pp}d)$: rudder area ratio;

α_H : interference coefficient of a rudder.

c) In many cases, the effective aspect ratios λ_a of rudders are set at 1.4 to 1.9.[10)]

d) When the rudder area ratios $A_R/(L_{pp}d)$ of the design ships are unknown, the following values can be used as references.

- High speed cargo ships: 1/35 to 1/40
- Conventional cargo ships: 1/45 to 1/60
- Tankers: 1/60 to 1/75

e) When the interference coefficients of the rudders α_H are unknown, the values estimated from the **Fig. 2.3.8** proposed by Kose et al.[14)] can be used as references.

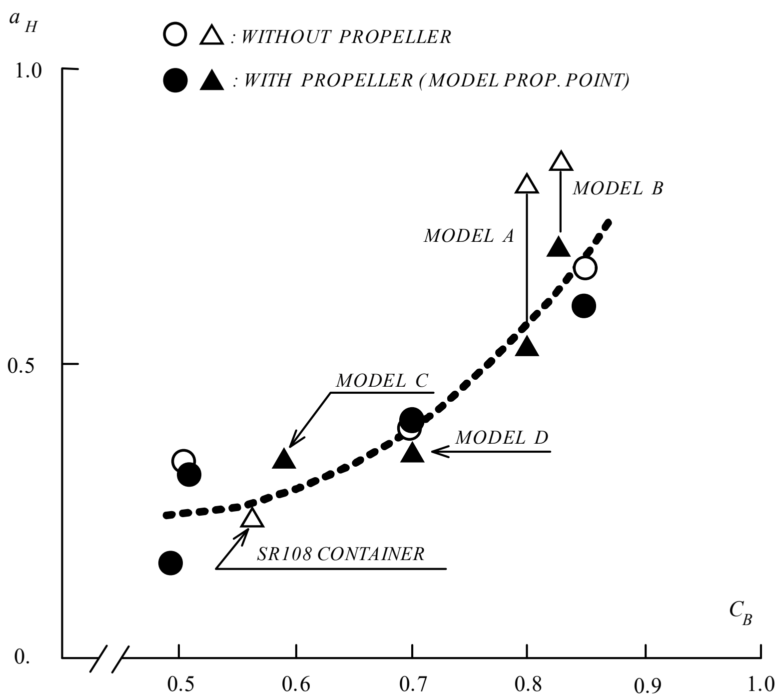


Fig. 2.3.8 Estimation of α_H Based on C_b[13)]

f) **Table 2.3.1** summarizes the dimensions of 22 types of ships and the calculation results of their coefficients of fluid dynamic forces (Y'_β, N'_β, Y'_δ, N'_δ). The coefficients of fluid dynamic forces calculated in the table are also required when calculating not only W_m, but also W_b, W_c and W_{ov}. Specific calculation examples are shown in the literature 15).

Table 2.3.1 Calculation Examples of Coefficients of Fluid Dynamic Forces by Ship Type (D/d_0 = 1.2)

	Ship type	GT/DWT	L_{oa} (m)	L_{pp} (m)	B (m)	d_0 (m)	C_b	Y'_β	N'_β	Y'_δ	N'_δ
1	Cargo ship	5,000 GT	109.0	103.0	20.0	7.00	0.7402	1.688	0.590	-0.0723	0.0362
2	Cargo ship (small size)	499 GT	63.8	60.4	11.2	4.20	0.5395	1.653	0.597	-0.0881	0.0441
3	Container ship (14,000 TEU)	150,166 DWT	368.8	352.0	51.0	15.50	0.6845	1.253	0.419	-0.0526	0.0263
4	Container ship (10,000 TEU)	99,563 DWT	336.0	318.3	45.8	14.04	0.6437	1.252	0.416	-0.0691	0.0345
5	Container ship (6,000 TEU OVER PANAMAX)	77,900 DWT	299.9	283.8	40.0	14.00	0.6472	1.340	0.457	-0.0720	0.0360
6	Container ship (4,000 TEU PANAMAX)	59,500 DWT	288.3	273.0	32.2	13.25	0.6665	1.312	0.449	-0.0781	0.0391
7	Bulk carrier (VLOC)	297,736 DWT	327.0	318.0	55.0	21.40	0.8698	1.689	0.585	-0.0730	0.0365
8	Bulk carrier (CAPESIZE)	172,900 DWT	289.0	279.0	45.0	17.81	0.8042	1.612	0.562	-0.0699	0.0350
9	Bulk carrier (NEW PANAMAX)	98,681 DWT	240.0	236.0	38.0	14.48	0.8528	1.591	0.543	-0.0794	0.0397
10	Bulk carrier	74,000 DWT	225.0	216.0	32.3	13.50	0.8383	1.587	0.553	-0.0696	0.0348
11	Bulk carrier (small size)	10,000 DWT	125.0	119.2	21.5	6.90	0.8057	1.551	0.519	-0.0773	0.0387
12	Tanker (VLCC)	280,000 DWT	333.0	316.0	60.0	20.40	0.7941	1.658	0.564	-0.0880	0.0440
13	Tanker (small size)	6,000 DWT	100.6	92.0	20.0	7.00	0.7968	1.835	0.640	-0.0811	0.0406
14	Pure car carrier (PCC) (VLCC)	25,272 DWT	199.8	190.9	36.5	10.60	0.5866	1.466	0.504	-0.0671	0.0336
15	Pure car carrier (PCC) (large size)	21,500 DWT	199.9	190.0	32.2	10.06	0.6153	1.417	0.484	-0.0731	0.0365
16	Pure car carrier (PCC)	18,000 DWT	190.0	180.0	32.2	8.20	0.5470	1.287	0.427	-0.0753	0.0376
17	LNG ship	69,500 DWT	283.0	270.0	44.8	10.80	0.7000	1.213	0.382	-0.0762	0.0381
18	LPG ship	54,500 DWT	225.0	220.0	36.6	12.00	0.7422	1.469	0.495	-0.0741	0.0371
19	Refrigerated cargo carrier	10,000 GT	152.0	144.0	23.5	7.00	0.7526	1.372	0.451	-0.0705	0.0353
20	Passenger ship (large, 2 shafts, 2 propellers)	142,714 GT	330.0	306.0	38.4	8.30	0.6800	0.908	0.269	-0.0780	0.0390
21	Passenger ship (2 shafts, 2 propellers)	28,700 GT	192.8	160.0	24.7	6.60	0.6030	1.214	0.387	-0.1000	0.0500
22	Ferry boat (2 shafts, 1 propeller)	18,000 GT	192.9	181.0	29.4	6.70	0.5547	1.125	0.354	-0.0875	0.0437

iii. Calculation of the coefficients for wind pressure resistance and wind pressure moment

a) The coefficients for wind pressure resistance and wind pressure moment can be calculated by **equation (2.3.10)** proposed by Yamano et al.[16)]

$$\left.\begin{aligned} C_x &= C_{x_0} + C_{x_1}\cos\theta_w + C_{x_2}\cos 2\theta_w + C_{x_3}\cos 3\theta_w + C_{x_4}\cos 4\theta_w + C_{x_5}\cos 5\theta_w \\ C_y &= C_{y_1}\sin\theta_w + C_{y_2}\sin 2\theta_w + C_{y_3}\sin 3\theta_w \\ C_m &= 0.1\left(C_{m_1}\sin\theta_w + C_{m_2}\sin 2\theta_w + C_{m_3}\sin 3\theta_w\right) \end{aligned}\right\} \quad \textbf{(2.3.10)}$$

where

C_x : coefficient for longitudinal wind pressure resistance;

C_y : coefficient for lateral wind pressure resistance;

C_m : coefficient for wind pressure moment around the central axis of the hull;

θ_w : wind direction with respect to the bow (°).

Each coefficient is the sum of A_y/L^2, X_g/L, L/B and A_y/A_x multiplied by the respective coefficients in **Table 2.3.2**. For example, using the coefficients in the table, C_{x0} can be calculated by $C_{x0} = -0.0358 + 0.925\ A_y/L^2 + 0.0521\ X_g/L$. In the table, the meanings of the respective symbols are as follows:

L : length between perpendiculars (= L_{pp}) (m);

A_x : projected front area above the water line (m^2);

A_y : projected lateral area above the water line (m^2);

X_g : distance between the centroid of A_y and F.P. (m).

(F.P.: fore perpendicular [refer to **Part II, Chapter 8, 1 Main Dimensions of Design Ships**])

Table 2.3.2 Regression Coefficients (When $L = L_{pp}$)

C_x	*Const.*	A_y/L^2	X_g/L	L/B	A_y/A_x
C_{x0}	-0.0358	0.925	0.0521		
C_{x1}	2.58	-6.087		-0.1735	
C_{x2}	-0.97		0.978	0.0556	
C_{x3}	-0.146			-0.0283	0.0728
C_{x4}	0.0851			-0.0254	0.0212
C_{x5}	0.0318	0.287		-0.0164	
Cy	*Const.*	A_y/L^2	X_g/L	L/B	A_y/A_x
C_{y1}	0.509	4.904			0.022
C_{y2}	0.0208	0.230	-0.075		
C_{y3}	-0.357	0.943		0.0381	
C_m	*Const.*	A_y/L^2	X_g/L	L/B	A_y/A_x
C_{m1}	2.650	4.634	-5.876		
C_{m2}	0.105	5.306			0.0704
C_{m3}	0.616		-1.474	0.0161	

b) A_x and A_y can be calculated by **equation (2.3.11)** proposed by Akakura and Takahashi.[17)]

$$\log(Y) = \alpha_w + \beta_w \log(X) \qquad \textbf{(2.3.11)}$$

where

Y : A_x or A_y;

X : DWT or GT of the design ship;

α_w, β_w : coefficients (refer to **Table 2.3.3**).

Table 2.3.3 Coefficients to Estimate A_x and A_y

Fully Loaded Condition

	Object unit	Coefficient when Y is A_x				Coefficient when Y is A_y			
		α_w	β_w	R^2	σ	α_w	β_w	R^2	σ
Cargo ship	DWT	-0.228	0.666	0.929	0.0451	0.507	0.616	0.824	0.1302
Bulk carrier	DWT	0.944	0.370	0.823	0.0497	1.218	0.425	0.841	0.0729
Container ship	DWT	0.136	0.609	0.812	0.0598	0.417	0.703	0.949	0.0675
Tanker	DWT	0.469	0.474	0.901	0.0625	0.556	0.558	0.931	0.0708
RORO ship	DWT	1.029	0.435	0.901	0.0469	1.453	0.464	0.719	0.1453
Passenger ship	GT	0.947	0.426	0.956	0.0715	0.059	0.680	0.998	0.0552
Ferry	GT	0.728	0.473	0.891	0.0578	0.564	0.674	0.974	0.0391
Gas carrier	GT	0.423	0.553	0.960	0.0593	0.705	0.613	0.939	0.0706

Ballast Condition

	Object unit	Coefficient when Y is A_x				Coefficient when Y is A_y			
		α_w	β_w	R^2	σ	α_w	β_w	R^2	σ
Cargo ship	DWT	0.099	0.615	0.935	0.0365	0.479	0.662	0.906	0.1007
Bulk carrier	DWT	0.629	0.469	0.935	0.0376	0.970	0.530	0.956	0.0460
Container ship	DWT	0.574	0.526	0.696	0.0741	0.731	0.625	0.819	0.1016
Tanker	DWT	0.251	0.551	0.962	0.0408	0.650	0.592	0.984	0.0333
RORO ship	DWT	0.917	0.473	0.910	0.0453	1.541	0.456	0.792	0.1123
Passenger ship	GT	0.986	0.419	0.953	0.0746	0.656	0.666	0.996	0.0466
Ferry	GT	0.710	0.484	0.901	0.0557	0.569	0.679	0.976	0.0377
Gas carrier	GT	0.503	0.547	0.980	0.0468	0.828	0.604	0.976	0.0420

c) When the distances X_G between the centroids of the lateral areas and F.P. are unknown, X_G can be calculated with reference to the average (0.517) and deviation (0.032) of X_G/L_{pp} in the literature 15).

iv. Calculation of rudder angles and drift angles β_1 based on the motion equation in an equilibrium situation

a) The motion equation of ships in an equilibrium situation under steady winds with rudder angles δ and drift angles β can be expressed by **equation (2.3.12)**.

$$\left.\begin{aligned} &Y_\beta \beta + Y_\delta \delta + C_y \left(\frac{\rho_a}{\rho_w}\right)\left(\frac{A_y}{Ld}\right)\left(\frac{U_a}{U}\right)^2 = 0 \\ &N_\beta \beta + N_\delta \delta + C_m \left(\frac{\rho_a}{\rho_w}\right)\left(\frac{A_y}{Ld}\right)\left(\frac{U_a}{U}\right)^2 = 0 \end{aligned}\right\} \qquad \textbf{(2.3.12)}$$

where

Y_β : coefficient for the reaction force in a transverse direction from a fluid when a ship diagonally navigates with a drift angle β;

N_β : coefficient for the turning reaction moment from a fluid when a ship diagonally navigates with a drift angle β;

Y_δ : coefficient for the lateral force generated by a rudder at rudder angle δ;

N_δ : coefficient for the rudder force moment generated by a rudder at rudder angle δ;

U : ship speed (m/s);

U_a : wind speed (m/s);

ρ_w : density of seawater (t/m^3);

ρ_a : density of air (t/m^3);

d : maximum draft of a moored design ship in still water (m);

L : length between perpendiculars (= L_{pp}) (m);

A_y : projected lateral area above the water line (m^2);

C_y : coefficient for lateral wind pressure resistance;

C_m : coefficient for wind pressure moment around the central axis of the hull.

b) Based on the equation above, the rudder and drift angles can be calculated by **equation (2.3.13)**.

$$
\left.
\begin{aligned}
&\text{Rudder angle: } \delta = -\left(\frac{\rho_a}{\rho_w}\right)\left(\frac{U_a}{U}\right)^2\left(\frac{A_y}{Ld}\right)\left(\frac{C_m Y'_\beta - C_y N'_\beta}{Y'_\beta N'_\delta - Y'_\delta N'_\beta}\right)\\
&\text{Drift angle: } \beta = \left(\frac{\rho_a}{\rho_w}\right)\left(\frac{U_a}{U}\right)^2\left(\frac{A_y}{Ld}\right)\left(\frac{C_m Y'_\delta - C_y N'_\delta}{Y'_\beta N'_\delta - Y'_\delta N'_\beta}\right)\\
&\text{provided that}\\
&\quad Y'_\beta = Y_\beta \big/ (0.5\rho_w L d U^2)\\
&\quad N'_\beta = N_\beta \big/ (0.5\rho_w L^2 d U^2)\\
&\quad Y'_\delta = Y_\delta \big/ (0.5\rho_w L d U^2)\\
&\quad N'_\delta = N_\delta \big/ (0.5\rho_w L^2 d U^2)
\end{aligned}
\right\}
\qquad \textbf{(2.3.13)}
$$

where

Y'_β : dimensionless value of the coefficient Y_β for the reaction force in a transverse direction from a fluid when a ship diagonally navigates with a drift angle β;

N'_β : dimensionless value of the coefficient N_β for the turning reaction moment from a fluid when a ship diagonally navigates with a drift angle β;

Y'_δ : dimensionless value of the coefficient Y_δ for the lateral force generated by a rudder at rudder angle δ;

N'_δ : dimensionless value of the coefficient N_δ for the rudder force moment generated by a rudder at rudder angle δ;

d : maximum draft of a moored design ship in still water (m);

L : length between perpendiculars (= L_{pp}) (m);

A_y : lateral projected area above the water line (m^2);

C_y : coefficient for lateral wind pressure resistance;

C_m : coefficient for wind pressure moment around the central axis of the hull;

ρ_w : density of seawater (t/m^3);

ρ_a : the density of air (t/m^3).

c) **Table 2.3.4** shows the calculation results of the required check rudder angles and drift angles β_1 for the types of ships listed in **Table 2.3.1** in a case where the ratio of wind speeds to ship speeds U_a/U (called as the "K value") with respect to the respective wind directions is 1.0. Here, the wind direction angles are measured from the bows of the respective ships. As is evident in **equation (2.3.13)**, the required check rudder and drift angles in cases where K values are other than 1 can be calculated by multiplying the require check rudder and drift angles when the K value is 1 by the square of the K values. As already mentioned in "Fundamentals of Performance Verification," the check rudder angles to compensate for the effect of winds shall be up to 15°. In cases where the check rudder angles exceed 15°, it is necessary to reassess the setting of maximum wind speed as one of the port call conditions, the normal direction of navigation channels, etc. The calculation results of the required check rudder and drift angles when K values are 1 to 7 are shown in **Reference (Part III), Chapter 4, 3 Required Check Rudder Angles and Drift Angles by Ship Type and Wind Direction Angle When *K* Values Are 1 to 7**. Cases with check rudder angles larger than 30° are eliminated from the calculation results. The values in **Table 2.3.1** can be used as references when calculating the approximate values of the required widths to cope with the effects of winds in cases where the types and sizes of design ships are equivalent to those listed in **Table 2.3.1**.

Table 2.3.4 Required Check Rudder and Drift Angles by Ship Type and Wind Direction Angle (D/d = 1.2)

Ship type			Ratio of wind speed to ship speed	Wind direction angle (°)												
				0	15	30	45	60	75	90	105	120	135	150	165	180
1	Cargo ship	Check rudder angle (°)	K = 1	0.000	0.017	0.049	0.102	0.169	0.233	0.276	0.284	0.257	0.204	0.138	0.068	0.001
		Drift angle (°)	K = 1	0.000	0.003	0.007	0.011	0.014	0.017	0.017	0.015	0.011	0.007	0.003	0.001	0.000
2	Cargo ship (small size)	Check rudder angle (°)	K = 1	0.000	0.028	0.069	0.128	0.199	0.267	0.313	0.325	0.300	0.245	0.170	0.087	0.001
		Drift angle (°)	K = 1	0.000	0.006	0.011	0.017	0.021	0.024	0.024	0.021	0.016	0.011	0.006	0.003	0.000
3	Container ship (14,000 TEU)	Check rudder angle (°)	K = 1	0.000	0.191	0.406	0.660	0.952	1.258	1.531	1.711	1.738	1.567	1.191	0.644	0.000
		Drift angle (°)	K = 1	0.000	0.040	0.074	0.099	0.113	0.116	0.109	0.095	0.077	0.058	0.039	0.019	0.000
4	Container ship (10,000 TEU)	Check rudder angle (°)	K = 1	0.000	0.113	0.245	0.406	0.593	0.787	0.956	1.063	1.070	0.958	0.723	0.389	0.000
		Drift angle (°)	K = 1	0.000	0.030	0.057	0.077	0.088	0.091	0.086	0.075	0.061	0.045	0.029	0.014	0.000
5	Container ship (6,000 TEU OVER PANAMAX)	Check rudder angle (°)	K = 1	0.000	0.082	0.178	0.293	0.425	0.559	0.671	0.736	0.732	0.648	0.485	0.261	0.002
		Drift angle (°)	K = 1	0.000	0.019	0.036	0.049	0.056	0.059	0.056	0.049	0.040	0.029	0.019	0.009	0.000
6	Container ship (4,000 TEU PANAMAX)	Check rudder angle (°)	K = 1	0.000	0.070	0.143	0.220	0.303	0.387	0.461	0.510	0.517	0.468	0.357	0.195	0.002
		Drift angle (°)	K = 1	0.000	0.015	0.029	0.038	0.042	0.043	0.040	0.036	0.030	0.023	0.016	0.008	0.000
7	Bulk carrier (VLOC)	Check rudder angle (°)	K = 1	0.000	0.012	0.035	0.072	0.119	0.164	0.195	0.202	0.184	0.147	0.100	0.050	0.000
		Drift angle (°)	K = 1	0.000	0.002	0.005	0.008	0.010	0.012	0.012	0.010	0.008	0.005	0.002	0.001	0.000
8	Bulk carrier (CAPESIZE)	Check rudder angle (°)	K = 1	0.000	0.015	0.039	0.077	0.124	0.169	0.199	0.206	0.189	0.153	0.105	0.053	0.000
		Drift angle (°)	K = 1	0.000	0.002	0.005	0.008	0.010	0.012	0.012	0.010	0.008	0.005	0.003	0.001	0.000
9	Bulk carrier (NEW PANAMAX)	Check rudder angle (°)	K = 1	0.000	0.014	0.036	0.070	0.112	0.153	0.180	0.186	0.170	0.137	0.094	0.047	0.000
		Drift angle (°)	K = 1	0.000	0.003	0.005	0.008	0.011	0.012	0.012	0.011	0.008	0.005	0.003	0.001	0.000
10	Bulk carrier	Check rudder angle (°)	K = 1	0.000	0.015	0.036	0.067	0.104	0.139	0.162	0.167	0.153	0.124	0.085	0.043	0.000
		Drift angle (°)	K = 1	0.000	0.002	0.004	0.006	0.008	0.009	0.009	0.008	0.006	0.004	0.002	0.001	0.000
11	Bulk carrier (small size)	Check rudder angle (°)	K = 1	0.000	0.027	0.070	0.135	0.217	0.296	0.351	0.367	0.340	0.278	0.194	0.099	0.001
		Drift angle (°)	K = 1	0.000	0.006	0.012	0.018	0.024	0.027	0.026	0.023	0.018	0.012	0.006	0.003	0.000
12	Tanker (VLCC)	Check rudder angle (°)	K = 1	0.000	0.008	0.027	0.059	0.102	0.143	0.170	0.174	0.157	0.123	0.082	0.040	0.000
		Drift angle (°)	K = 1	0.000	0.002	0.005	0.008	0.011	0.013	0.013	0.011	0.008	0.005	0.002	0.001	0.000
13	Tanker (small size)	Check rudder angle (°)	K = 1	0.000	0.015	0.044	0.095	0.160	0.223	0.264	0.272	0.245	0.193	0.129	0.064	0.001
		Drift angle (°)	K = 1	0.000	0.003	0.007	0.011	0.014	0.017	0.017	0.015	0.011	0.007	0.003	0.001	0.000
14	Pure car carrier (PCC) (VLCC)	Check rudder angle (°)	K = 1	0.000	0.264	0.550	0.873	1.234	1.611	1.954	2.189	2.235	2.029	1.551	0.842	0.000
		Drift angle (°)	K = 1	0.000	0.059	0.110	0.147	0.168	0.172	0.161	0.141	0.114	0.085	0.056	0.028	0.000
15	Pure car carrier (PCC) (large size)	Check rudder angle (°)	K = 1	0.000	0.159	0.340	0.556	0.806	1.067	1.298	1.450	1.470	1.324	1.006	0.546	0.005
		Drift angle (°)	K = 1	0.000	0.041	0.076	0.103	0.118	0.122	0.115	0.100	0.080	0.059	0.038	0.019	0.000
16	Pure car carrier (PCC)	Check rudder angle (°)	K = 1	0.000	0.161	0.353	0.593	0.877	1.176	1.440	1.609	1.626	1.458	1.104	0.598	0.006
		Drift angle (°)	K = 1	0.000	0.051	0.097	0.132	0.152	0.158	0.149	0.130	0.104	0.076	0.048	0.024	0.000
17	LNG ship	Check rudder angle (°)	K = 1	0.000	0.092	0.211	0.374	0.573	0.780	0.952	1.049	1.040	0.914	0.680	0.364	0.003
		Drift angle (°)	K = 1	0.000	0.033	0.063	0.087	0.103	0.109	0.105	0.091	0.072	0.052	0.032	0.015	0.000

Ship type			Ratio of wind speed to ship speed	Wind direction angle (°)												
				0	15	30	45	60	75	90	105	120	135	150	165	180
18	LPG ship	Check rudder angle (°)	$K = 1$	0.000	0.053	0.125	0.223	0.341	0.459	0.550	0.591	0.570	0.487	0.353	0.185	0.000
		Drift angle (°)	$K = 1$	0.000	0.012	0.024	0.034	0.041	0.044	0.043	0.037	0.029	0.020	0.012	0.005	0.000
19	Refrigerated cargo carrier	Check rudder angle (°)	$K = 1$	0.000	0.036	0.089	0.164	0.255	0.342	0.405	0.425	0.397	0.328	0.231	0.119	0.001
		Drift angle (°)	$K = 1$	0.000	0.008	0.015	0.023	0.028	0.032	0.031	0.028	0.022	0.015	0.008	0.004	0.000
20	Passenger ship (large, 2 shafts, 2 propellers)	Check rudder angle (°)	$K = 1$	0.000	0.298	0.600	0.920	1.285	1.706	2.154	2.540	2.729	2.588	2.044	1.132	0.000
		Drift angle (°)	$K = 1$	0.000	0.151	0.276	0.358	0.392	0.386	0.354	0.308	0.257	0.202	0.141	0.073	0.000
21	Passenger ship (2 shafts, 2 propellers)	Check rudder angle (°)	$K = 1$	0.000	0.174	0.363	0.578	0.826	1.097	1.361	1.561	1.629	1.507	1.169	0.643	0.006
		Drift angle (°)	$K = 1$	0.000	0.082	0.152	0.201	0.226	0.227	0.212	0.185	0.151	0.115	0.078	0.039	0.000
22	Ferry boat (2 shafts, 1 propeller)	Check rudder angle (°)	$K = 1$	0.000	0.113	0.253	0.438	0.662	0.900	1.111	1.244	1.257	1.126	0.851	0.460	0.004
		Drift angle (°)	$K = 1$	0.000	0.053	0.100	0.136	0.158	0.164	0.155	0.135	0.108	0.078	0.050	0.024	0.000

v. Calculation of drift angles β_2 due to the effects of tidal currents

Drift angles can be calculated by **equation (2.3.14)** using ship speeds and the abeam components of tidal constituent speeds.

$$\beta_2 = \arctan(U_c / U) \qquad \textbf{(2.3.14)}$$

where

β_2 : drift angle due to the effects of tidal currents (°);

U : ship speed (m/s);

U_c : abeam component of the tidal constituent speed with respect to the centerline of the navigation channel (m/s).

vi. Calculation of the required widths W_m (β) to account for wind forces and current forces

The required widths to account for wind forces and current forces can be calculated by **equation (2.3.15)** using the drift angles β to compensate for these forces, and are obtainable by combining the drift angles β_1 and β_2 to compensate for the effects of winds and tidal currents, respectively.

$$\left.\begin{aligned} &\beta = \beta_1 + \beta_2 \\ &W(\beta) = L_{oa}\sin\beta + B\cos\beta \end{aligned}\right\} \qquad \textbf{(2.3.15)}$$

where

$W(\beta)$: required widths to account for wind forces and current forces (m);

L_{oa} : length overall of the ship (m);

B : molded breadth (m);

B : drift angle to compensate for the effects of winds and tidal currents (°);

β_1 : drift angle to compensate for the effect of winds (°);

β_2 : drift angle to compensate for the effect of tidal currents (°).

vii. Calculation of the required widths $W(y)$ to account for yawing motion

a) The required widths $W(y)$ to account for yawing motion can be calculated by **equation (2.3.16)** using the maximum meandering amount (either side).

$$W(y) = U\int_0^{T_y/4} \sin\varphi(t)\,dt = \frac{1}{4}UT_y\sin\varphi_0 \qquad \textbf{(2.3.16)}$$

where

$W(y)$: required widths to account for yawing motion (m);

U : ship speed (m/s);

T_y : yawing period (s);

φ_0 : maximum yawing angle (°);

$\varphi(t)$: yawing amount at clock time t, $\varphi(t) = \varphi_0 \sin(2\pi t/T_y)$ (m).

b) When yawing periods T_y and the maximum yawing angle φ_0 are unknown, T_y = 12s and φ_0 = 4° can be used as values on the safe side.

viii. Calculation of the required widths $W_m(\beta, y)$ to account for wind forces, current forces and yawing motion

The required widths $W_m(\beta, y)$ to account for wind forces, current forces and yawing motion can be calculated by **equation (2.3.17)**.

$$W_m(\beta, y) = W(\beta) + 2W(y) = L_{oa}\sin\beta + B\cos\beta + 0.5UT_y\sin\phi_0 \quad \textbf{(2.3.17)}$$

where

$W_m(\beta, y)$: required width to account for wind forces, current forces and yawing motion (m);

$W(\beta)$: required width to account for wind forces and current forces (m);

$W(y)$: required width to account for yawing motion (m).

(b) The required widths $W_m(S)$ to account for drift detection can be calculated by the following procedure.

1) Basic concept of calculation

i. In general, a ship sailing in the fairway more or less makes some amount of lateral deviation from its course line even if the ship handler does believe that his ship is running on the right course line. This drift may hardly be detected within small amount of deviation. However, the ship handler can recognize the drift when the lateral deviation from the fairway center line becomes considerable amount. The required widths $W_m(S)$ are to enable navigators to recognize a lateral drift of ships through a deviation from the predetermined courses.

ii. Estimations of the required width $W_m(S)$ for the drift detection are provided for the following four types of on-board navigation equipment, which are currently available in the actual ship operation.

a) Recognition of lateral drift through the visual identification of buoys on both sides of the navigation channels $W_m(S)=W_m(\alpha)$

b) Recognition of lateral drift through the identification of buoys on both sides of the navigation channels by radar $W_m(S)=W_m(R)$

c) Recognition of lateral drift using GPS $W_m(S)=W_m(GPS)$ or $W_m(D\cdot GPS)$

d) Recognition of lateral drift using guide marks (lights) $W_m(S)=W_m(L)$

(2.3.18)

The appropriate methods for drift detection shall be selected depending on the design ships and navigation channels.

2) Standard calculation methods and calculation equations

i. Calculation of the required width $W_m(a)$ for drift detection by observing light buoys on both sides of the navigation channels with naked eyes

a) The required width $W_m(a)$ for drift detection by observing light buoys on both sides of the navigation channels with naked eye can be calculated by **equation (2.3.19)** proposed by the West Japan Society of Naval Architects.[18)]

$$\left.\begin{aligned}
&\theta = 2\arctan\left(\frac{W_{buoy}}{2LF}\right)\\
&\alpha_r = 0.00044\theta^2 + 0.0002\theta + 0.55343\\
&\alpha_{\max} = 4\alpha_r\\
&W_m(\alpha) = LF\tan(\alpha_{\max})
\end{aligned}\right\} \quad \textbf{(2.3.19)}$$

where

θ : angle between the lines connecting the ship with anterior buoys on both sides of the navigation channel (°);

W_{buoy} : distance between anterior buoys on both sides of the navigation channel (m);

LF : distance between the ship and the anterior buoy (m);

$W_m(a)$: required width for drift detection by observing light buoys on both sides of the navigation channels with naked eye (m);

α_r : observation error of middle point (°);

α_{max} : maximum observation error of middle point (the maximum error with which 99.8% of navigators can recognize lateral deflection) (°).

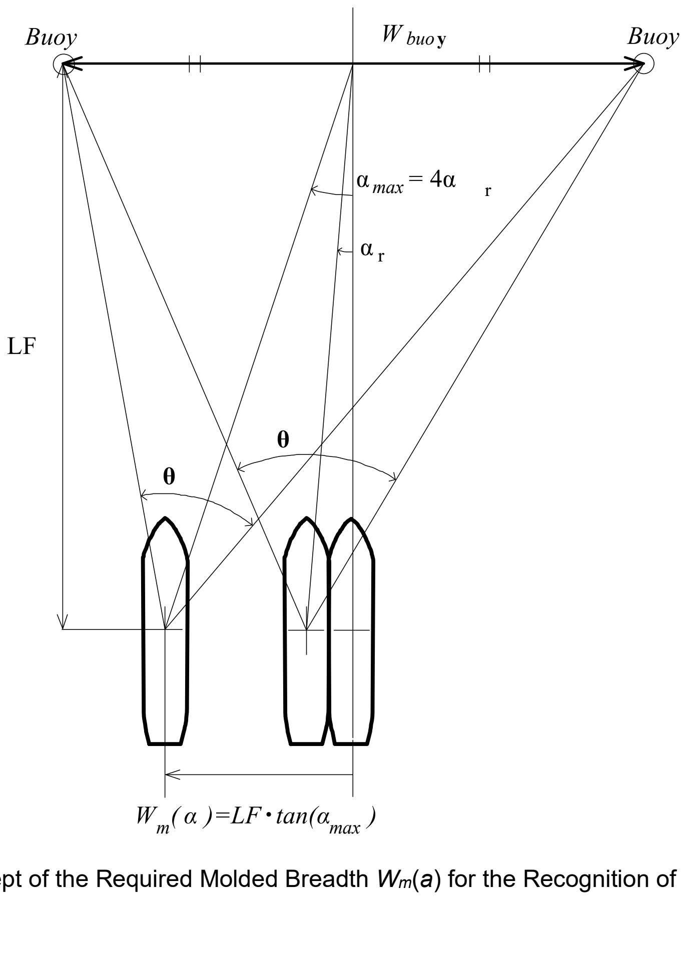


Fig. 2.3.9 Concept of the Required Molded Breadth $W_m(a)$ for the Recognition of Lateral Deflection

b) The distances LF from the ships to the anterior buoys can be set as shown below based on the concept shown in the literature 1).

One-way navigation channel $LF = 7L_{oa}$ **(2.3.20)**

Two-way navigation channel $LF = 3.5L_{oa} \sim 7L_{oa}$ **(2.3.21)**

where

L_{oa} : length overall.

c) For existing navigation channels, LF can be the distances between anterior buoys in the case of one-way navigation channels and 0.5 to 1.0 times the distances between anterior buoys in the case of two-way navigation channels.

ii. Calculation of the required widths $W_m(R)$ for drift detection by observing light buoys on both sides of the navigation channels with radar

a) The required widths $W_m(R)$ for drift detection by observing light buoys on both sides of the navigation channels with radar can be calculated by **equations (2.3.22)** and **(2.3.23)** proposed by the West Japan Navigation Technology Study Group.[18)]

The maximum deflection error in the lateral direction when confirming the positions of ships through cross bearings by measuring the buoys on both sides of the ships by radar can be expressed by the following equation, provided that the orientation error of radar observation is 2°.

$$\text{Maximum drift error in the lateral direction} = \frac{W_{buoy} \sin 2^\circ}{\sin \theta} \quad \textbf{(2.3.22)}$$

Therefore,

$$W_m(R) = 0.0349 \frac{W_{buoy}}{\sin \theta} \quad \text{(When the measurement error is 2°)} \quad \textbf{(2.3.23)}$$

where

$W_m(R)$: required width for drift detection by observing light buoys on both sides of the navigation channels with radar (m);

W_{buoy} : distance between anterior buoys (m);

θ : angle between the lines connecting the ship with the anterior buoys on both sides of the navigation channel (°);

where

$$\theta = 2 \arctan\left(\frac{W_{buoy}}{2LF}\right) \quad \textbf{(2.3.24)}$$

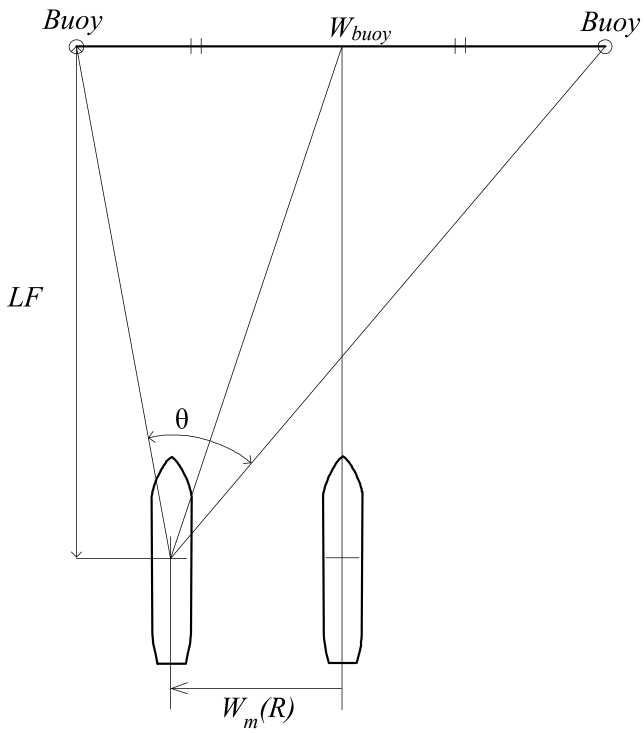


Fig. 2.3.10 Concept of the Required Molded Breadth $W_m(R)$ for the Drift Detection

b) It has been said that the measurement error of radar observation has been reduced to 1° due to the development of radar observation technologies since the West Japan Navigation Technology Study Group first proposed the equations in 1977.

Thus, for design ships equipped with accurate radar observation devices (with an orientation error of 1°), the required widths for the recognition of lateral drift can be calculated by **equation (2.3.25)**.

$$W_m(R) = 0.0175\frac{W_{buoy}}{\sin\theta} \quad \text{(When the measurement error is 1°)} \qquad \textbf{(2.3.25)}$$

c) As is the case with $W_m(a)$, the distance LF from ships to anterior buoys can be set as shown below based on the concept shown in **Reference 1)**.

One-way navigation channel $LF = 7L_{oa}$ **(2.3.26)**

Two-way navigation channel $LF = 3.5L_{oa} \sim 7L_{oa}$ **(2.3.27)**

where

L_{oa} : length overall.

d) For existing navigation channels, LF can be the distances between anterior buoys in the case of one-way navigation channels and 0.5 to 1.0 times the distances between anterior buoys in the case of two-way navigation channels.

iii. Calculation of the required widths $W_m(GPS)$ and $W_m(D{\cdot}GPS)$ for drift detection by GPS

a) The maximum measurement error of a GPS (single GPS) shall be set at 28 m as observed by the Japan Coast Guard.[19] For the maximum measurement error of a Differential GPS (D·GPS), the following values can be used based on the correction information by the Japan Coast Guard GPS Center.

- Error for single GPS = 30 m

- Error for D·GPS = 1 m

b) The use of GPS information in positioning is based on the assumption that electronic nautical charts accurately show measurement results. Considering that navigators actually determine ship positions based on the images of GPS information shown on displays, $W_m(GPS)$ and $W_m(D{\cdot}GPS)$ can be set as follows based on the display image magnification ratios of the ECDIS (Electronic Chart Display and Information System). For the calculation of $W_m(D{\cdot}GPS)$, the error of 1 m for D·GPS measurements can be ignored.

$$\left.\begin{array}{ll}\text{(For single GPS)} & : W_m(GPS) = 0.5B + 30 \quad (\text{m}) \\ \text{(For D·GPS)} & : W_m(D \cdot GPS) = 0.5\text{B} \quad (\text{m})\end{array}\right\} \qquad \textbf{(2.3.28)}$$

where

B : molded breadth (m).

iv. Calculation of the required widths $W_m(L)$ for drift detection by guide marks (lights)

a) Following the method adopted by the Hydrographic Service of the Royal Netherlands Navy, the required widths $W_m(L)$ for drift detection by guide marks (lights) can be calculated based on vertical angles θ_v and horizontal angles θ_h.

b) Calculation of vertical angles θ_v

The vertical angle θ_v between the lines connecting the navigator of the ship with the anterior and posterior navigation marks (lights) can be calculated by **equations (2.3.29)** and **(2.3.30)**.

$$\theta_v = \theta_{v1} - \theta_{v2} - \theta_{v3} \qquad \textbf{(2.3.29)}$$

$$\left.\begin{array}{l}\theta_{v1} = \arctan\left(\dfrac{H_H - H_L}{L_H}\right) \\ \theta_{v2} = \arctan\left(\dfrac{H_L - H_h}{L_L}\right) - \arctan\left(\dfrac{1\ H_L - H_h}{L_H}\right) \\ \theta_{v3} = \arctan\left(\dfrac{(1-K)L_D}{2R}\right) = 2.27 \cdot 10^{-4} L_D\end{array}\right\} \qquad \textbf{(2.3.30)}$$

(Terms to correct the effects of the curvature of the Earth, where R: the radius of the Earth [6,360 km] and K: the refraction coefficient [0.16])

where

θ_v : vertical angle between the lines connecting the navigator of the ship with the anterior and posterior navigation marks (lights) (minutes);

H_H : height of the posterior guide mark (light) (m);

H_L : height of the anterior guide mark (light) (m);

H_h : eye height of the navigator on the ship (m);

L_H : distance between the ship and the posterior guide mark (light) (m);

L_L : distance between the ship and the anterior guide mark (light) (m);

L_D : distance between the posterior and anterior guide marks (lights) (= $L_H - L_L$) (m).

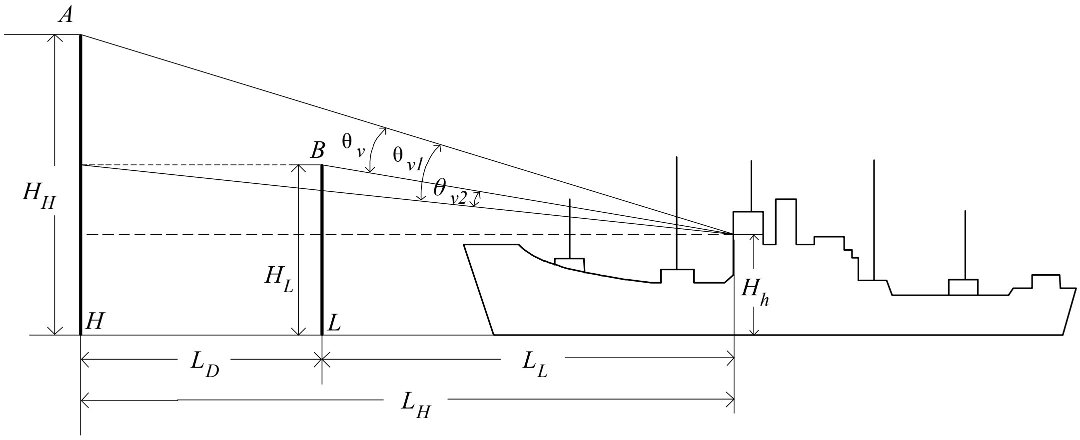


Fig. 2.3.11 Positional Relationship between the Design Ship and Guide Marks (Lights) (Elevation)

c) Calculation of vertical angles θ_h

The horizontal angles θ_h (minutes), with which navigators having healthy eyesight can recognize lateral deflection based on the breakup effects of the guide marks (lights), can be obtained from **Fig. 2.3.12** in relation to the calculated vertical angles θ_v (minutes).

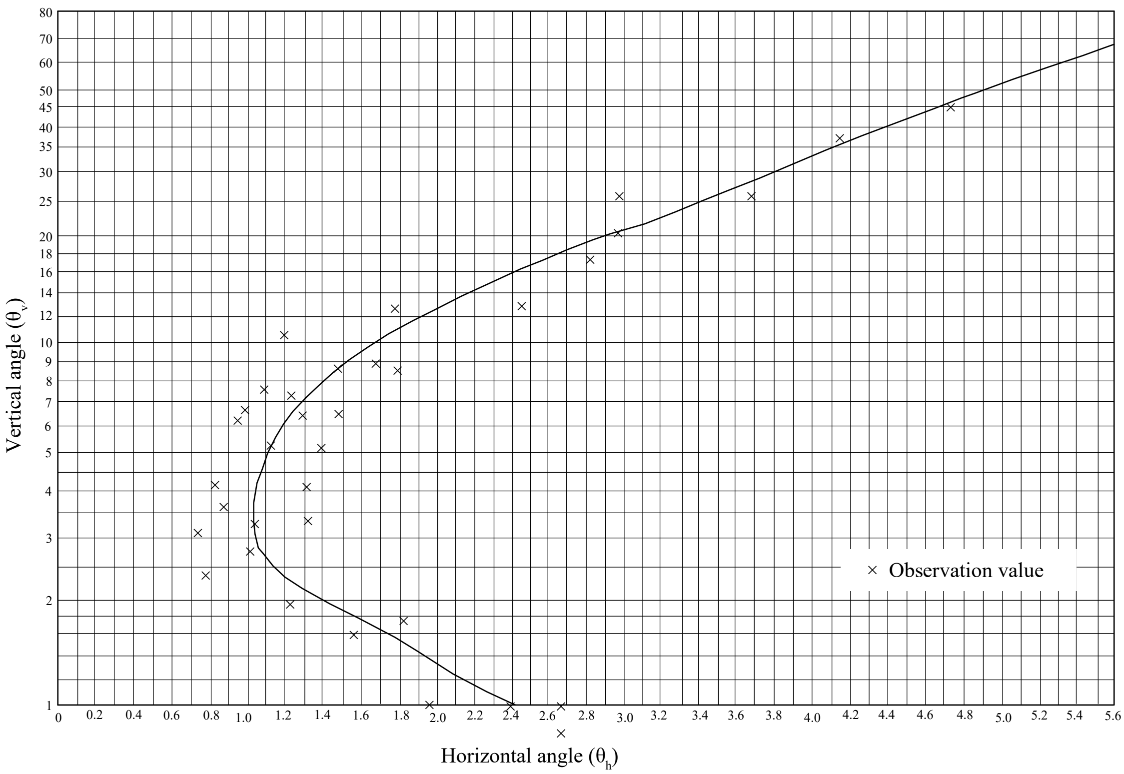


Fig. 2.3.12 Relationship Diagram between Vertical Angle (θ_v) and Horizontal Angle (θ_h) of Guide Marks (Lights)

d) Calculation of the required widths $W_m(L)$ for drift detection by guide marks (lights)

Based on the horizontal angles θ_h obtained from **Fig. 2.3.12**, the required widths $W_m(L)$ for drift detection by guide marks (lights) can be calculated by the following equation.

$$W_m(L) = \frac{L_H L_L \sin(\theta_h)}{L_D} \quad \textbf{(2.3.31)}$$

where

$W_m(L)$: required width for drift detection by guide marks (lights) (m);

L_H : distance between the ship and the posterior guide mark (light) (m);

L_L : distance between the ship and the anterior guide mark (light) (m);

L_D : distance between the posterior and anterior guide marks (lights) (= $L_H - L_L$) (m);

θ_h : horizontal angle with which a navigator having healthy eyesight can recognize lateral deflection on the basis of the breakup effects of the guide marks (lights) (minutes).

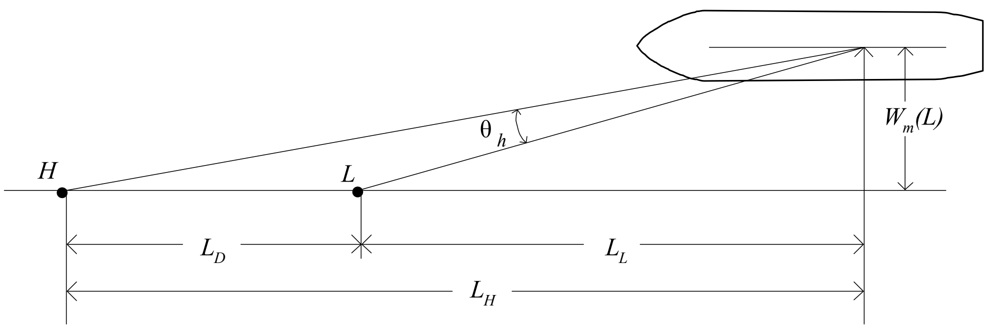


Fig. 2.3.13 Positional Relationship between the Design Ship and Guide Marks (Lights) (Plan)

② Widths W_{bi} considering an allowance for bank effect forces (the required widths to account for bank effect forces of navigation channels) can be calculated through the methods described in (a) and (b) 1) to 5) below.

(a) Basic concept of calculation

Because the bank effect forces of navigation channels are continuous, the required widths can be calculated as the distances from the side walls which enable ships to account for bank effect forces with a maximum check rudder angle of 5°.

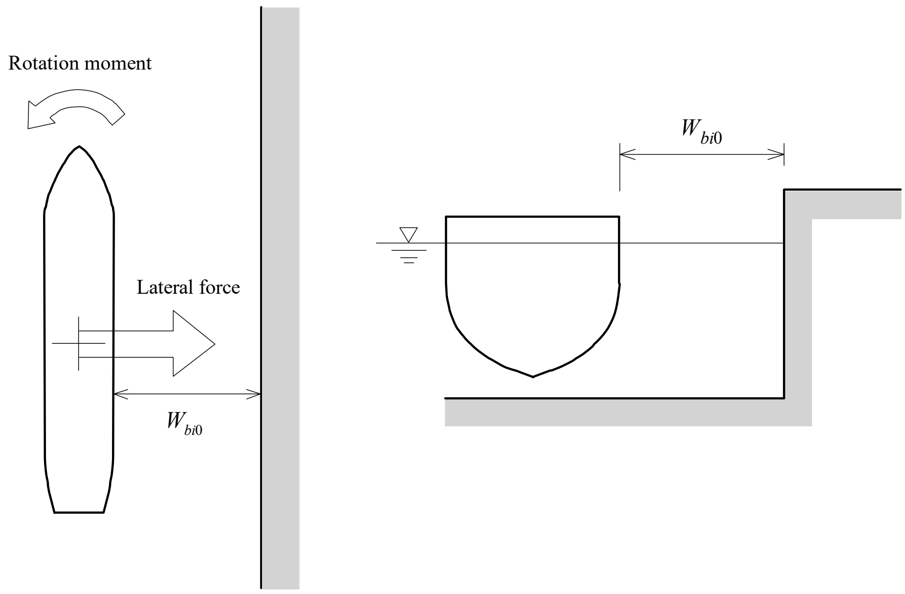


Fig. 2.3.14 Concept of Width to Account for Bank Effect Forces

(b) Standard calculation method and calculation equation

1) Calculation of the widths W_{bi} (subscript *b*: bank) to account for bank effect forces

The widths W_{bi} to account for bank effect forces can be calculated by the following phased calculation method.

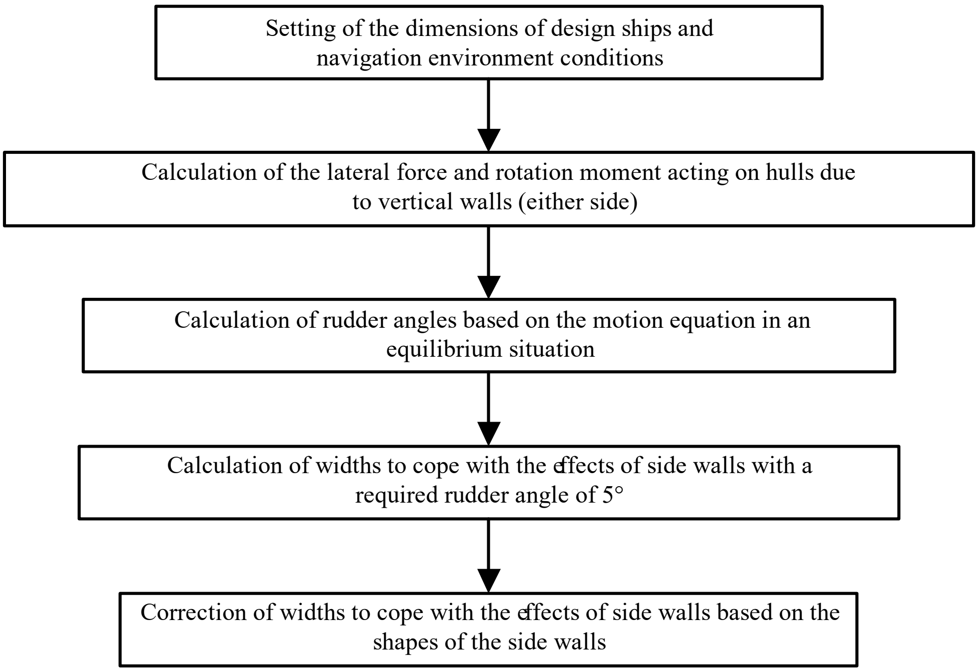


Fig. 2.3.15 Calculation of Width to Account for Bank Effect Forces

2) Calculation of the lateral force and rotation moment acting on hulls due to bank walls (either side)

The values of the lateral force C_F and rotation moment C_M acting on the hulls of ships navigating close to bank walls can be obtained through **Fig. 2.3.16** proposed by Kijima et al.[20] according to S_p/L (= S_{pb}/L) values. In the figure, C_F (= C_{Fb}) and C_M (= C_{Mb}) are defined by **equation (2.3.32)**.

$$\left.\begin{aligned} C_{Fb} &= \frac{F_b}{0.5\rho_w L d U^2} \\ C_{Mb} &= \frac{M_b}{0.5\rho_w L^2 d U^2} \end{aligned}\right\} \qquad \textbf{(2.3.32)}$$

where

S_{pb} : distance from the centerline of the o the bank wall (S_p in **Fig. 2.3.16**) (m);

L : length between perpendiculars L_{pp} (m);

F_b : lateral force acting on the hull of a ship navigating close to a bank wall (kg·m/s^2);

C_{Fb} : dimensionless value of the lateral force acting on the hull of a ship navigating close to a bank wall;

M_b : rotation moment acting on the hull of a ship navigating close to a bank wall (N·m);

C_{Mb} : dimensionless value of the rotation moment acting on the hull of a ship navigating close to a bank wall;

U : ship speed (m/s);

d : maximum draft of a moored design ship in still water (m);

ρ_w : density of seawater (kg/m^3).

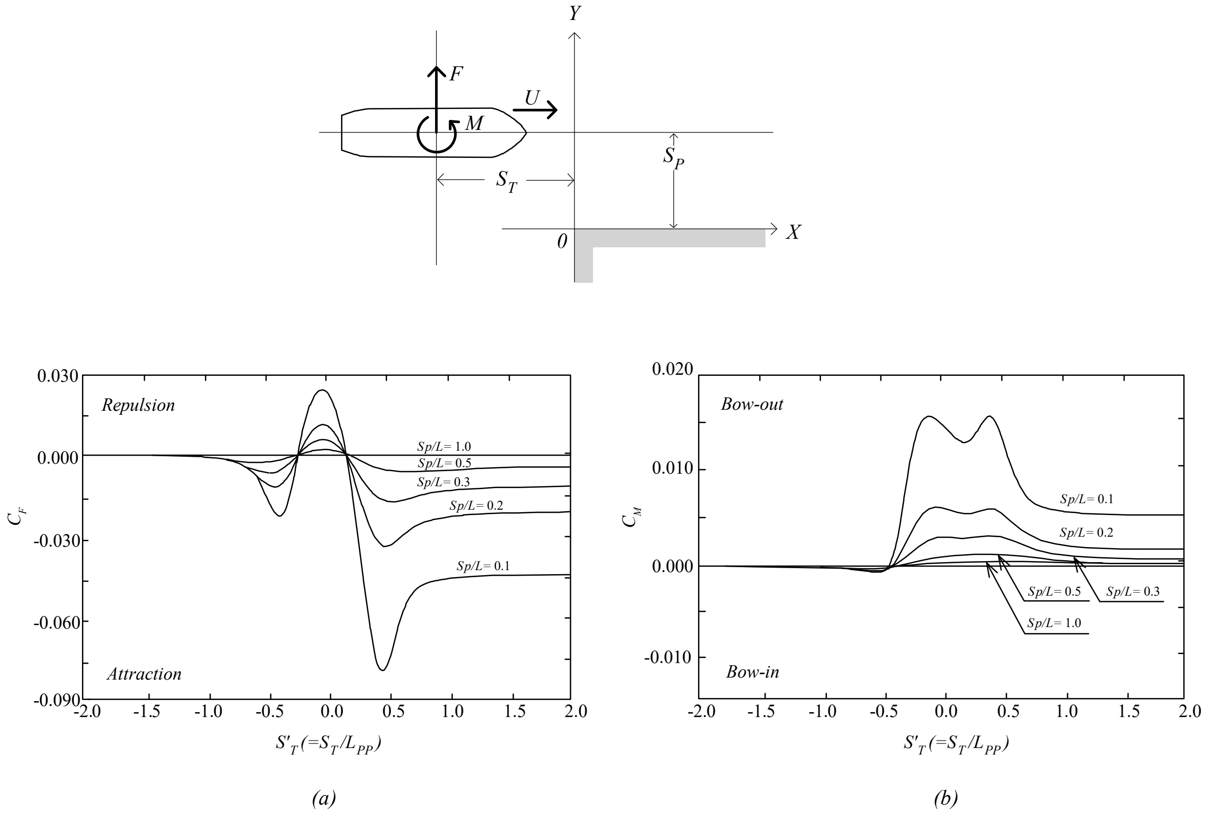


Fig. 2.3.16 Suction Force and Repulsive Moment[20] Acting on Ships Navigating Close to Bank Walls (in the figure, $S_p = S_{pb}$)

3) Calculation of the check rudder angle based on the motion equation in an equilibrium situation

The motion equation of ships navigating with rudder angles δ and drift angles β in an equilibrium situation can be expressed by **equation (2.3.33)** in the coordination system of **Fig. 2.3.16**.

$$\left.\begin{aligned} -C_{Fb} + Y'_{\beta}\beta + Y'_{\delta}\delta = 0 \\ -C_{Mb} + N'_{\beta}\beta + N'_{\delta}\delta = 0 \end{aligned}\right\} \qquad \textbf{(2.3.33)}$$

where

C_{Fb} : dimensionless value of the lateral force acting on the hull of a ship navigating close to a bank wall;

C_{Mb} : dimensionless value of the rotation moment acting on the hull of a ship navigating close to a bank wall;

Y'_{β} : dimensionless value of the coefficient Y_{β} for the reaction force in a transverse direction from a fluid when a ship diagonally navigates with a drift angle β;

N'_{β} : dimensionless value of the coefficient N_{β} for the turning reaction moment from a fluid when a ship diagonally navigates with a drift angle β;

Y'_{δ} : dimensionless value of a transverse force coefficient Y_{δ} generated by a rudder set at rudder angle δ;

N'_{δ} : dimensionless value of the coefficient N_{δ} for a rudder force moment generated by a rudder at rudder angle δ.

Then, rudder angles δ and drift angles β can be calculated by **equation (2.3.34)** obtained by solving **equation (2.3.33)**.

$$\left.\begin{aligned}\delta &= \frac{C_{Mb}Y'_{\beta} - C_{Fb}N'_{\beta}}{Y'_{\beta}N'_{\delta} - Y'_{\delta}N'_{\beta}} \\ \beta &= -\frac{C_{Mb}Y'_{\delta} - C_{Fb}N'_{\delta}}{Y'_{\beta}N'_{\delta} - Y'_{\delta}N'_{\beta}}\end{aligned}\right\} \quad \textbf{(2.3.34)}$$

where

δ : rudder angle (rad);

β : drift angle (rad).

However, it is noted that the unit system of δ and β needs to be changed to degrees (°) for the following calculations.

Here, in **Fig. 2.3.16 (a)**, C_F (= C_{Fb}) values are –0.044, –0.021 and –0.012 when S_{pb}/L values are 0.1, 0.2 and 0.3, respectively, in the range of a steady situation ($S'_T = S_T/L > 1.5$). Also, in **Fig. 2.3.16 (b)**, C_M (= C_{Mb}) values are 0.0050, 0.0012 and 0.0002 when S_{pb}/L values are 0.1, 0.2 and 0.3, respectively.

4) Calculation of the widths W_{bi0} to account for bank effect forces when the check rudder angle is 5°

The widths W_{bi0} can be calculated in a manner that obtains a regression equation of S_{pb}/L with rudder angles δ as a variable from the calculation results of δ corresponding to S_{pb}/L, calculates S_{pb}/L values by substituting δ = 5° into the regression equation, and calculates W_{bi0} by substituting the obtained S_{pb}/L value into **equation (2.3.35)**. However, in case the calculated rudder angles with S_{pb}/L exceeds 30° which is unrealistically large, the value of S_{pb}/L shall be ignored for developing the regression equation.

$$W_{bi0} = S_{pb} - 0.5B \quad \textbf{(2.3.35)}$$

where

W_{bi0} : width to account for bank effect forcess (m);

S_{pb} : distance from the centerline of a ship to the side wall (m);

B : molded breadth of the design ship (m).

The calculation results of the widths to account for bank effect forces for the type of ships listed in **Table 2.3.1** are shown in **Table 2.3.5**, and the values in the table can be used as approximate values of W_{bi0}. It shall be noted that W_{bi0} values are not affected by ship speeds.

Table 2.3.5 W_{bi0} by Ship Type

(Required Width to Cope with the Effects of Vertical Side Walls with a Check Rudder Angle of 5° and D/d = 1.2)

	Ship type	L_{pp}	B	S_{pb}/L_{pp}	S_{pb}	W_{bi0}	W_{bi0}/B
1	Cargo ship	103.0	20.0	0.267	27.4	17.4	0.87
2	Cargo ship (small size)	60.4	11.2	0.255	15.4	9.8	0.87
3	Container ship (14,000 TEU)	352.0	51.0	0.282	99.4	73.9	1.45
4	Container ship (10,000 TEU)	318.3	45.8	0.268	85.2	62.3	1.36
5	Container ship (6,000 TEU OVER PANAMAX)	283.8	40.0	0.266	75.5	55.5	1.39
6	Container ship (4,000 TEU PANAMAX)	273.0	32.2	0.261	71.3	55.2	1.71
7	Bulk carrier (VLOC)	318.0	55.0	0.266	84.5	57.0	1.04
8	Bulk carrier (CAPESIZE)	279.0	45.0	0.269	75.1	52.6	1.17
9	Bulk carrier (NEW PANAMAX)	236.0	38.0	0.260	61.3	42.3	1.11
10	Bulk carrier	216.0	32.3	0.269	58.1	41.9	1.30

	Ship type	L_{pp}	B	S_{pb}/L_{pp}	S_{pb}	W_{bi0}	W_{bi0}/B
11	Bulk carrier (small size)	119.2	21.5	0.261	31.1	20.3	0.95
12	Tanker (VLCC)	316.0	60.0	0.252	79.7	49.7	0.83
13	Tanker (small size)	92.0	20.0	0.259	23.8	13.8	0.69
14	Pure car carrier (PCC) (VLCC)	190.9	36.5	0.271	51.7	33.5	0.92
15	Pure car carrier (PCC) (large size)	190.0	32.2	0.265	50.4	34.3	1.06
16	Pure car carrier (PCC)	180.0	32.2	0.263	47.3	31.2	0.97
17	LNG ship	270.0	44.8	0.260	70.1	47.7	1.07
18	LPG ship	220.0	36.6	0.264	58.1	39.8	1.09
19	Refrigerated cargo carrier	144.0	23.5	0.267	38.4	26.6	1.13
20	Passenger ship (large, 2 shafts, 2 propellers)	306.0	38.4	0.256	78.3	59.1	1.54
21	Passenger ship (2 shafts, 2 propellers)	160.0	24.7	0.239	38.3	25.9	1.05
22	Ferry boat (2 shafts, 1 propeller)	181.0	29.4	0.250	45.2	30.5	1.04

5) Corrections for widths to account for bank effect forces based on wall shapes

i. When the shape of a side wall is as shown in **Fig. 2.3.17**, it is necessary to set a correction coefficient h_f based on the ratios of the depths outside the navigation channels to navigation channel depths (h_1: navigation channel depth ratio). The correction coefficients can be calculated by **equation (2.3.36)** proposed by Kijima et al.[21)]

$$h_f = \exp\left(-2\frac{h_1}{1-h_1}\right) \qquad \textbf{(2.3.36)}$$

where

h_f : correction coefficient corresponding to the navigation channel depth ratio h_1;

h_1 : navigation channel depth ratio (= depth outside navigation channel D_{out}/navigation channel depth D).

In the case of **Fig. 2.3.14**, $h_1 = 0$. For navigation channels with no bank walls, $h_1 = 0.9999$.

ii. The widths to account for bank effect forces W_{bi} corresponding to navigation channel depth ratios can be calculated by multiplying the widths account for vertical bank wall effect forces W_{bi0} by the correction coefficients h_f.

$$W_{bi} = W_{bi0} h_f \qquad \textbf{(2.3.37)}$$

where

W_{bi} : width to account for bank effect forces when the bank wall is not vertical (m);

W_{bi0} : width to account for vertical bank wall effect forces with a required check rudder angle of 5° (m);

h_f : correction coefficient based on the ratio of the navigation channel depth to the depth outside the navigation channel (h_1).

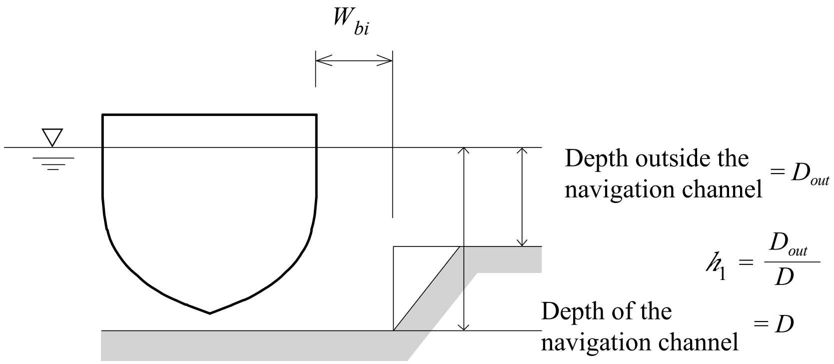


Fig. 2.3.17 Concept of Width to Account for Bank Effect Forces Based on Wall Shapes

iii. In cases where the slopes of side walls are gentle ($D_\theta \leq 45°$), as shown in **Fig. 2.3.18**, the depths outside the navigation channels can be modified to D_{out}' using **equation (2.3.38)** for calculating the widths to account for bank effect forces.

Modified depth outside the navigation channel : $D_{out}'=0.5\ (D + D_{out})$ (m) **(2.3.38)**

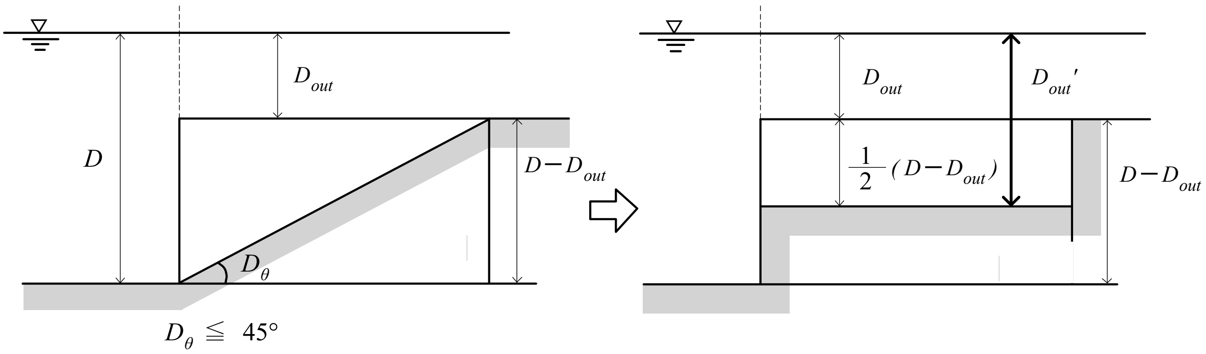


Fig. 2.3.18 Modified Depth outside the Navigation Channel When the Slopes of the Bank Walls are Gentle ($D_\theta \leq 45°$)

③ The widths to account for edges effect forces W_p (required widths to cope with the effects of the edges of breakwaters and jetties) can be calculated by the following procedures for special cases of side walls.

(a) Basic concept of calculation

Because the duration of the effects of the edges of breakwaters and jetties on ship navigation is considered to be relatively short, the required widths to account for edges effect forces can be calculated as the distances from the edges necessary to compensate for the effects with a maximum check rudder angle of 15°.

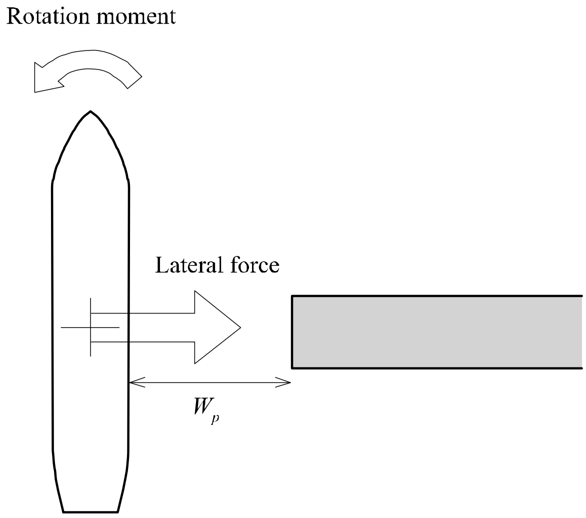


Fig. 2.3.19 Concept of Widths to Account for Edges Effect Forces

(b) Calculation of standard widths to account for edges effect forces W_p

1) Calculation of the widths to account for edges effect forces (subscript *p*: pier) when the crossing angles between the navigation channels and breakwaters or jetties are 90°

The widths to account for edges effect forces W_p can be calculated by the following phased calculation method.

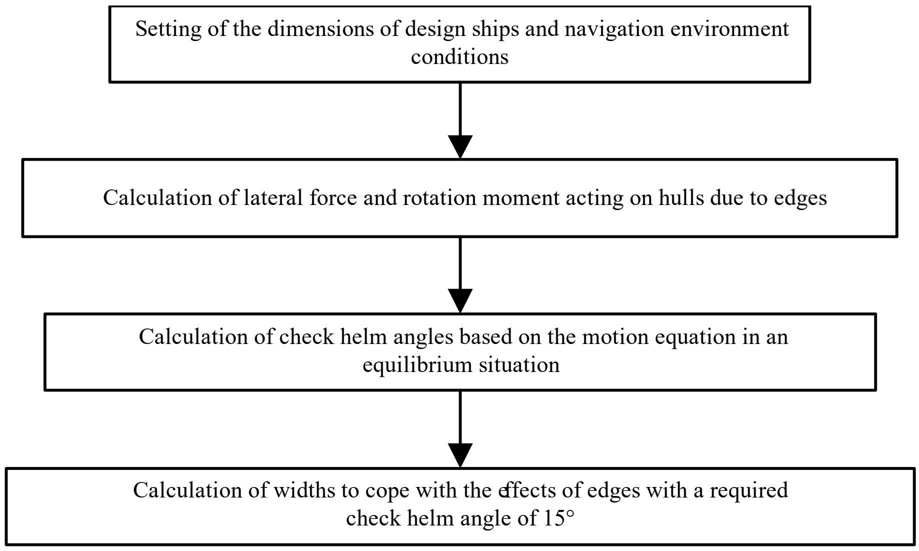


Fig. 2.3.20 Widths to Account for Edges Effect Forces

2) Calculation of the lateral force and rotation moment acting on hulls due to edges

The values for the lateral force C_F and rotation moment C_M acting on the hulls of ships navigating close to the edges of breakwaters and jetties for each S_p/L (= S_{pp}/L) can be obtained from **Fig. 2.3.21** proposed by Kijima et al.[20] Here, C_F (= C_{Fp}) and C_M (= C_{Mp}) are defined by **equation (2.3.39)**.

$$\left.\begin{aligned} C_{F_p} &= \frac{F_p}{0.5\rho_w L d U^2} \\ C_{M_p} &= \frac{M_p}{0.5\rho_w L^2 d U^2} \end{aligned}\right\} \quad \textbf{(2.3.39)}$$

where

S_{pp} : distance from the centerline of the navigation channel to the edge (S_p in **Fig. 2.3.21**) (m);

L : length between perpendiculars L_{pp} (m);

F_n : lateral force acting on the hull of a ship navigating close to the edge of a breakwater or jetty (N);

C_{Fp} : dimensionless value of the lateral force acting on the hull of a ship navigating close to the edge of a breakwater or jetty;

M_p : rotation moment acting on the hull of a ship navigating close to the edge of a breakwater or jetty (N·m);

C_{Mp} : dimensionless value of the rotation moment acting on the hull of a ship navigating close to the edge of a breakwater or jetty;

U : ship speed (m/s);

d : maximum draft of a moored design ship in still water (m);

ρ_w : density of seawater (kg/m^3).

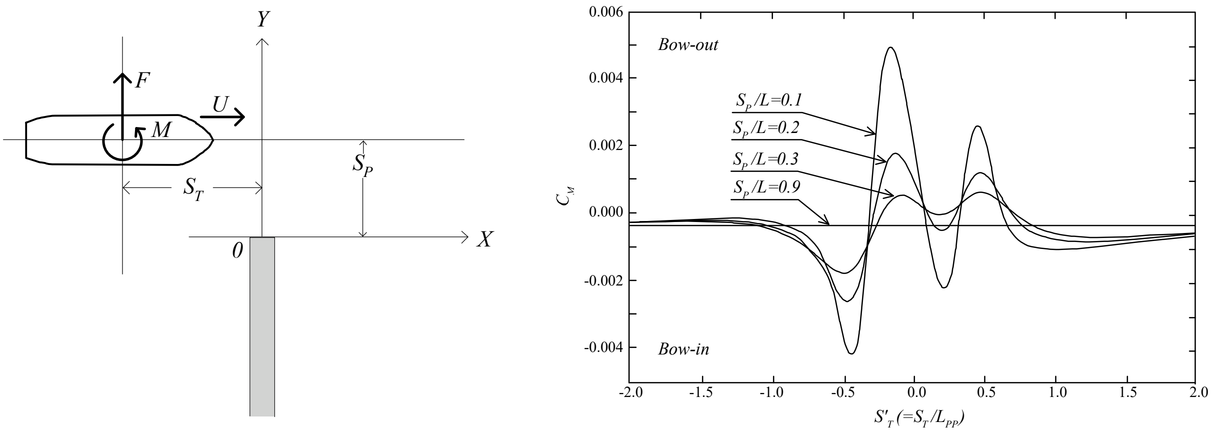


Fig. 2.3.21 Repulsive Moment on Ships Navigating Close to Edges [Shallow Water Areas, *D/d* = 1.2]

*Partial modification is made on the figure shown in the literature 20) ($S_p = S_{pp}$ in the figure)

3) Calculation of check rudder angles based on the motion equation in an equilibrium situation

Unlike the continuous effects of side walls, the duration of the effects of the edges of breakwaters and jetties on ship navigation is relatively short. Therefore, it is not likely that ships moving straight ahead will suddenly undergo oblique navigation with steady drift angles. Considering that ships have less chance of developing drift angles due to the effects of edges, the motion equation in an equilibrium situation in the coordinate system of **Fig. 2.3.21** as expressed by **equation (2.3.40)** can be changed to **equation (2.3.41)** by setting $\beta = 0$.

$$\left.\begin{aligned} -C_{Fp} + Y'_\beta \beta + Y'_\delta \delta = 0 \\ -C_{Mp} + N'_\beta \beta + N'_\delta \delta = 0 \end{aligned}\right\} \quad \textbf{(2.3.40)}$$

$$-C_{Mp} + N'_\delta \delta = 0 \quad \textbf{(2.3.41)}$$

Thus, rudder angle δ can be calculated by **equation (2.3.42)**.

$$\delta = \frac{C_{Mp}}{N'_{\delta}} \quad \textbf{(2.3.42)}$$

where

C_{Fp} : dimensionless value of the lateral force acting on the hull of a ship navigating close to the edge of a breakwater or jetty;

C_{Mp} : dimensionless value of the rotation moment acting on the hull of a ship navigating close to the edge of a breakwater or jetty;

Y'_{β} : dimensionless value of the coefficient Y_{β} for the reaction force in a transverse direction from a fluid when a ship diagonally navigates with a drift angle β;

N'_{β} : dimensionless value of the coefficient N_{β} for the turning reaction moment from a fluid when a ship diagonally navigates with a drift angle β;

Y'_{δ} : dimensionless value of a transverse force coefficient Y_{δ} generated by a rudder set at rudder angle δ;

N'_{δ} : dimensionless value of the coefficient N_{δ} for a rudder force moment generated by a rudder at rudder angle δ;

δ : rudder angle (rad);

β : drift angle (rad).

It is noted that the unit system of δ and β needs to be changed to degrees (°) for the following calculations.

Here, among the figures in the literature 20), **Fig. 2.3.21** shows the case of C_M (= C_{Mp}) only with a coordinate system converted into that of **Fig. 2.3.16**. In **Fig. 2.3.21**, the maximum values of C_M (= C_{Mp}) are 0.0050, 0.0018 and 0.00056 when the values of S_{pp}/L are 0.1, 0.2 and 0.3, respectively.

4) **Calculation of the widths W_p to account for edges effect forces when the required check rudder angle is 15°**

The widths W_p can be calculated in a manner that obtains a regression equation of S_{pp}/L with rudder angles δ as a variable from the calculation results of δ corresponding to S_{pp}/L, calculates S_{pp}/L values by substituting δ = 15° into the regression equation, and calculates W_p by substituting the obtained S_{pp}/L values into **equation (2.3.43)**. However, in case the calculated rudder angles with S_{pp}/L exceeds 30° which is unrealistically large, the value of S_{pp}/L shall be ignored for developing the regression equation.

$$W_p = S_{pp} - 0.5B \quad \textbf{(2.3.43)}$$

where

W_p : width to cope with the effects of an edge (m);

S_{pp} : distance from the centerline of the ship to the edge (m);

B : molded breadth (m).

However, as will be seen after obtaining the calculation results of **equation (2.3.43)**, in cases where the widths of breakwaters and jetties are not wide (widths ≤ 0.1 L_{pp}), their edges generally have fairly minor hydrodynamic interference effects on ships navigating nearby. In such cases, it is reasonable to consider that $W_p \approx 0$.

(c) **Calculation** of widths to account for edges effect forces W_p when the widths of breakwaters or jetties are large compared to the ship lengths or when the crossing angles between navigation channels and breakwaters or jetties are other than 90°

1) Basic concept of calculation

Realistically, there are breakwaters and jetties which have widths larger than the ship lengths (widths > 0.1 L_{pp}), and the crossing angles between the navigation channels and breakwaters or jetties are not always 90°. Although even in such cases, the widths to account for edges effect forces W_p can be basically calculated in the same way as in the case of (b) above, and **Fig. 2.3.22** proposed by Kijima et al.[20] can be used in place of **Fig. 2.3.21**.

2) Standard calculation method and calculation equation

i. **Fig. 2.3.22** shows C_M (= C_{Mp}) acting on ships in navigation channels that have wedge-shaped side walls with tip angles (E_β) ranging from 0 to 180°. The case of E_β = 180° in **Fig. 2.3.22** is equivalent to the case of a steady state with S'_T > 1.5 in **Fig. 2.3.16 (b)**, and both cases show the value of 0.0050 for C_M (= C_{Mp}) when S_p/L (= S_{pp}/L) = 0.1. In contrast, when there are breakwaters along the moving directions of ships in navigation channels (E_β = 0°), C_M (= C_{Mp}) is maximized and the hydrodynamic interference effects on ships are considered to be significant. Furthermore, the C_M (= C_{Mp}) value of 0.015 when E_β = 90° and S_p/L (= S_{pp}/L) = 0.1 in **Fig. 2.3.22** is larger than that of 0.0050 when the crossing angle is 90° in **Fig. 2.3.21**.

ii. **Fig. 2.3.22** shows only the case of C_M (= C_{Mp}) when S_p/L (= S_{pp}/L) = 0.1. Thus, in order to obtain the values of C_M (= C_{Mp}) corresponding to the cases of S_p/L (= S_{pp}/L) = 0.2, 0.3 and 0.5, their approximated values need to be calculated in a manner that obtains ratios of the values of C_M (= C_{Mp}) at E_β respective of the set conditions in **Fig. 2.3.21** to the peak value of C_M (= C_{Mp}) when E_β = 90°, and multiplies the peak values in **Fig. 2.3.16 (b)** in the respective states of S'_T by the ratios.

iii. In calculating the widths of the navigation channels to account for edges effect forces when the widths of the breakwaters or jetties are narrow and the crossing angles between the navigation channels and the breakwaters or jetties are almost 90°, with particular focus on uncertain factors such as the effects of unsteady actions (wind pressure, wave drift forces, tidal currents, etc.) and errors in identifying the positions of the edges, **equation (2.3.44)** can be used in accordance with the type of ships.

$$W_p = aB \qquad \textbf{(2.3.44)}$$

where

W_p : width to account for edges effect forces (m);

B : molded breadth (m);

a : 0.5 to 1.0.

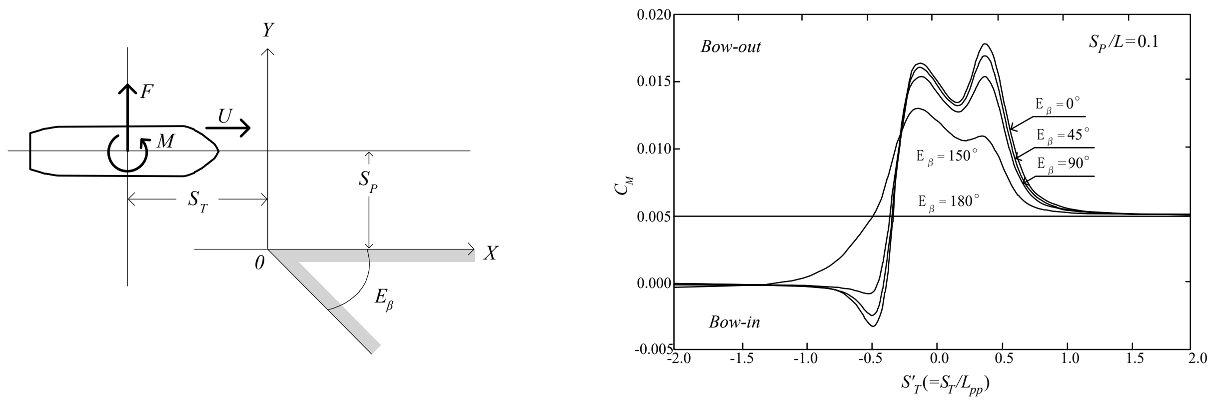


Fig. 2.3.22 Repulsive Moment on Ships Navigating Close to Edges [Shallow Water Areas, *D/d* = 1.2][20]
(S_p = S_{pp} in the figure)

④ Widths to account for two-ship interaction in passing W_c (the required widths to cope with the effects of ships passing each other) can be calculated by the following procedures.

(a) Basic concept of calculation

1) Because the duration of the effects due to ships passing each other is relatively short, the required widths can be calculated as safe inter-ship distances enabling ships to account for two-ship interaction in passing with a maximum check rudder angle of 15°.

2) In this calculation, the inter-ship distances are determined by assuming a dangerous positional relationship between ships passing each other as shown in the dotted lines in **Fig. 2.3.23**, even when the ships move diagonally in an actual situation.

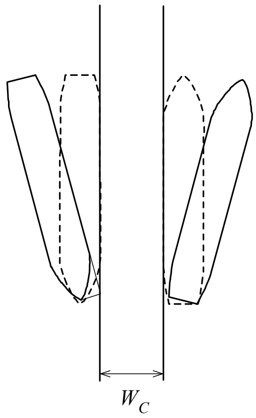


Fig. 2.3.23 Concept of Widths to Account for Two-ship Interaction in Passing

(b) Standard calculation method and calculation equation

1) **Calculation of widths to account for two-ship interaction in passing W_c** (subscript c: center)

Widths to account for two-ship interaction in passing W_c when the ships have identical types and speeds can be calculated by the following phased calculation method.

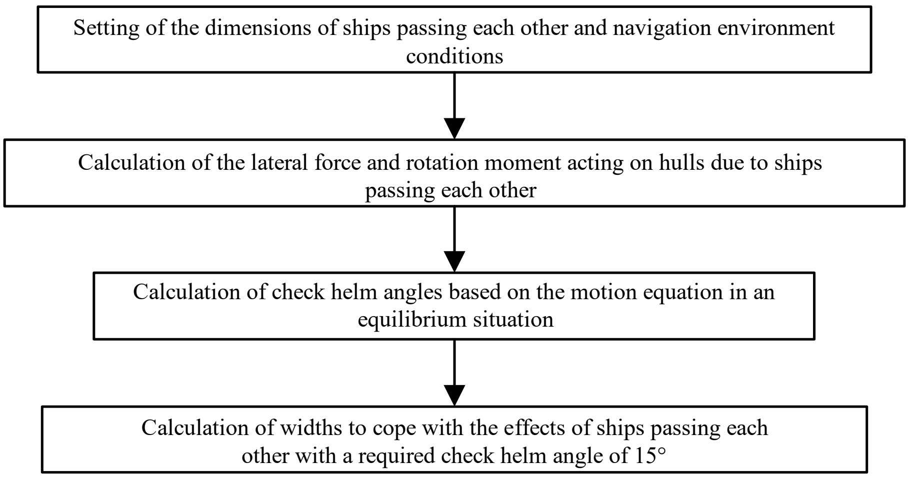


Fig. 2.3.24 Calculation of Width to Account for Two-ship Interaction in Passing

2) **Calculation of the lateral force and rotation moment acting on the hulls of ships in passing**

The values for the lateral force C_F and rotation moment C_M acting on the hulls of ships in passing for the respective S_p/L (= S_{pc}/L) values can be obtained from **Fig. 2.3.25** proposed by Kijima et al.[22] Here, C_F (= C_{Fc}) and C_M (= C_{Mc}) are the values defined by **equation (2.3.45)**.

$$\left.\begin{aligned} C_{Fc} &= \frac{F_c}{0.5\rho_w L d U^2} \\ C_{Mc} &= \frac{M_c}{0.5\rho_w L^2 d U^2} \end{aligned}\right\} \qquad \textbf{(2.3.45)}$$

where

S_{pc} : distance between the centerlines of the ships (S_p in **Fig. 2.3.25**)

L : length between perpendiculars (= L_{pp}) (m);

F_c : lateral force acting on the hulls of the respective ships in passing (N);

C_{Fc} : dimensionless value of the lateral force acting on the hulls of the respective ships in passing;

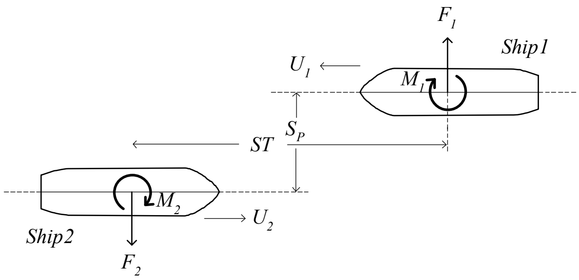
M_c : rotation moment acting on the hulls of the respective ships in passing (N·m);

C_{Mc} : dimensionless value of the rotation moment acting on the hulls of the respective ships in passing;

U : ship speed (m/s);

d : maximum draft of a moored design ship in still water (m);

ρ_w : density of seawater (kg/m^3).



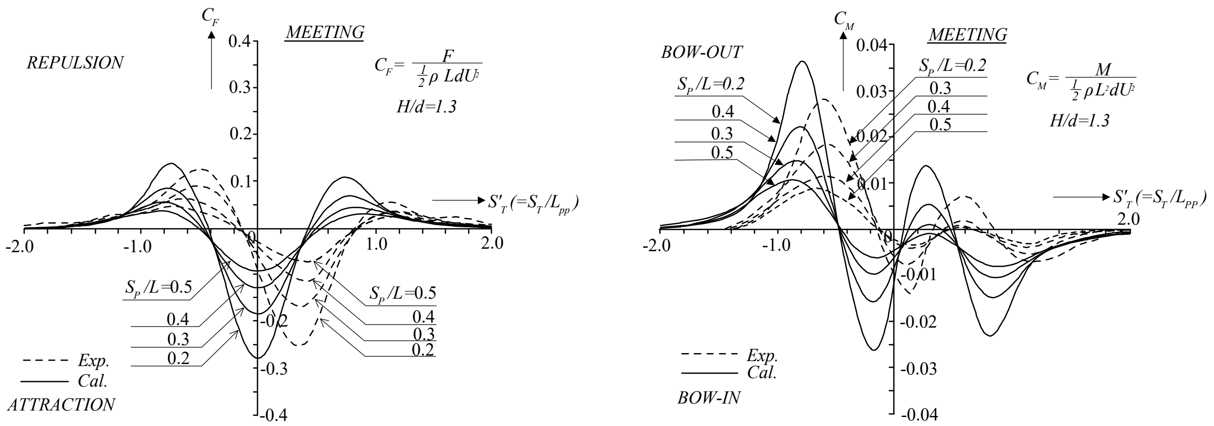


Fig. 2.3.25 Suction Force and Repulsive Moment on Ships in Passing (S_p = S_{pc} in the figure)[22)]

3) Calculation of the check rudder angle based on the motion equation in an equilibrium situation

Unlike the continuous effects of bank walls, the duration of the effects of ships in passing is relatively short. Therefore, it is not likely that ships moving straight ahead will suddenly undergo oblique navigation with steady drift angles. Considering that ships have less chance of developing drift angles due to the effects of ships in passing, the motion equation in an equilibrium situation in the coordinate system of **Fig. 2.3.25** as expressed by **equation (2.3.46)** can be changed to **equation (2.3.47)** by setting $\beta = 0$.

$$\left.\begin{aligned} -C_{Fc} + Y'_{\beta}\beta + Y'_{\delta}\delta = 0 \\ -C_{Mc} + N'_{\beta}\beta + N'_{\delta}\delta = 0 \end{aligned}\right\} \quad \textbf{(2.3.46)}$$

$$-C_{Mc} + N'_{\delta}\delta = 0 \quad \textbf{(2.3.47)}$$

Therefore, rudder angle δ can be calculated by **equation (2.3.48)**.

$$\delta = \frac{C_{Mc}}{N'_{\delta}} \quad \textbf{(2.3.48)}$$

where

C_{Fc} : dimensionless value of the lateral force acting on the hulls of the respective ships in passing;

C_{Mc} : dimensionless value of the rotation moment acting on the hulls of the respective ships in passing;

Y'_{β} : dimensionless value of the coefficient Y_{β} for the reaction force in a transverse direction from a fluid when a ship diagonally navigates with a drift angle β;

N'_{β} : dimensionless value of the coefficient N_{β} for the turning reaction moment from a fluid when a ship diagonally navigates with a drift angle β;

Y'_{δ} : dimensionless value of the coefficient Y_{δ} for the lateral force generated by a rudder at rudder angle δ;

N'_{δ} : dimensionless value of the coefficient N_{δ} for the rudder force moment generated by a rudder at rudder angle δ;

δ : rudder angle (rad);

β : drift angle (rad).

However, it is noted that the unit system of δ and β needs to be changed to degrees (°) for the following calculations.

In **Fig. 2.3.25**, which shows both test and calculation results, the calculation results which are larger than the test results (evaluated to represent more dangerous cases than in the test cases) can be used. In **Fig. 2.3.25**, the maximum values of C_M (= C_{Mc}) are 0.023, 0.015 and 0.011 when the values of S_{pc}/L are 0.3, 0.4 and 0.5, respectively.

4) Calculation of the widths W_c to account for two-ship interaction in passing when the required check rudder angle is 15°

The widths W_c can be calculated in a manner that obtains a regression equation of S_{pc}/L with rudder angles δ as a variable from the calculation results of δ corresponding to S_{pc}/L, calculates S_{pc}/L values by substituting δ = 15° into the regression equation, and calculates W_c by substituting the obtained S_{pc}/L values into **Equation (2.3.49)**. However, in case the calculated rudder angles with S_{pc}/L exceeds 30° which is unrealistically large, the value of S_{pc}/L shall be ignored for developing the regression equation.

$$W_c = S_{pc} - (0.5B + 0.5B) = S_{pc} - B \quad \textbf{(2.3.49)}$$

where

W_c : width to account for two-ship interaction in passing (m);

S_{pc} : distance between the centerlines of the ships (m);

B : molded breadth (m).

The calculation results of the widths to account for two-ship interaction in passing for the type of ships listed in **Table 2.3.1** are shown in **Table 2.3.6**. The values in the table can be used as approximate values of W_c. It shall be noted that W_c values are not affected by ship speeds.

Table 2.3.6 W_c by Ship Type (Required Width to Account for Two-ship Interaction in Passing with a Check Rudder Angle of 15° and D/d = 1.3)

	Ship type	L_{pp}	B	S_{pc}/Lpp	S_{pc}	W_c	W_c/B
1	Cargo ship	103.0	20.0	0.511	52.6	32.6	1.63
2	Cargo ship (small size)	60.4	11.2	0.477	28.8	17.6	1.57
3	Container ship (14,000 TEU)	352.0	51.0	0.551	194.1	143.1	2.81
4	Container ship (10,000 TEU)	318.3	45.8	0.517	164.6	118.8	2.59
5	Container ship (6,000 TEU OVER PANAMAX)	283.8	40.0	0.511	145.0	105.0	2.63
6	Container ship (4,000 TEU PANAMAX)	273.0	32.2	0.498	135.8	103.6	3.22
7	Bulk carrier (VLOC)	318.0	55.0	0.510	162.0	107.0	1.95
8	Bulk carrier (CAPESIZE)	279.0	45.0	0.516	143.8	98.8	2.20
9	Bulk carrier (NEW PANAMAX)	236.0	38.0	0.496	117.1	79.1	2.08
10	Bulk carrier	216.0	32.3	0.516	111.3	79.0	2.45
11	Bulk carrier (small size)	119.2	21.5	0.501	59.7	38.2	1.77
12	Tanker (VLCC)	316.0	60.0	0.478	151.0	91.0	1.52
13	Tanker (small size)	92.0	20.0	0.492	45.2	25.2	1.26
14	Pure car carrier (PCC) (VLCC)	190.9	36.5	0.521	99.5	63.0	1.73
15	Pure car carrier (PCC) (large size)	190.0	32.2	0.510	96.8	64.6	2.01
16	Pure car carrier (PCC)	180.0	32.2	0.504	90.6	58.4	1.81
17	LNG ship	270.0	44.8	0.502	135.5	90.7	2.03
18	LPG ship	220.0	36.6	0.507	111.5	74.9	2.05
19	Refrigerated cargo carrier	144.0	23.5	0.514	74.0	50.5	2.15
20	Passenger ship (large, 2 shafts, 2 propellers)	306.0	38.4	0.499	152.7	114.3	2.98
21	Passenger ship (2 shafts, 2 propellers)	160.0	24.7	0.453	72.4	47.7	1.93
22	Ferry boat (2 shafts, 1 propeller)	181.0	29.4	0.478	86.5	57.1	1.94

(c) Calculation method when ships of different types pass each other

When ships of different types (type 1 and type 2) pass each other, the widths to account for two-ship interaction in passing can be the average of the widths (W_{c1} and W_{c2}) respectively calculated by assuming two cases where type 1 and type 2 ships each pass ships of identical types.

⑤ Widths to account for two-ship interaction in overtaking W_{ov} (the required widths to cope with the effects of ships overtaking other ships) can be calculated by the following procedures.

(a) Basic concept of calculation

1) The required widths can be calculated as safe inter-ship distances enabling ships to cope with the maximum rotation moment as an effect of ships overtaking other ships with a maximum check rudder angle of 15°.

2) In this calculation, the inter-ship distances are determined by assuming the most dangerous positional relationship between ships overtaking other ships as shown in the dotted lines in **Fig. 2.3.26**, even when the ships navigate diagonally in an actual situation.

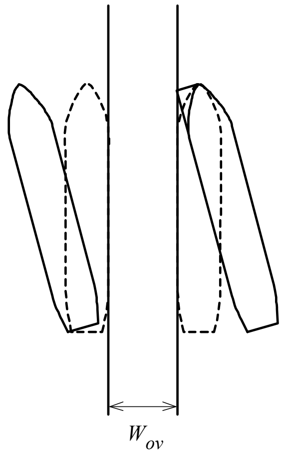


Fig. 2.3.26 Concept of Widths to Account for Two-ship Interaction in Overtaking

(b) Standard calculation method and calculation equation when ships in overtaking other ships of identical types

1) Widths to cope with the effects of ships overtaking other ships W_{ov} (subscript *ov*: overtake) when the ships have identical types can be calculated by the following phased calculation method.

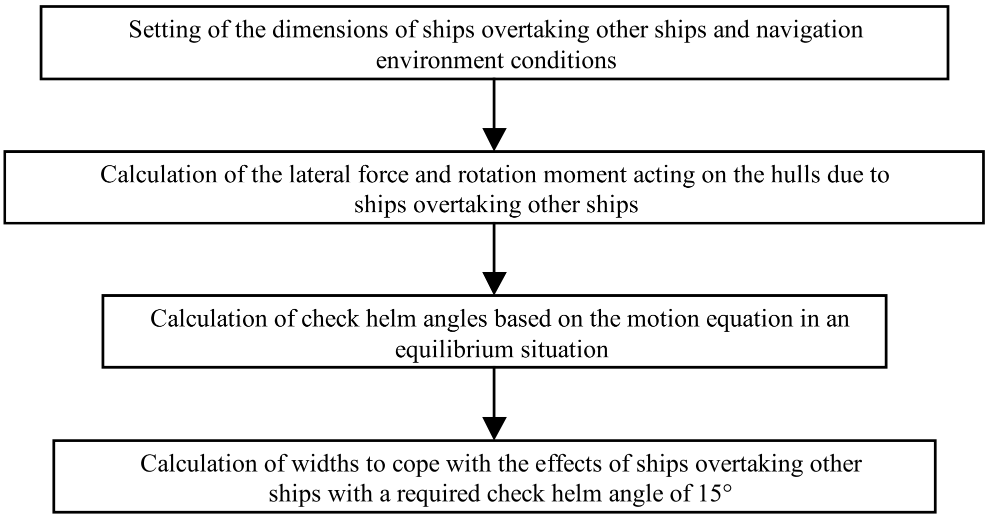


Fig. 2.3.27 Calculation of Width to Account for Two-ship Interaction in Overtaking

2) Calculation of the lateral force and rotation moment acting on the hulls of ships in overtaking

The values for the lateral force C_{Fi} and rotation moment C_{Mi} acting on the hull of a ship *i* overtaking another ship for the respective S_{p12}/L_i (= S_{pov12}/L_i) value can be those obtained from two types of graphs for the respective values in **Fig. 2.3.28** proposed by Lee et al.[23)] and the other based on additional calculation results—whichever is larger. Here, C_{Fi} (= C_{Fovi}) and C_{Mi} (= C_{Movi}) are the values defined by **equation (2.3.50)**.

$$\left.\begin{aligned} C_{Fovi} &= \frac{F_{ovi}}{0.5\rho_w L_i d_i U_i^2} \\ C_{Movi} &= \frac{M_{ovi}}{0.5\rho_w L_i d_i U_i^2} \end{aligned}\right\} \quad \textbf{(2.3.50)}$$

where

S_{pov12} : distance between the centerlines of the ships (m) (S_{p12} in **Fig. 2.3.28**);

L : length between perpendiculars L_{pp} (m);

F_{ovi} : lateral force acting on the hull of a ship i in overtaking (N);

C_{Fovi} : dimensionless value of the lateral force acting on the hull of a ship i in overtaking;

M_{ovi} : rotation moment acting on the hull of a ship in overtaking (N·m);

C_{Movi} : dimensionless value of the rotation moment acting on the hull of a ship i in overtaking ;

U : ship speed (m/s);

d : maximum draft of a moored design ship in still water (m);

ρ_w : density of seawater (kg/m^3).

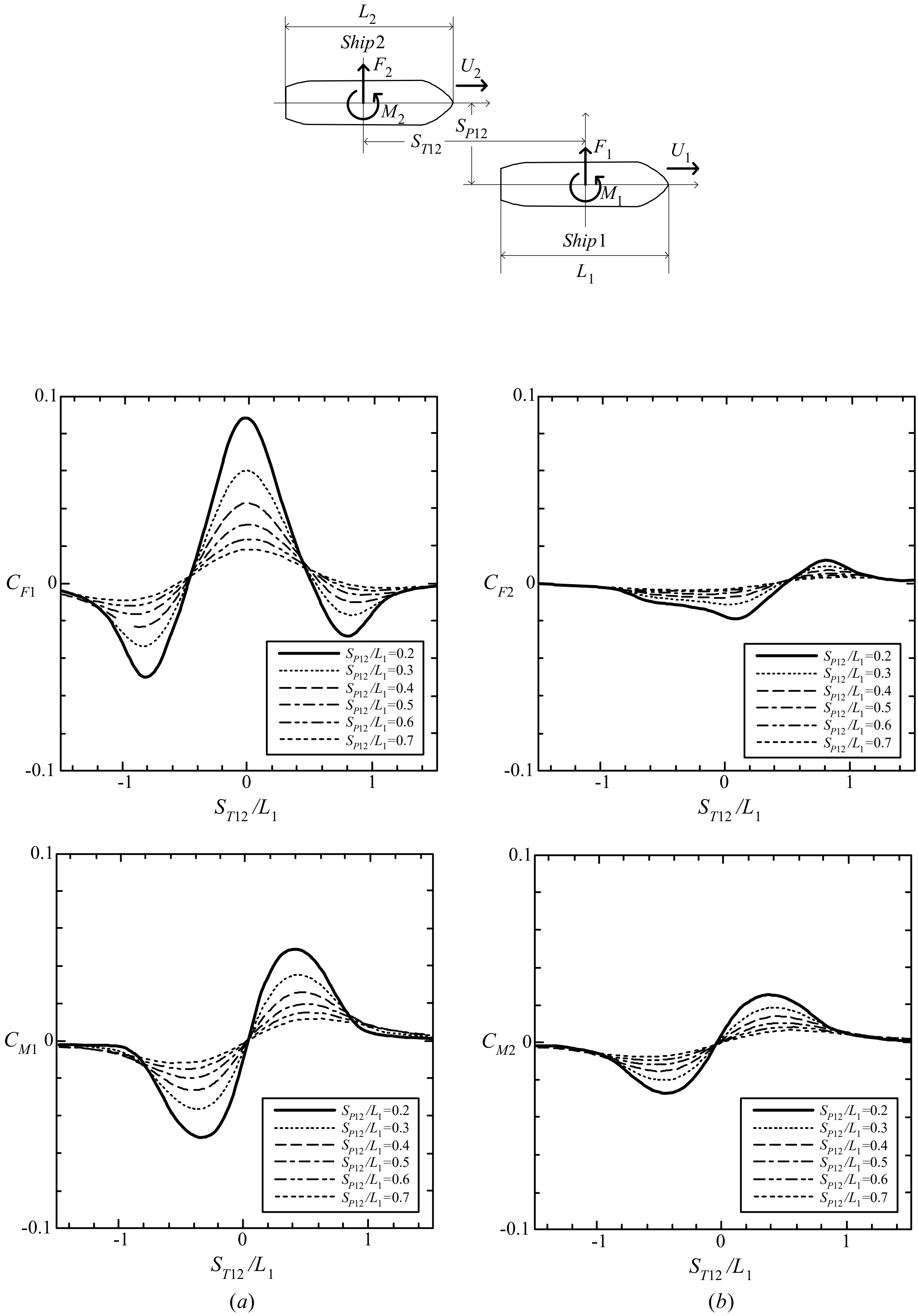


Fig. 2.3.28 Suction Force and Repulsive Moment on Ships in Overtaking (h/d = 1.2, U_2/U_1 = 1.2)[18)]

3) Calculation of rudder and drift angles based on the motion equation

Although the effects of ships in overtaking are continuous, the duration of the effects is relatively short. Therefore, it is not likely that ships moving straight ahead will suddenly undergo oblique navigation with steady drift angles. Considering that ships have less chance of developing drift angles due to the effects of ships overtaking others, the motion equation in an equilibrium situation in the coordinate system of **Fig. 2.3.28** as expressed by **equation (2.3.51)** can be changed to **equation (2.3.52)** by setting $\beta = 0$.

$$\left.\begin{array}{l} -C_{Fovi} + Y'_{\beta i}\beta_i + Y'_{\delta i}\delta_i = 0 \\ -C_{Movi} + N'_{\beta i}\beta_i + N'_{\delta i}\delta_i = 0 \end{array}\right\} \qquad \textbf{(2.3.51)}$$

$$-C_{Movi} + N'_{\delta i}\delta_i = 0 \qquad \textbf{(2.3.52)}$$

Therefore, rudder angles δ_i can be calculated by **equation (2.3.53)**.

$$\delta_i = \frac{C_{Movi}}{N'_{\delta i}} \qquad \textbf{(2.3.53)}$$

where

C_{Fovi} : dimensionless value of the lateral force acting on the hulls of ships in overtaking;

C_{Movi} : dimensionless value of the rotation moment acting on the hulls of ships in overtaking;

$Y'_{\beta i}$: dimensionless value of the coefficient Y_β for the reaction force in a transverse direction from a fluid when a ship diagonally navigates with a drift angle β;

$N'_{\beta i}$: dimensionless value of the coefficient N_β for the turning reaction moment from a fluid when a ship diagonally navigates with a drift angle β;

$Y'_{\delta i}$: dimensionless value of the coefficient $Y_{\delta i}$ for the lateral force generated by a rudder of a ship i at rudder angle δ;

$N'_{\delta i}$: dimensionless value of the coefficient $N_{\delta i}$ for the rudder force moment generated by a rudder of a ship i at rudder angle δ;

δ : rudder angle (rad);

β : drift angle (rad).

However, it is noted that the unit system of δ and β needs to be changed to degrees (°) for the following calculations.

In **Fig. 2.3.28** showing C_M (= C_{Mov}) in the case of D/d = 1.2, U_1 = 10 (kt) and U_2/U_1 = 1.2, the values of C_{M1} (= C_{Mov1}) can be selected because $C_{M1} > C_{M2}$ (= $C_{Mov1} > C_{Mov2}$). Furthermore, in **Fig. 2.3.28**, the maximum values of C_{M1} (= C_{Mov1}) are –0.0190, –0.0144 and –0.0111 when the values of S_{p12}/L_1 are 0.5, 0.6 and 0.7, respectively.

4) Calculation of the widths W_{ov} to account for two-ship interaction in overtaking when the required check rudder angle is 15°

The widths W_{ov} can be calculated in a manner that obtains a regression equation of S_{pov}/L with rudder angles δ as a variable from the calculation results of δ corresponding to S_{pov}/L, calculates S_{pov}/L values by substituting δ = 15° into the regression equation, and calculates W_{ov} by substituting the obtained S_{pov}/L values into **equation (2.3.54)**. However, in case the calculated rudder angles with S_{pov}/L exceeds 30° which is unrealistically large, the value of S_{pov}/L shall be ignored for developing the regression equation.

$$W_{ov} = S_{pov12} - (0.5B + 0.5B) = S_{pov12} - B \qquad \textbf{(2.3.54)}$$

where

W_{ov} : width to account for two-ship interaction in overtaking (m);

S_{pov12} : distance between the centerlines of the ships (m);

B : molded breadth of the design ship (m).

The calculation results of widths to account for two-ship interaction in overtaking for the types of ships listed in **Table 2.3.1** are shown in **Table 2.3.7**. The values in the table can be used as approximate values of W_{ov}.

Table 2.3.7 W_{ov} by Ship Type (Required Width to Account for Two-ship Interaction in Overtaking with a Check Rudder Angle of 15° and D/d = 1.2)

	Ship type	L_{pp}	B	S_{pov}/L_{pp}	S_{pov}	W_{ov}	W_{ov}/B
1	Cargo ship	103.0	20.0	0.735	75.7	55.7	2.79
2	Cargo ship (small size)	60.4	11.2	0.683	41.2	30.0	2.68
3	Container ship (14,000 TEU)	352.0	51.0	0.800	281.5	230.5	4.52
4	Container ship (10,000 TEU)	318.3	45.8	0.746	237.4	191.6	4.18
5	Container ship (6,000 TEU OVER PANAMAX)	283.8	40.0	0.737	209.1	169.1	4.23
6	Container ship (4,000 TEU PANAMAX)	273.0	32.2	0.716	195.4	163.2	5.07
7	Bulk carrier (VLOC)	318.0	55.0	0.732	232.8	177.8	3.23
8	Bulk carrier (CAPESIZE)	279.0	45.0	0.743	207.2	162.2	3.60
9	Bulk carrier (NEW PANAMAX)	236.0	38.0	0.711	167.8	129.8	3.42
10	Bulk carrier	216.0	32.3	0.744	160.7	128.4	3.98
11	Bulk carrier (small size)	119.2	21.5	0.719	85.7	64.2	2.98
12	Tanker (VLCC)	316.0	60.0	0.683	215.7	155.7	2.60
13	Tanker (small size)	92.0	20.0	0.705	64.9	44.9	2.24
14	Pure car carrier (PCC) (VLCC)	190.9	36.5	0.752	143.5	107.0	2.93
15	Pure car carrier (PCC) (large size)	190.0	32.2	0.732	139.1	106.9	3.32
16	Pure car carrier (PCC)	180.0	32.2	0.725	130.4	98.2	3.05
17	LNG ship	270.0	44.8	0.722	194.9	150.1	3.35
18	LPG ship	220.0	36.6	0.729	160.4	123.8	3.38
19	Refrigerated cargo carrier	144.0	23.5	0.741	106.7	83.2	3.54
20	Passenger ship (large, 2 shafts, 2 propellers)	306.0	38.4	0.716	219.0	180.6	4.70
21	Passenger ship (2 shafts, 2 propellers)	160.0	24.7	0.644	103.0	78.3	3.17
22	Ferry boat (2 shafts, 1 propeller)	181.0	29.4	0.686	124.1	94.7	3.22

(c) Calculation method when ships overtake other ships of different types or different relative speed ratios

1) Basic concept of calculation

When ships overtake others, there may be cases where the types of ships overtaking or being overtaken are different from each other or are at several relative speed ratios. Although the calculation procedures of the widths to account for two-ship interaction in overtaking W_{ov} is basically the same as those described in (b), the values shown in **Fig. 2.3.29** and **2.3.30** by Lee et al.[23] can be used in place of those in **Fig. 2.3.28** (in **Fig. 2.3.29** and **2.3.30**, $S_{pov12} = S_{p12}$).

2) Standard calculation method and calculation equation

i. **Fig. 2.3.29** and **Fig. 2.3.30** show only the case when S_{p12}/L_1 = 0.2. Thus, in order to obtain the values of C_{M1} (= C_{Mov1}) corresponding to the cases of S_{p12}/L_i = 0.3, 0.4 and 0.5, their approximated values need to be calculated in a manner that obtains the ratios of the peak value of C_{M1} (= C_{Mov1}) when S_{p12}/L_1 = 0.2 corresponding to the respective conditions in **Fig. 2.3.29** and **Fig. 2.3.30** to the peak value of C_{M1} (= C_{Mov1}) when S_{p12}/L_1 = 0.2 in **Fig. 2.3.28**, and multiplies the peak values for S_{p12}/L_i by the ratios.

ii. For example, the C_{M1} (= C_{Mov1}) value when U_1 = 10 (kt) and U_2 = 15 (kt); that is, U_2/U_1 = 1.5, in **Fig. 2.3.29**, is −0.0769, and the C_{M1} (= C_{Mov1}) value when Sp_{12}/L_1 = 0.2 in **Fig. 2.3.28** is −0.050. Thus, the ratio of the two values is 1.56. Then, the C_{M1} (= C_{Mov1}) values when U_2/U_1 = 1.5 can be obtained by multiplying the C_{M1} (= C_{Mov1}) values when Sp_{12}/L_i = 0.3, 0.4 and 0.5 when U_2/U_1 = 1.2 by the ratio.

iii. When ships of different types overtake or are overtaken, C_{M1} (= C_{Mov1}) can be obtained in the same way as above using the values in **Fig. 2.3.30**.

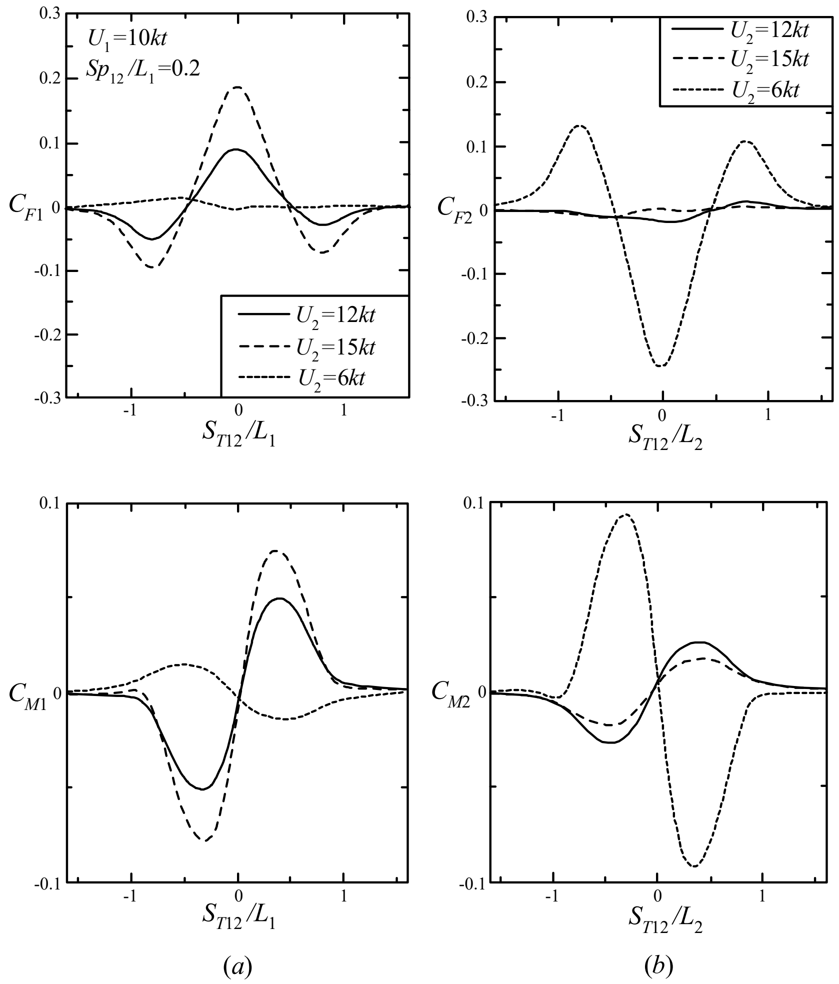


Fig. 2.3.29 Suction Force and Repulsive Moment Acting on Ships in Overtaking (h/d = 1.2, L_2/L_1 = 1.0)[18)]

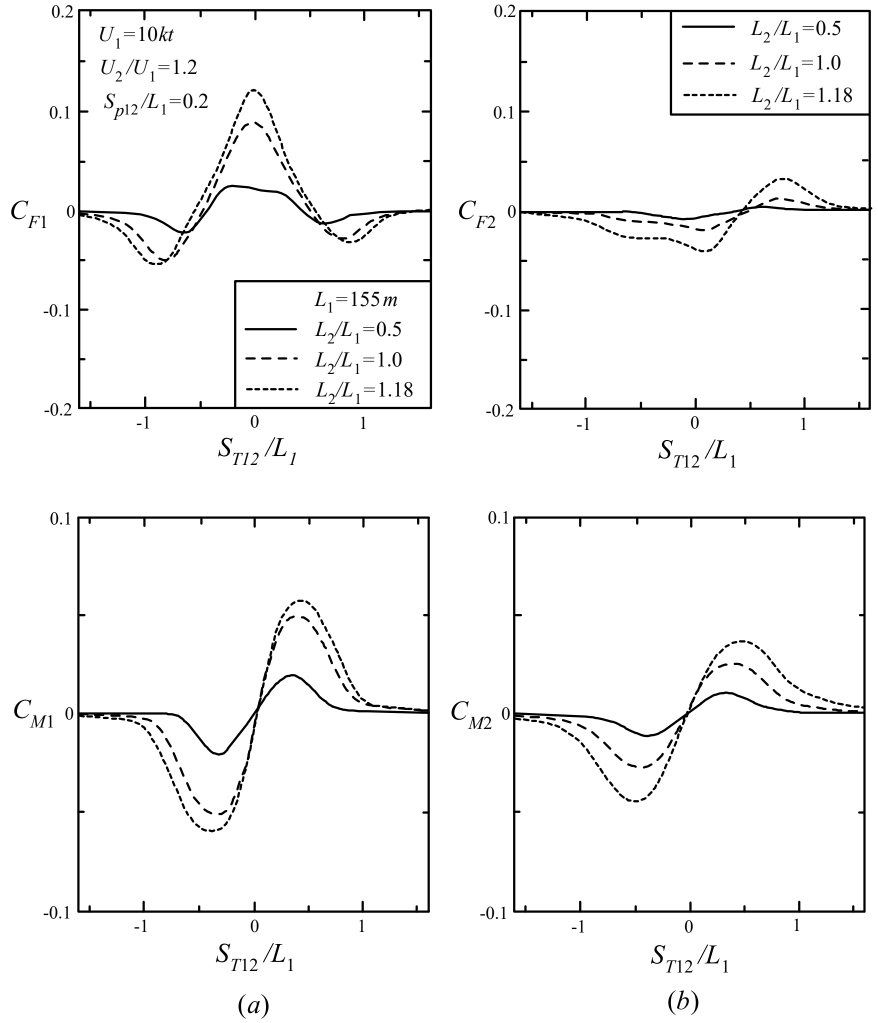


Fig. 2.3.30 Suction Force and Repulsive Moment Acting on Ships in Overtaking (h/d = 1.2)[18)]

(2) Convergence Calculation to Obtain the Widths of Newly Planned Navigation Channels

In calculating a basic ship maneuvering width W_{mi} which serves as an element to obtain the navigation channel width W using the required widths $W_m(a)$ and $W_m(R)$ to detect drift through visual and radar observation, respectively, the calculation procedure needs to start with W_{buoy} (the distance between anterior buoys); that is, the navigation channel width that will eventually be calculated, as an initial value. Thus, convergence calculation needs to be repeated until W_{buoy}, the initial value, becomes equal to W (the navigation channel width) that will eventually be calculated. The flow chart of this kind of convergence calculation is shown in **Fig. 2.3.31**.

In the figure, $W(i)$ represents the navigation channel width W obtained as a result of the ith calculation.

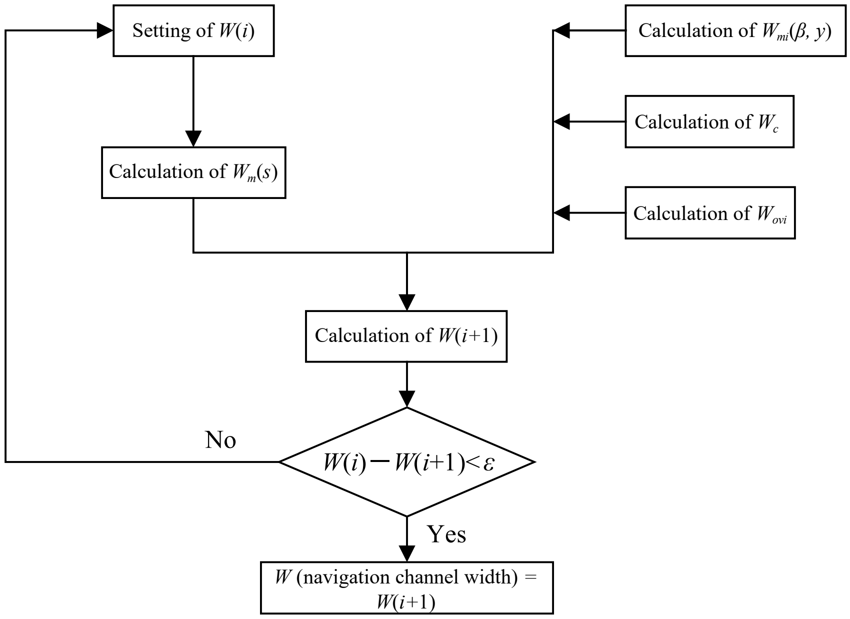


Fig. 2.3.31 Concept of Convergence Calculation

Convergence calculation is not required for the required widths $W_m(GPS)$, $W_m(D{\cdot}GPS)$ and $W_m(L)$ in cases where navigators are enabled to detect drift using GPS and guide marks (lights) because the calculation procedures of the required widths do not require W_{buoy} (the distance between anterior buoys) to be used as an initial entry.

(3) Application to the Design Changes of Existing Navigation Channels

When changing the design ships and navigation environment of existing navigation channels with the navigation channel widths W calculated by using the required widths $W_m(a)$ and $W_m(R)$ for enabling navigators to detect drift through visual and radar observation of navigation buoys on both sides of the navigation channels, W_{buoy} (the distance between anterior buoys) can be applied to the distance between buoys on both sides of the existing navigation channels. The navigation channel widths W calculated in this way can be evaluated by **equation (2.3.55)**.

$$W \text{ (width of the existing navigation channel)} \geq W \text{ (calculated navigation channel width)} \quad \textbf{(2.3.55)}$$

In cases where the above equation cannot be satisfied, it is advisable to reassess the design changes or to expand the widths to a level equivalent to those obtained through convergence calculation as is the case with newly planned navigation channels.

2.4 Alignment of Navigation Channels (Bends)

2.4.1 Fundamentals of Performance Verification

(1) In Class 1 navigation channels, in cases where the bend angles exceed 30º and the design ships and features of the navigation environment such as rudder angles and ship speeds are not specified, it is advisable that the centerlines of the bends in the navigation channels be arcs with curvature radius roughly 4 times the lengths between perpendiculars of the design ships L_{pp} or greater, and that the widths of the navigation channels be equal to or greater than the necessary widths. When the angles of the intersection of the centerlines are 30º or greater in two-way navigation channels having widths W, it is advisable that the corner cuts be designed as shown in **Fig. 2.4.1**.

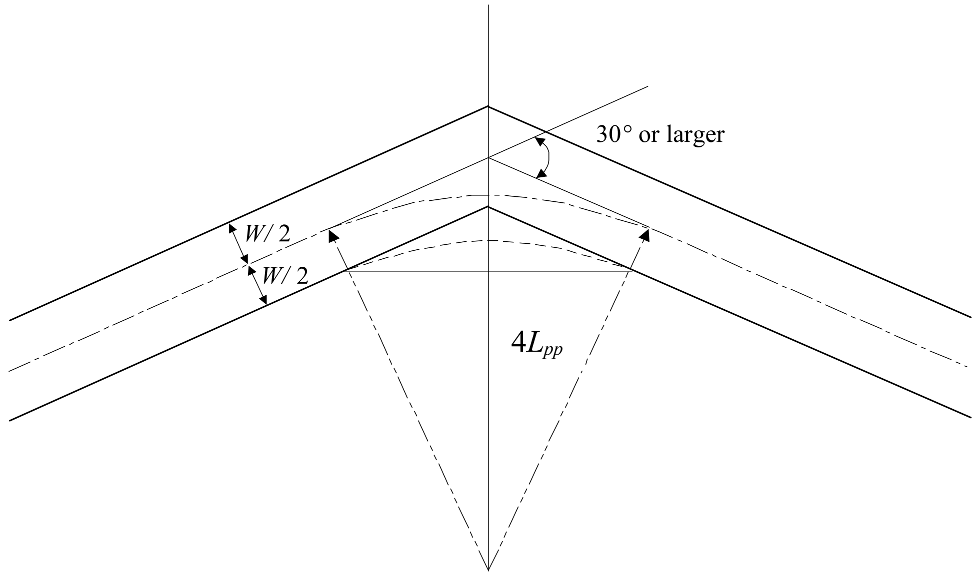


Fig. 2.4.1 Corner Cuts at the Bend Sections of Width *W* of Navigation Channels

(2) In Class 2 navigation channels, in cases where the bend angles exceed 30° and the design ships and features of the navigation environment such as rudder angles and ship speeds are specified, the curvature radius can be calculated based on the maneuverability indexes of turning, which show the turning performance factor of ships. It is advisable that the widths at the bends be expanded by corner cuts, etc., so as to be greater than the required widths.

The widths at bends may be expanded, not by corner cuts, but by curved corners, etc., considering the installation of buoys and other equipment based on adjustments with the parties concerned with maritime affairs. In particular, corner cuts are not always effective in cases where the angles of the intersection between the centerlines are large; therefore, it is advisable to consider the possibility of employing curved corners in such cases.

2.4.2 Performance Verification of Class 2 Navigation Channels

(1) The required ship turning radius of Class 2 navigation channels can be calculated by the following method.

① The required ship turning radius at the bends in navigation channels can be calculated by **equation (2.4.1)**.

$$R = L_{pp} / (K'\delta) = U / (K\delta) \qquad \textbf{(2.4.1)}$$

where

R : ship turning radius of the centerline at a bend in the navigation channel (m);

K : turning performance factor;

K' : dimensionless value of the turning performance factor [$K' = K/(U/L_{pp})$];

L_{pp} : length between perpendiculars of the design ship (m);

δ : rudder angle of the design ship navigating a bend section (rad);

U : speed of the design ship navigating a bend section (m/s).

② The following table shows the reference values of K' in shallow water areas obtained as a result of simulation studies of the maneuverability of the types of ships listed in **Table 2.3.1** under calm conditions with a rudder angle fixed at 20°. For a method for calculating K' values, refer to the literature 1). The values in the table may be applicable to the rudder angles in the range of 15 to 20°.

For ships which are subjected to strong winds or which have particularly large superstructures, K' values need to be calculated separately.

Table 2.4.1 Dimensionless Values of Turning Performance Factor *K'* in Shallow Water Areas [Shallow Water Areas: *D/d* = 1.2]

	Ship type	*K'*
1	Cargo ship	0.55
2	Cargo ship (small size)	0.46
3	Container ship (10,000 TEU)	0.60
4	Container ship (6,000 TEU OVER PANAMAX)	0.50
5	Container ship (4,000 TEU PANAMAX)	0.51
6	Bulk carrier (VLOC)	0.64
7	Bulk carrier (CAPESIZE)	0.51
8	Bulk carrier (NEW PANAMAX)	0.67
9	Bulk carrier	0.51
10	Bulk carrier (small size)	0.61
11	Tanker (VLCC)	0.62
12	Tanker (small size)	0.58
13	Pure car carrier (PCC) (large size)	0.63
14	Pure car carrier (PCC)	0.65
15	LNG ship	0.72
16	Refrigerated cargo carrier	0.58
17	Passenger ship (2 shafts, 2 propellers)	0.70
18	Ferry boat (2 shafts, 1 propeller)	0.56

Table 2.4.2 shows the ship turning radii of different types of ships. The values given in this table can be used as approximate values of *R*.

Table 2.4.2 Ship Turning Radii *R* in Shallow Water Areas [Shallow Water Areas: *D/d* = 1.2]

	Ship type	*R*
1	Cargo ship	4.9
2	Cargo ship (small size)	5.9
3	Container ship (10,000 TEU)	4.5
4	Container ship (6,000 TEU OVER PANAMAX)	5.5
5	Container ship (4,000 TEU PANAMAX)	5.3
6	Bulk carrier (VLOC)	4.4
7	Bulk carrier (CAPESIZE)	5.4
8	Bulk carrier (NEW PANAMAX)	4.2
9	Bulk carrier	5.4
10	Bulk carrier (small size)	4.4
11	Tanker (VLCC)	4.4
12	Tanker (small size)	4.5
13	Pure car carrier (PCC) (large size)	4.4
14	Pure car carrier (PCC)	4.2
15	LNG ship	3.8
16	Refrigerated cargo carrier	4.6
17	Passenger ship (2 shafts, 2 propellers)	3.4
18	Ferry boat (2 shafts, 1 propeller)	4.8

(2) For the determination of the curved geometry at the bend sections, reference can be made to the **Reference 24)** and the examples and guidelines at overseas ports.

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3 Basins

[Ministerial Ordinance] (Performance Requirements for Basins)

Article 10

The performance requirements for basins shall be such that the requirements specified by the Minister of Land, Infrastructure, Transport and Tourism are satisfied in light of geotechnical characteristics, waves, water currents and wind conditions along with the usage conditions of the surrounding water areas for securing safe and smooth use by ships.

[Public Notice] (Performance Criteria for Basins)

Article 31

The performance criteria for basins shall be as specified in the subsequent items:

(1) The size of a basin shall satisfy the following standards, provided, however, that the standards shall not be applied to basins for design ships with a gross tonnage of less than 500 tons:

(a) Basins which are provided for use in the anchorage or mooring of ships excluding basins in front of quay walls, mooring piles, piers and floating piers shall have an area greater than a circle that has a radius obtained by adding an appropriate value to the length of the design ship in light of the conditions of geotechnical characteristics, waves, water currents and winds, as well as the usage conditions of the surrounding water areas. Provided, however, that in cases where the area specified above is not required, owing to the mode of anchorage or mooring, the basin size can be reduced to an area that shall not hinder the safe anchorage or mooring of ships.

(b) Basins which are provided for use in the anchorage or mooring of ships in front of quay walls, mooring piles, piers and floating piers shall have an appropriate area of which the length and width are greater than those of the design ship, respectively, in light of the conditions of geotechnical characteristics, waves, water currents and winds, the usage condition of the surrounding water areas and the mode of anchorage or mooring.

(c) Basins which are provided for use in turning the bow of a ship shall have an area greater than a circle that has a radius obtained by multiplying the length of the design ship by 1.5, provided, however, that in cases where the area specified above is not required depending on the method for turning the bow, the basin size can be reduced to an area that shall not hinder safe turning.

(2) The basin shall have an appropriate depth that is greater than the draft of a design ship, in light of the degree of the motions of the design ship due to waves, water currents, winds and other forces.

(3) Basins which are provided for use in the anchorage or mooring of ships in front of quay walls, mooring piles, piers and floating piers shall in principle secure harbor calmness, enabling the working rate of cargo handling operation at equal to or greater than 97.5% in terms of time throughout the year. Provided, however, that this rate shall not be applied to basins where the mode of utilization of mooring facilities or the water areas in front of them are regarded as special.

(4) In basins which are provided as safe harbor for refuge during stormy weather, the wave conditions during the storm shall remain below the level that is admissible for refuge of the design ship.

(5) In basins which are provided for the anchorage or mooring of ships for the main purpose of timber sorting, measures shall be taken to prevent the timber from drifting.

[Interpretation]

(2) Performance Criteria of Basins (Article 10 of the Ministerial Ordinance and the interpretation related to Article 31 of the Public Notice)

① The required performance of basins shall be serviceability. Here, serviceability means the performance of basins enabling ships to anchor, moor and shelter safely and smoothly.

② **The size of basins provided for use in the anchorage and mooring of ships**

Cases where the specified area is not required owing to the mode of anchorage or mooring are cases of buoy mooring. In such circumstances, the possible horizontal displacement of buoys due to the use conditions of basins and the effects of the tidal changes shall be appropriately examined.

③ **The size of basins provided for use in turning the bow of a ship**

Cases where the specified area is not required owing to the method of turning the bow mean ship turning with the use of tug boats, thrusters having sufficient thrust, or anchors.

④ **The depth of basins**

An appropriate depth that is greater than the draft of a design ship means the assumed maximum laden draft of the design ship, plus a keel clearance to be set according to the maximum draft.

⑤ **The harbor calmness of basins provided for use in the anchorage and mooring of ships**

Basins where the mode of utilization of mooring facilities or the water areas in front of them is regarded as special mean those which have a low annual usage frequency and marginal conditions for their use.

3.1 General

(1) Basins are preferably designed in consideration of the following factors: safe anchorage, facilitation of ship handling, efficiency of cargo handling, meteorological and hydrographic conditions, the effects of reflected waves and ship wake waves on harbor calmness, and consistency with related facilities.

(2) Because basins include not only anchorages and buoy mooring basins but also other water areas such as turning basins for ship handling, it is preferable that they have:

① calm and sufficiently wide water areas ;

② bottom sediment with good anchoring ;

③ buoys;

④ favorable meteorological and hydrographic conditions such as winds and tidal currents.

(3) The determination of the locations and areas of basins can be based on the results of ship maneuvering simulation systems using the data from an automatic identification system (AIS). Examples of ship maneuvering simulation based on AIS data are shown in **Fig. 3.1.1**. In addition, the literature 1) is one such case which studies the required area of a basin in front of a quay wall using AIS data.

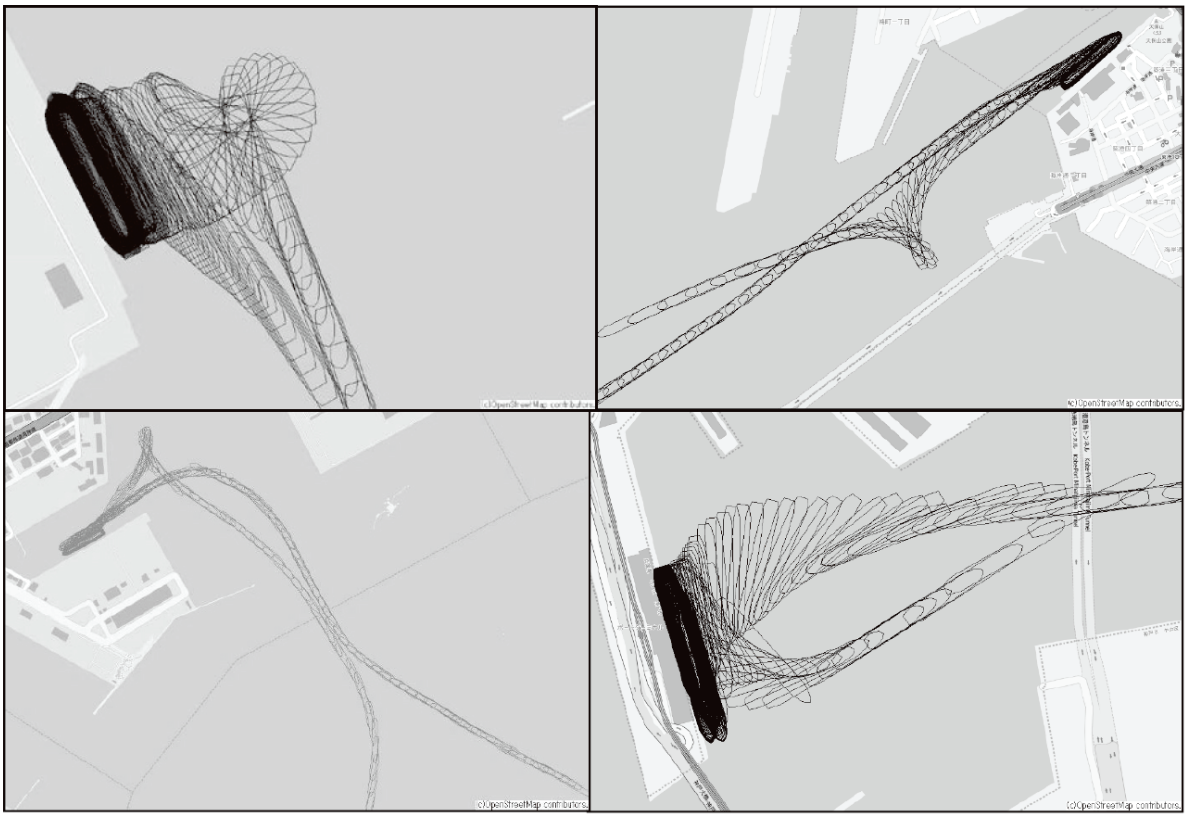


Fig. 3.1.1 Examples of Actual Ship Maneuvering Simulation Using AIS Data (Prepared by the Port Planning Division, the National Institute for Land and Infrastructure Management)

3.2 Performance Criteria

(1) Areas of Basins (Serviceability)

① **Basins provided for use in the anchorage or mooring of ships**

(a) Basins excluding those in front of quay walls or other facilities

Basins provided for use in the anchorage or mooring of ships, excluding those in front of quay walls, mooring piles, piers and floating piers, mean basins provided for use in anchoring and buoy mooring. In determining the areas of the basins for their performance verification, appropriate consideration shall be given to seabed properties, the effects of winds and water depths depending on the required functions and expected use conditions of the objective facilities. Cases where the specified area is not required owing to the mode of anchorage or mooring are cases of buoy mooring. In such circumstances, when determining the areas of the basins for their performance verification, the possible horizontal displacement of buoys due to the use conditions of basins and the effects of the tidal changes shall be appropriately examined.

(b) Basins in front of quay walls and other facilities

In the performance verification of basins in front of quay walls, mooring piles, piers and floating piers, the proper areas of the basins that shall be wider than the lengths overall and the widths of the design ships shall be determined with due consideration to: the additional lengths necessary for allowing design ships to come alongside mooring facilities and additional widths suitable for the methods to handle, moor and unmoor the design ships; the maneuverability of the design ships; the layouts of mooring facilities and navigation channels; the facilitation of ship handling; and safety when the design ships come alongside or leave mooring facilities.

(c) Other

In the performance verification of basins between piers, their widths shall be set with due consideration to the types of design ships, the number of berth and the presence or absence of the operation of tug boats.

Furthermore, in the performance verification of basins, their areas shall be determined with due consideration to: the expected use conditions, such as design ships coming alongside and leaving mooring facilities, as well as entering and leaving the basins concerned as needed; anchorage errors in the case of anchorage basins; and safety distances for basins used by ships loaded with hazardous cargo.

② **Basins provided for use in turning the bow of a ship**

(a) Basins provided for use in turning of the bow (hereinafter called “ship turning”) are also called turning basins. In the performance verification of the turning basins concerned, their scales shall be properly determined with due consideration to the design ships’ methods for ship turning, the positions and turning performance of the design ships, the arrangement of the mooring facilities and navigation channels, and the maneuverability of the design ships. Cases where the specified area is not required owing to the method of turning the bow mean ship turning with the use of tug boats, thrusters having sufficient thrust, or anchors.

(b) Basin areas not hindering safe ship turning

1) In the performance verification of turning basins, the areas of the turning basins that do not hinder safe ship turning can be the following values. Here, these values are determined for the sake of safety and are applicable to all cases regardless of the types of ships, performance of ship turning, wind speeds or topographical conditions.

For ship turning with thrusters having sufficient thrust, the value for the case of ship turning with use of a tug boat can be used.

- In the case of ship turning under a ship’s own power: a circle having a diameter 3 times the length overall of a design ship
- In the case of ship turning with the use of a tug boat: a circle having a diameter 2 times the length overall of a design ship

2) Special turning basins for small craft

For basins provided for use in the turning of small craft, in cases where it is of necessity to reduce the areas for the turning basins due to topographical constraints, the areas that do not hinder safe ship turning can be set by using the following values based on the utilization of mooring anchors, winds or tidal currents.

For ship turning with thrusters having sufficient thrust, the value in the case of ship turning with the use of tug boats can be used.

- In the case of ship turning under a ship’s own power: a circle having a diameter 2 times the length overall of the design ship
- In the case of ship turning with the use of a tug boat: a circle having a diameter 1.5 times the length overall of the design ship

3) Other special cases

- In cases where topographical constraints or other local conditions do not allow turning basins to have enough area for safe ship turning unless the water areas of neighboring navigation channels are temporarily available for ship turning in emergency situations, water areas smaller than those specified above can be set as turning basins that do not hinder safe ship turning, provided that the dimensions and navigation performance of the design ships are known and such temporary measures are determined to be implemented safely.
- In cases where the positional relationships between the mooring facilities and navigation channels are determined to allow ships to turn their bows with turning angles required for anchorage and mooring less than 90° without hindering safe navigation of other ships, the shapes of the turning basins may be appropriately set in accordance with the local situations of the turning basins concerned and the maneuvering methods of the design ships.

(c) Mooring and unmooring basins

In the performance verification of basins provided for use in mooring and unmooring, the scales of the basins shall be appropriately determined with due consideration to the design ships’ turning methods, the presence or absence of the use of thrusters, the effects of winds and tidal currents, and the maneuverability of the design ships.

(2) Water Depths of Basins (Serviceability)

① An appropriate depth that is greater than the draft of the design ship means an assumed maximum draft, such as the full laden draft of the design ship, plus a keel clearance to be set according to the maximum draft. In the performance verification of basins, water depths shall be appropriately determined so as to ensure depths greater than the drafts of the design ships below the datum levels for port management, provided, however, that this provision shall not apply to basins for use in hull fitting and other basins provided for use in the special anchorage or mooring of ships.

② **Ship turning with thrusters**

In the performance verification of basins expected to be used for special ship turning with thrusters, as is the case for ferries, keel clearances shall be appropriately set; for example, a value larger than approximately 10% of the general maximum draft, taking into consideration the effects of special ship turning.

(3) Harbor Calmness of Basins (Serviceability)

The harbor calmness of basins means the percentage of time when ships can use the basin safely and smoothly. In the performance verification of basins, when necessary, harbor calmness shall be appropriately verified by evaluating local conditions such as waves which may hinder the anchorage, mooring and cargo handling of ships in the basins. Although the harbor calmness of basins can be generally verified with wave heights as an index, due consideration shall be given to the directions and periods of waves which may cause the ship motion as well as mooring methods of the design ships as needed.

(4) Wave Conditions in Basins during Adverse Weather (Serviceability)

In the performance verification of basins, the allowable range of wave conditions during adverse weather shall be appropriately set giving due consideration to the heights, directions and periods of waves in the basins concerned, depending on the types and principal dimensions of the design ships and sheltering methods.

3.3 Performance Verification

[1] Locations and Areas

(1) Locations

① It is preferable to decide the locations of basins with due consideration to the positional relationships with breakwaters, wharves and navigation channels, as well as ensuring harbor calmness.

(2) Areas of Basins Provided for Use in Anchorage and Mooring

① Single anchoring (**Fig. 3.3.1 (a)**) and dual anchoring (**Fig. 3.3.1 (b)**) are the mooring methods most frequently employed. Other mooring methods include two-anchoring and bow-and-stern anchoring.

② It is necessary to determine the lengths of anchor chains in a manner that enables the anchor holding power of mooring anchors and chains lying on the seabed to resist possible actions acting on the hulls depending on the types of ships, mooring methods and meteorological, as well as hydrographic, conditions. In general, the stability of moored ships is improved with an increase in the lengths of anchor chains.

③ The swinging radius of anchorage can be determined from the sum of the ship's length and the horizontal distance between the bow and the center of rotation of the laying chain.

④ When the conditions required to calculate the lengths of the anchor chains are unknown, the values in **Table 3.3.1** may be used as references.

⑤ The conceptual diagrams of single buoy mooring and dual buoy mooring using two buoys at the bow and stern sides are shown in **Figs. 3.3.1 (c)** and **3.3.1 (d)**, respectively. For dual buoy mooring, the buoys shall be arranged in a manner that aligns the bow-and-stern directions of the ships parallel to the directions of the winds and tidal currents. For the sizes of water areas required for this kind of buoy mooring, refer to **Table 3.3.2**.

⑥ The widths of basins positioned between piers can be determined with reference to the following values.

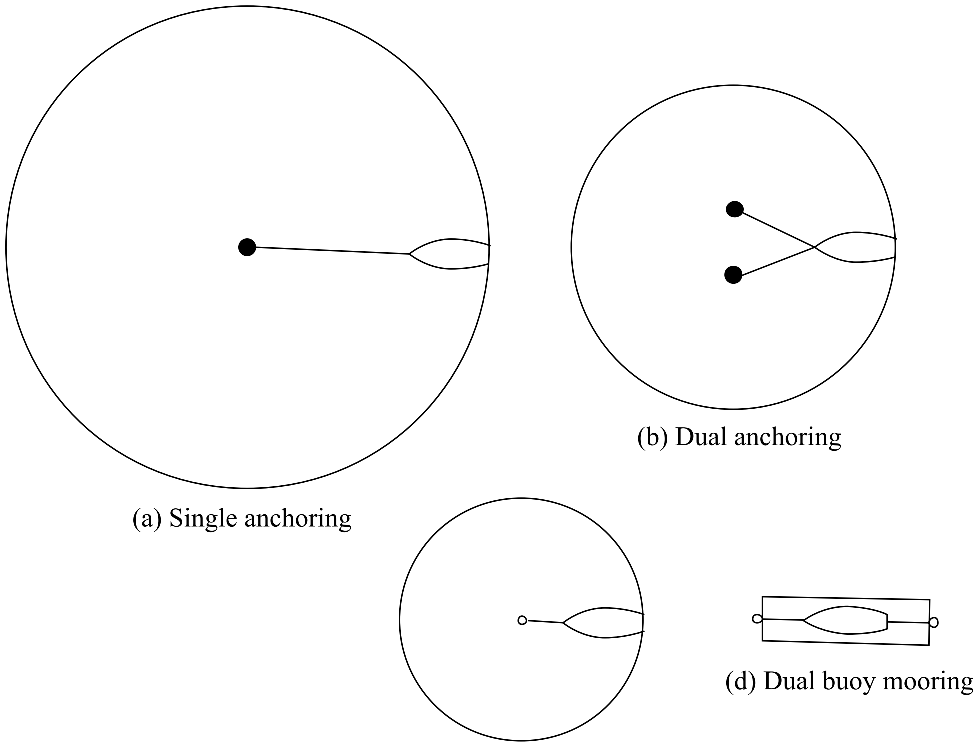
(L_{oa}: the length overall of the design ship)

(a) When the number of berths on one side of the pier is 3 or fewer: 1.0 L_{oa}

(b) When the number of berths on one side of the pier is 4 or more: 1.5 L_{oa}

When the innermost part of the water area between the piers is to be used as a small craft basin or reserved for the use of bunkering ships or barges, the widths of the basins between piers shall be determined in consideration of such use.

⑦ When examining anchoring methods and the scales of basins to cope with adverse weather, refer to the literature in 2) to 6).



(a) Single anchoring (b) Dual anchoring (c) Single buoy mooring (d) Dual buoy mooring

Fig. 3.3.1 Concept of the Scale of Basins (Per Ship)

Table 3.3.1 Anchorage Basins

Usage purpose	Usage method	Sea bottom sediment	Radius (m)
Offshore waiting or cargo handling	Single anchoring	Good anchoring	$L_{oa} + 6D$
		Poor anchoring	$L_{oa} + 6D + 30$
	Dual anchoring	Good anchoring	$L_{oa} + 4.5D$
		Poor anchoring	$L_{oa} + 4.5D + 25$

Note: L_{oa}: length overall of the design ship (m), D: water depth (m)

Table 3.3.2 Sizes of Basins for Buoy Mooring

Usage method	Area
Single buoy mooring	A circle with a radius of (L_{oa} + 25) (m)
Dual buoy mooring	A rectangle with sides of (L_{oa} + 50) (m) and L_{oa}/2 (m)

Note: L_{oa}: length overall of the design ship (m)

(3) Areas of Mooring/Unmooring Basins Provided for Use in Maneuvering

Basin for mooring/unmooring

① In general, basins used for mooring/unmooring and navigation channels can be planned in the same water areas for the sake of efficient arrangement and for the use of port facilities, provided, however, that the basins and navigation channels are preferably separated in the case of dense marine traffic.

② When examining the sizes of basins for mooring/unmooring with the use of tug boats, refer to the literature in 7) and 8).

(4) Other

There may be cases where ships anchor in water areas inside and outside of ports in the event of a tsunami following an earthquake. The literature 9) shows the concept of determining the sizes of anchoring circles and the required water areas with Tokyo Bay given as an example.

[2] Water Depths

(1) The appropriate depths of basins shall be those that ensure the assumed maximum drafts, such as the full laden drafts of design ships, plus keel clearances to be set according to the maximum drafts below the datum levels for construction work.

(2) Basins provided for use in special anchorage or mooring mean those used by ships under outfitting or unloading at multiple ports in single voyages as part of normal operation, or design ships entering and leaving ports with drafts smaller than their standard full load drafts.

(3) When the drafts of design ships cannot be identified beforehand, refer to **Part III, Chapter 5, 2.1 Items Common to Quay Walls**.

(4) When water levels fall below the lowest astronomical tides due to seasonal variations in mean water levels larger than the variations in the astronomical tides, as is the case on the coast of the Sea of Japan, or when basins are subjected to significant propagation of a swell, it is necessary to determine the water depths of the basins with due consideration to the effects of the variation in water levels and the propagation of a swell.

[3] Harbor Calmness

(1) The performance verification of harbor calmness can be carried out with reference to **Part II, Chapter 2, 4.6 Concept of Harbor Calmness**.

(2) In the performance verification, the critical wave heights for cargo handling shall be appropriately set with due consideration to the types, dimensions and cargo handling performance of the design ships, as well as the directions and periods of object waves. When setting the critical wave heights for cargo handling, refer to the **Impact Evaluation Manual for Long-period Waves in Ports**.[10] Furthermore, in cases where ship motion due to a swell or long-period waves is not likely to cause problems with cargo handling, the critical wave heights for cargo handling can be set with reference to **Table 3.3.3**.

Table 3.3.3 Reference Values of Critical Wave Heights for Cargo Handling without the Influence of Swelling or Long-Period Waves

Ship type	Critical wave height for cargo handling ($H_{1/3}$)
Small craft	0.3 m
Medium/large ships	0.5 m
Very large ships	0.7 to 1.5 m

Note: Here, small craft mean ships of roughly 500 GT class or less, which mainly use small craft basins; very large ships mean ships of roughly 50,000 GT class or greater, which mainly use large-scale dolphins or offshore berths; and medium/large ships mean those other than small craft or very large ships.

[4] Timber Sorting Ponds

For structures and facilities used for timber sorting ponds, refer to Part III, Chapter 4, 8 Breakwaters for Timber Handling Facilities and Part III, Chapter 4, 3.2 Cargo Sorting Areas for Timber.

[References]

1) Takahashi, H. and Yanagihara, K.: Analysis about the scale of the mooring and unmooring basin by NILIM-AIS system, Technical Note of National Institute for Land and Infrastructure Management No.496, 2009 (in Japanese)

2) Iwai, S.: New Edition Ship maneuvering theory, Kaibun-do Publishing, 1977 (in Japanese)

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4 Small Craft Basins

[Ministerial Ordinance] (Performance Requirements for Small Craft Basins)

Article 11

The performance requirements for small craft basins shall be such that the requirements specified by the Minister of Land, Infrastructure, Transport and Tourism are satisfied in light of geotechnical characteristics, waves, water currents and wind conditions, as well as the usage conditions of the surrounding water areas so as to secure safe and smooth use by ships .

[Public Notice] (Performance Criteria for Small Craft Basins)

Article 32

1 The requirements specified in the preceding Article, item (ii) shall be applied mutatis mutandis to the performance criteria for small craft basins.

2 In addition to the provisions of the preceding paragraph, the performance criteria for small craft basins shall provide the shape, area and calmness necessary for the safe and smooth use of ships.

[Interpretation]

9. Waterways and Basins

(3) Performance Criteria of Small Craft Basins (Article 11 of the Ministerial Ordinance and the interpretation related to Article 32 of the Public Notice)

① With regard to the performance criteria and the interpretation of small craft basins, those of the depth of basins in Section 3.2(2) shall apply mutatis mutandis.

② In addition to the above, the performance verification of small craft basins shall be carried out with due consideration to the design ships and use conditions.

(1) Small craft basins are water areas where small crafts enable to be safely moored, landed and put to rest, as well as fulfill their functions in conjunction with breakwaters for harbors, mooring facilities and rest facilities. Small crafts include port service boats, public boats operated by government offices, work ships, tug boats, fishing boats, leisure fishing boats and pleasure boats etc.

(2) It is recommended that small craft basins shall designed with due consideration to safe mooring, facilitation of ship maneuvering and suitability for meteorological and hydrographic conditions, as well as consistency with the related facilities.

(3) Performance Criteria of Small Craft Basins

① **The performance criteria of basins shall apply mutatis mutandis. (serviceability)**

The provisions in item (2), Article 31 of the Standard Public Notice (Performance Criteria of the Depths of Basins) shall apply to small craft basins mutatis mutandis.

② **Shapes, areas and harbor calmness of small craft basins (serviceability)**

(a) Shapes

In the performance verification of small craft basins, their shapes shall be properly determined with due consideration to ensuring the required harbor calmness and for the prevention of accidental contacts between small crafts and the breakage of mooring lines.

(b) Areas

In the performance verification of small craft basins, their areas shall be properly determined with due consideration to the following items.

- **Design ships**

  The ship types and ship dimensions of the design ships shall consider in the design. However there are wide variability of those information, it is difficult to set a standard value. Therefore, the dimensions of the design ships are preferably set based on specifications of the ships, which actually use the small craft basins concerned, through hearings or other means. The Register of Ships in Japan[1)]can be used as a reference.

- **Mooring facilities**

  The scales of onshore facilities and water areas for ship mooring shall be determined after the determination of mooring methods and, preferably, based on the actual operational condition of the design ships. For example, literature 2) introduces the actual operational condition of tug boats.

- **Waterways and basins**

  It is necessary to properly determine water areas provided for use in ship navigation and turning and the dimensions of the navigation channels (widths, depths and the shapes of bends) connecting the inside and outside of basins as needed.

(c) Harbor calmness

Harbor calmness shall be appropriately determined in consideration of the wave conditions of the small craft basins concerned.

(4) For those small craft basins to be provided in marinas, refer to the descriptions in **Reference (Part III), Chapter 2, 4 Marina**.

[References]

1) Japan Shipping Exchange: Register of Ships (in Japanese)

2) Japan Association of Cargo-handling Machinery Systems: Cargo Handling, Vol.162, p233, 2017 (in Japanese)