# Design Standard for Fairway in Next Generation (Interim Report, Version-2)

September 2003

Japan Institute of Navigation, Standard committee
Ministry of Land, Infrastructure and Transport
National Institute for Land and Infrastructure Management
Port and Harbor Department

# Introduction

The depth, width and alignment of fairway should be designed considering the various elements including particulars of design ship and weather and sea conditions around fairway.

However in the existing Japanese design standard for fairway, such kind of elements are not taken into consideration and also no design standard considering various elements has been adopted in the world.

In this circumstance the new design standard [Approach Channels A Guide for Design] depending on classified elements and quantitative analysis was proposed in 1997 by PIANC and IAPH.

Before starting this project, the above design standard was analyzed by checking up with the result of naval architectural study, especially with the result of manoeuvability study.

As the result it was proved that calculated values according to this standard were unfounded and had some problems to output the discontinuous value by small difference of calculation condition because the each value for each element was simply added. And also it is hard to apply this standard to the design of port water facilities in Japan because this [A Guide for Design] is the design standard for long channels in European port.

The other hand, the proposal of more reasonable Japanese standard will be expected by applying the study result of naval architecture and navigation.

Considering the above situation, the study on new design standard for fairway that is able to design the depth, width and alignment of fairway depending on the particulars of design ship and weather and sea condition has been carried out jointly by Japan Institute of Navigation and National Institute for Land and Infrastructure Management.

Now, this report shows the study result up to now as [Design standard for fairway in next generation (Interim report, Version-2]. However the contents of this report are not so enough, therefore further study shall be continued and the final report shall be proposed later.

I would like to deeply thank personals concerned for participating in this project and request further cooperation.

April 2003
Japan Institute of Navigation, Standard committee
Chairman Dr. Kohei Otsu

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# Index

## 1. Concept of fairway and objective items for fairway design

Some useful routes are shown on navigation charts for use of navigators as reference. Ships navigate all most on he straight course line without altering course in ocean. In terminal water such as waiting anchorage and port, the depth of water becomes shallow and there are narrow channels that require often change course line in heavy traffic. And also ships have to pass through some traffic lanes to arrive the passage (or approach channel) to berths.

The concept of fairway in this report means passage (or approach channel) and traffic lane designated by light buoys as navigable water for safe navigation.

Though fairway design contains a lot of items, the depth, width and alignment of fairway are picked up in this report. And this report shows the method of design for each dimension depending on design ship characteristic and weather and sea condition.

On the other hand, in case of existing fairway, it is possible to decide the size of ship and navigation criteria by opposite analysis.

## 2. Depth of fairway

### First step

When the dimension of design ship is not specified, the depth of fairway is basically decided as bellow.

1) Fairway in a port where wave including swell dose not affect ship motion : $D=1.10d$
2) Fairway out of a port where wave including swell affects ship motion : $D=1.15d$
3) Fairway in open water where wave including swell exists : $D=1.20d$

D : Depth of fairway
d : Max draft of moored design ship at berth in still water under operational weather and sea condition

### Second step

When the dimension of design ship is specified, the necessary depth of fairway can be calculated by the following formula.

$$D=d+D1+\mathrm{Max}\,(D2, D3)+D4$$

D : Depth of fairway
d : Max draft of moored design ship at berth in still water under operational weather and sea condition
D1 : Squat (bow sink during underway)
D2 : Bow sink due to heaving and pitching motion (Additional element in case of $\lambda>0.45Lpp$)
D3 : Bilge keel sinks due to heaving and rolling motion (Additional element in case of $TR=TE$)
D4 : Allowance of depth
$\lambda$ : Length of wave including swell
Lpp : Length between perpendiculars of design ship
TR : Natural rolling period of design ship
TE : Meeting period of design ship and design wave

At the design stage, the necessary depth is calculated under the chart datum. In actual operation, the following elements should be taken into consideration.

| | |
|---|---|
| 1) Tide: | Generally tide height is above the chart datum during navigation, this tide height is considered as additional depth of water in actual operation. |
| 2) Accuracy of depth of water: | the error of depth of chart has some risk for navigation, but usually the dredged bottom is deeper than planned bottom. This additional dredging that is confirmed by enough depth survey can be considered as the additional depth of water in actual operation. |
| 3) Others: | Air pressure, bottom nature, obstruction in water, the density of seawater, and etc. should be taken into consideration if necessary. |

**(Explanation)**

1) Length of wave is fixed by the depth of fairway and design wave period.
2) Draft means max draft of moored design ship at berth in still water under operational weather and sea condition and max value is the full draft of design ship.
3) D1 is calculated by the following formula.

$D1=(0.7+1.5d/D)\ \{Cb/(Lpp/B)\}\cdot V^2/g+15d/D\cdot\{Cb/(Lpp/B)\}^3\cdot V^2/g$ (Formula by Dr. Yoshimura)

The result of the above calculation should satisfy the following condition.

$D-d-D1>0$

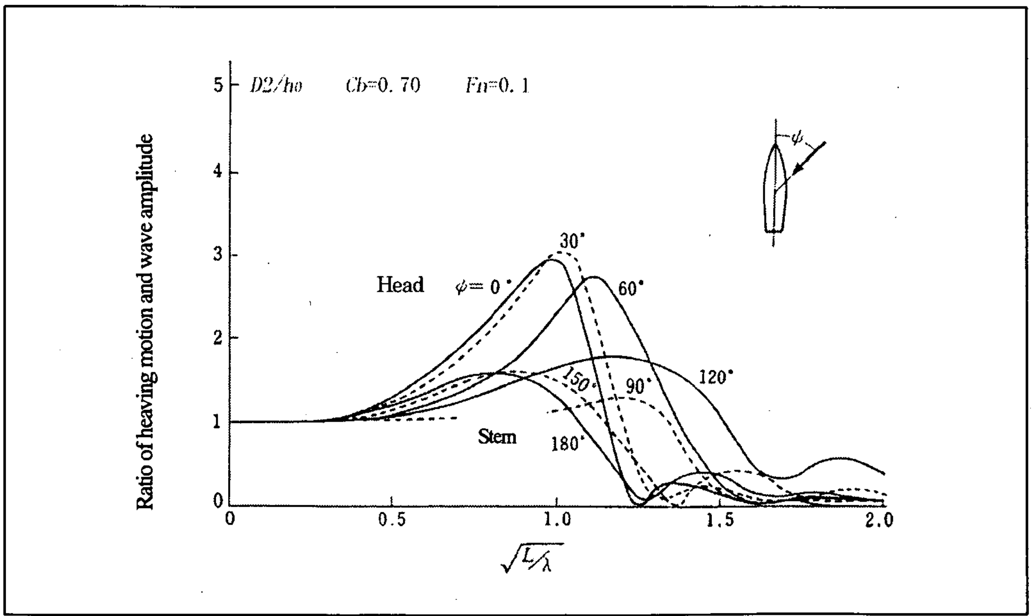
When the result does not satisfy the above formula, initial condition including ship speed should be reconsidered.

d : Max draft in still water

D : Depth of fairway
Lpp : Length between perpendiculars of design ship
B : Breadth of design ship
Cb : Block coefficient of design ship
V : Ship speed (m/s)
G : Acceleration of gravity ($9.8m/s^2$)

・Formula of Dr. Yoshimura "Mathematical model for the manoeuvring ship motion in shallow water" Journal of the Kansai society of naval architects, Japan, No.200, March 1986

4) In case of λ >0.45Lpp, D2 can be calculated according to the value of D2/h0 taken from the figure below.



Figur2-1 Ratio of heaving motion and wave amplitude

("10 sections regarding VLCC, VLCC Study Group")

Note: This figure shows only the case of Cb=0.7.Fn=0.1, but covers the case of deep sea where ship motion is bigger than one in shallow water. Therefore this figure can apply all cases regardless of Cb and Fn.

h0 : Amplitude of wave (h0=H/ 2)
H : Wave height

5) In case of TR (Natural rolling period) and TE (Meeting period of ship and wave) is nearly equal, D3 can be

calculated by the following formula.
(Modified formula for irregular wave from the formula for regular wave by Dr. Honda [Outline of ship handling, Appendix A11]).

$D3=0.7 \cdot (H_{1/3}/2)+(B/2) \cdot \sin\Theta$

$\Theta=\mu \cdot \gamma \cdot \Phi$

$\mu \cdot \gamma=7$ (Analysis by Dr. Takagi)

$\Phi=360 \cdot (0.35H_{1/3}/\lambda) \cdot \sin\psi$

Here, TR and TE can be calculated by the following formula.

$TR=0.8B/(GM)^{0.5}$

$TE=\lambda/(\lambda/TW+V\cos\psi)$

GM (Distance between the center of gravity of ship and metacentre) is nearly equal to B/25.

In this study, GM=0.5～2.0 (B / 25) is applied because real value of GM varies depending on ship condition.

GM: Distance between the center of gravity and metacentre
TW: Wave period
$H_{1/3}$: Significant wave height
B : Breadth of design ship
$\Theta$ : Max rolling angle of design ship(degree)
$\mu$ : Ratio of rolling induced by regular wave
$\gamma$ : Effective wave slope coefficient
$\Phi$ : Max wave slope angle
$\psi$ : Encounter angle between ship's head and wave direction (degree)

- Dr. Honda [Outline of ship handling (5th edition)] SEIZANDOSHOTEN (1998)
- Analysis by Dr. Takagi: Ship motion in shallow water No.3 (Figure-20) : Transactions of the west-Japan society of naval architects No.54 (1977)

6) D4 is given as follows.

$d \leqq 10m$ D0=0.5m

$d > 10m$ D0=5% of d

---

D : Depth of fairway
D : Max draft in still water

d0 : Full draft of design ship

Lpp : Length between perpendiculars of design ship
B : Breadth of design ship
Cb : Block coefficient of design ship
DT : Displacement of design ship

$\gamma$ : Density of sea water

V : Ship speed (m/s)

TR : Natural rolling period od design ship
GM : Distance between the center of gravity and metacentre

$\lambda$ : Length of wave including swell

TW : Wave period
TE : Meeting period of design ship and design wave
H : Wave height
$H_{1/3}$ : Significant wave height

h0 : Wave amplitude (h0=H/2)

$\Theta$ : Max rolling angle of design ship (degree)

$\psi$ : Encounter angle between ship's head and wave direction (degree)

$\mu$ : Ratio of rolling induced by regular wave

$\gamma$ : Effective wave slope coefficient

$\Phi$ : Max wave slope angle (degree)

## Calculation Example-1 Large CTNR ship

In case of the fairway in the port without wave effect

| | |
|---|---|
| Kind of ship : Large CTNR | |
| | |
| DWT : (ton) | 82,275 |
| GT : (ton) | 76,847 |
| Displacement : (ton) | 110,715 |
| TEU CAPACITY : TEU | 6,208 |
| Full draft : d0(m) | 14.0 |
| Max draft : d(m) | 14.0 |
| Breadth : B(m) | 40.0 |
| Length between perpendicular : Lpp(m) | 287 |
| Density of sea water : γ | 1.025 |
| Block coefficient : Cb | 0.671 |
| | |
| Ship's speed : V(knot) | 10.0 |
| Ship's speed : V(m/s) | 5.1 |
| | |
| Depth of fairway : D(m) | 15.4 |
| | |
| D1 : Squat underway | 0.55 |
| | |
| Reference : Tuck's formula (m) | 0.50 |
| | |
| D2 : Bow sinking due to heaving and pitching (m) | 0.0 |
| | |
| D3 : Bilge sinking due to heaving and rolling (m) | 0.0 |
| | |
| D4 : Allowance (m) | 0.7 |
| | |
| Depth of fairway :d+D1+D2+D3+D4 (m) | 15.3 |
| | |
| Reference : Max draft ×1.1 | 15.4 |

## Calculation Example-2 Large CTNR ship

In case of the fairway facing to open sea with wave effect

| | |
|---|---|
| Kind of ship : Large CTNR | |
| | |
| DWT : (ton) | 82,275 |
| GT : (ton) | 76,847 |
| Displacement : (ton) | 110,715 |
| TEU CAPACITY : TEU | 6,208 |
| Full draft : d0(m) | 14.0 |
| Max draft : d(m) | 14.0 |
| Breadth : B(m) | 40.0 |
| Length between perpendicular : Lpp(m) | 287 |
| Density of sea water : γ | 1.025 |
| Block coefficient : Cb | 0.671 |
| | |
| Ship's speed : V(knot) | 10.0 |
| Ship's speed : V(m/s) | 5.144 |
| | |
| Wave Period=TW(sec.) | 14 |
| Wave Height=H(m) | 2 |
| Wave Depth of water=D(m) | 18 |
| Wave Length=λ (m) | 174 |
| Attack angle of wave=ψ (degree) | 60 |
| | |
| D1 : Squat underway | 0.5 |
| Reference : Tuck's formula(m) | 0.42 |
| | |
| 0.45×Lpp(m) | 129 |
| (Length>0.45×Lpp) | |
| $(L/\lambda)^{0.5}$ | 1.28 |
| D2 / h0 : Heave amplitude／Wave amplitude | 2.1 |
| h0 : H / 2 | 1.0 |
| D2 : Bow sinking due to heaving and pitching(m) | 2.1 |
| | |
| GM=0.5～2.0×（B / 25） | 0.8～3.2 |
| Natural period=0.8B / $(GM)^{0.5}$=TR | 17.9～35.8 |
| TE=λ / (λ / TW+Vcosψ)(sec.) | 11.6 |
| TR≠TE | |
| D3 : Bilge sinking due to heaving and rolling(m) | 0.0 |
| | |
| D4 : Allowance (m) | 0.7 |
| | |
| Depth of fairway :d+D1+D2+D3+D4 (m) | 17.3 |
| | |
| Reference : Max draft ×1.2 | 16.8 |

## 3. Width of fairway

**First step**

When the dimension of design ship is not specified,

1) Fairway with one way should have reasonable width over than 0.5Loa of design ship. In case of the width is less than 1.0 Loa , it is preferable to apply safety measures such as installation and maintenance of navigation aids.
2) Fairway with two ways has reasonable width over than 1.0Loa depending on the following condition.

   ① Relatively long fairway: W=1.5Loa

   ② Fairway where ships meet each other frequently: W=1.5Loa

   ③ Relatively long fairway where ships meet each other frequently: W=2.0Loa

   The special fairway such as fairway with remarkably large traffic volume, fairway crossed by sailing or fairway for VLCC should have width larger than the above.

**Second step**

When the dimension of design ship is specified, necessary width of fairway can be calculated by the following formula.

1) Fairway without ship meeting (One-way fairway)

   $W = Wm0 + Wb1 + Wb2$

2) Fairway with ship meeting (Two-way fairway)

   $W = Wm1 + Wm2 + Wc + Wb1 + Wb2$

Loa : Length over all
W : Width of fairway
Wm0 : Basic manoeuvring lane for one-way fairway
Wb1, Wb2 : Bank clearance (Necessary lane against bank suction)
Wm1, Wm2 : Basic manoeuvring lane on two-way fairway (in case of meeting)
Wc : Passing distance (necessary lane for passing ship each other)

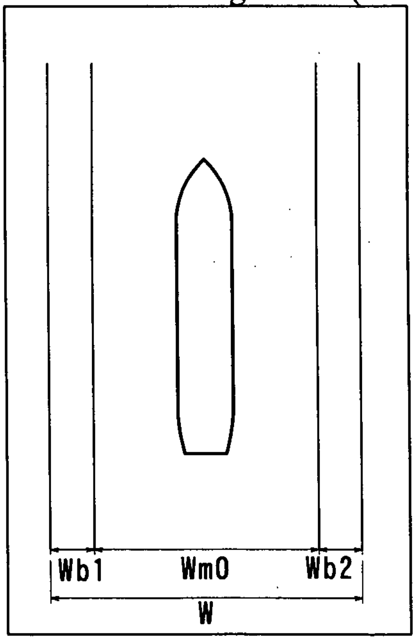


Figure 3-2 One-way fairway

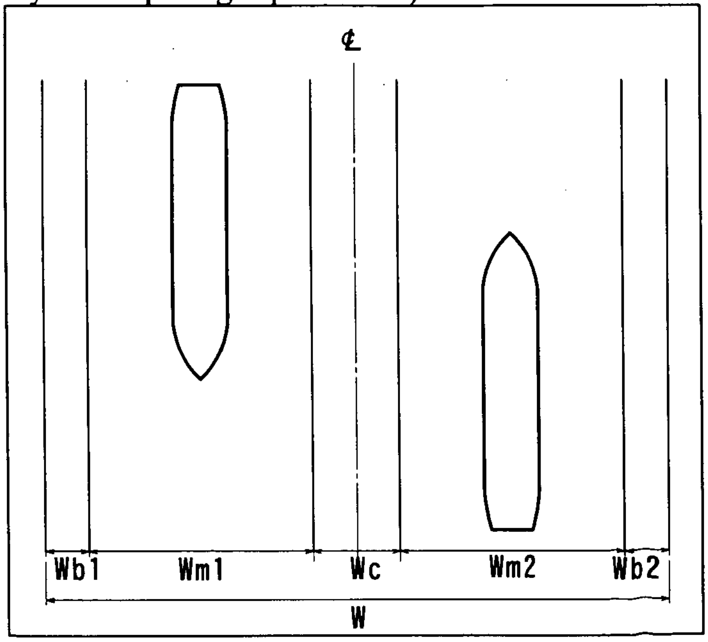


Figure 3-3 Two-way fairway

**(Explanation)**

1) Wmi (Basic manoeuvring lane) is composed of two elements.

①Wm( $\beta$ ,y): Manoeuvring lane against the effect of wind, current and etc.

②Wm( $\alpha$ ): Manoeuvring lane for the detection of drift

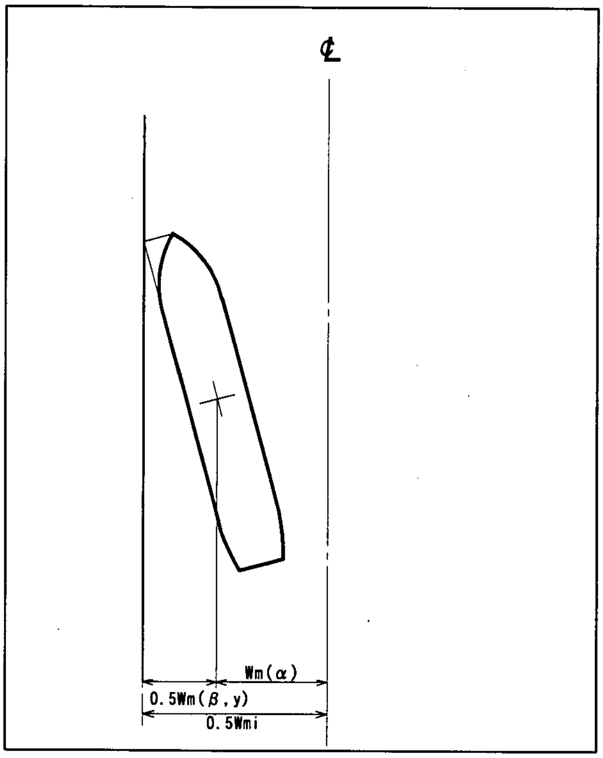


Figure 3-4 Idea of basic manoeuvring lane

2) Wm( $\beta$ ,y) (Necessary manoeuvring lane against the effect of wind, current and etc.) can be calculated by the following formula.

2-1) Basic idea for calculation

At first, counter rudder angle shall be calculated depending on wind velocity under the limit of 15 degrees max counter rudder. And in case that calculated angle is over 15 degrees, max wind velocity of the criteria for port entry should be reconsidered.

Secondly the drift angle due to cross current shall be calculated. Basic manoeuvring lane against wind and current shall be calculated by the total drift angle due to wind and current.

Then, the drift sideway due to ship yaw is added to the above basic manoeuvring lane.

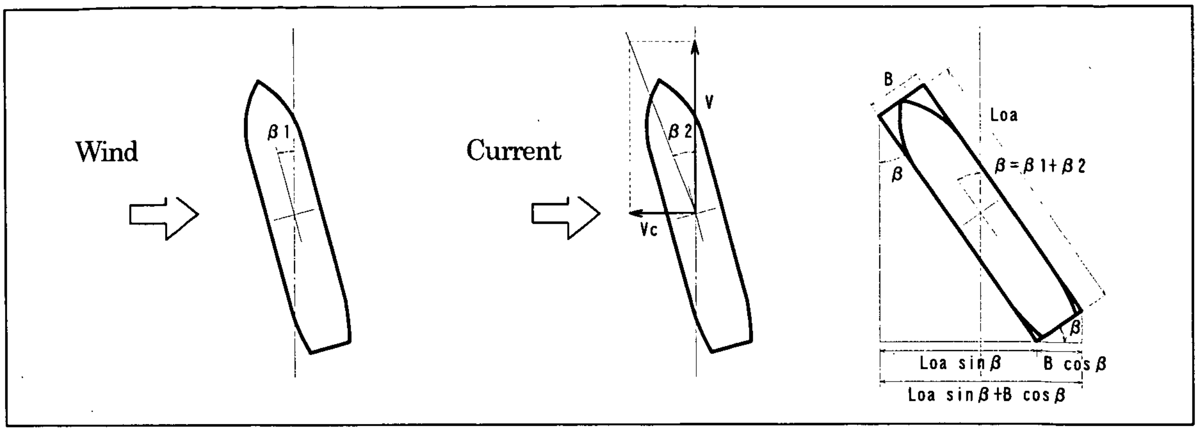


Figure 3-5　Idea for the drift angle due to wind and current

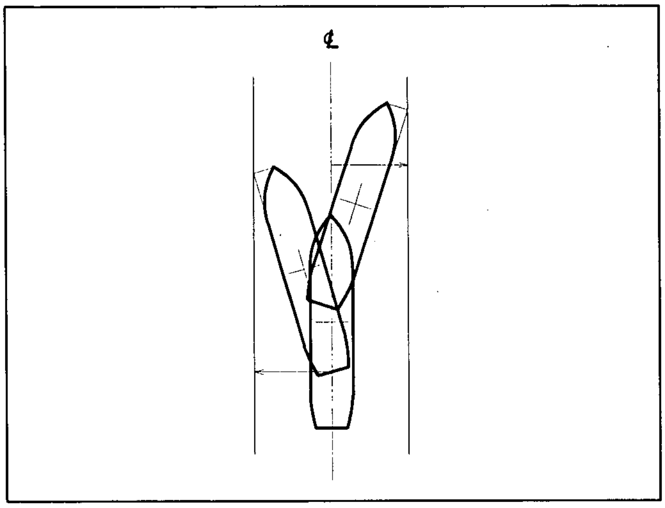


Figure 3-6　Idea for the drift sideway due to yaw

2-2) Calculation method and formula

① Calculation of the drift angle （$\beta 1$） due to wind effect

According to the following steps, the drift angle due to wind effect can be calculated.

a: Define the design ship particulars, ship speed and natural condition

b: Calculation of the hydrodynamic derivatives, interaction force coefficient of rudder of design ship (Formula by Dr. Hirano)

c: Calculation of wind pressure and moment coefficient (Formula by Dr. Yamano)

d: Calculation of necessary counter rudder by ship motion equation

Drift angle due to wind effect （$\beta 1$） = Mini (Drift angle corresponding to necessary counter rudder angle, drift angle corresponding to counter rudder angle of 15degrees)

$\beta 1$:Drift angle due to wind effect

- Formula by Dr. Hirano: Dr. Hirano, Dr Takashina, Mr. Moriya, Mr. Nakamura: An Experimental Study on Manoeuvering Hydrodynamic Forces in Shallow Water, Transactions of the west-Japan society of naval architects,No.69, 1985

Formula by Dr. Hirano calculating hydrodynamic derivatives

$Y'\beta=(\pi/2)ke+1.4Cb\cdot B/L$

$Y'r=-(\pi/4)ke$

$N'\beta=ke$

$N'r=-0.54ke+ke^2$

Here

$ke=k/(dk/2D+((\pi d/2D)\cdot \cot(\pi d/2D))^{\lambda}$

$k=2d/\pi$

$Y'\beta$: $\lambda=2.3$, $Y'r, N'r$: $\lambda=0.7$, $N'\beta$: $\lambda=1.7$

- Formula by Dr. Yamano, Dr. Yamano, Dr. Saito: A estimation method of wind force acting on ship's hull, Journal of the Kansai society of naval architects, Japan, No.228,1997

Formula by Dr. Yamano calculating wind force acting on ship's hull

$\theta w$ : attack angle between bow and wind direction

Ax : Transverse area

Ay : Longitudinal area

XG : Distance between F.P. and center of the area

Rx : Longitudinal wind force

Ry : Lateral wind force

Na : Wind force moment

U : Wind velocity

$\rho$ : Density of air

$Rx=(1/2)Cx\,\rho\,AxU^2$

$Ry=(1/2)Cy\,\rho\,AyU^2$

$Na=(1/2)Cm\,\rho\,LoaU^2$

$Cx=Cx0+Cx1\cos\theta w+Cx2\cos2\theta w+Cx3\cos3\theta w+Cx4\cos4\theta w+Cx5\cos5\theta w$

$Cy=Cy1\sin\theta w+Cy2\sin2\theta w+Cy3\sin3\theta w$

$Cm=0.1\cdot(Cm1\sin\theta w+Cm2\sin2\theta w+Cm3\sin3\theta w)$

Each coefficient shall be respectively given as the product and sum of value shown in Table 3-1

Table 3-1 Regression coefficient (L=Lpp)

| Cx | Const. | $Ay/L^2$ | XG/L | L/B | Ay/Ax | Cy | Const. | $Ay/L^2$ | XG/L | L/B | Ay/Ax | Cm | Const. | $Ay/L^2$ | XG/L | L/B | Ay/Ax |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cx0 | −0.0358 | 0.925 | 0.0521 | | | | | | | | | | | | | | |
| Cx1 | 2.58 | −6.087 | | −0.1735 | | Cy1 | 0.509 | 4.904 | | | 0.022 | Cm1 | 2.650 | 4.634 | −5.876 | | |
| Cx2 | −0.97 | | 0.978 | −0.0556 | | Cy2 | 0.0208 | 0.230 | −0.075 | | | Cm2 | 0.105 | 5.306 | | | 0.0704 |
| Cx3 | −0.146 | | | −0.0283 | 0.0728 | Cy3 | −0.357 | 0.943 | | 0.0381 | | Cm3 | 0.616 | | −1.474 | 0.0161 | |
| Cx4 | 0.0851 | | | −0.0254 | 0.0212 | | | | | | | | | | | | |
| Cx5 | 0.0318 | 0.287 | | −0.0164 | | | | | | | | | | | | | |

The calculation result of necessary counter rudder angle and drift angle are shown in Table 3-3 in case of the parameter of wind velocity/ship velocity ratio (K value) and wind attack angle for ships in Table 3-2.

This table is available for the calculation of rough Wm($\beta$,y) value (Manoeuvring lane against wind and current effect)

Wind attack angle ($\theta$) means the angle between bow and wind direction.

Table 3-2 Ship's Particulars

| | DWT | Loa | B | d0 |
|---|---|---|---|---|
| CTNR | 60,000 | 288 | 32.2 | 13.3 |
| TANKER | 280,000 | 333 | 60.0 | 20.4 |
| BULKER | 172,000 | 289 | 45.0 | 17.8 |
| LNG | 70,000 | 283 | 44.8 | 10.8 |
| PCC | 18,000 | 190 | 32.2 | 8.2 |

Table 3-3 Necessary rudder angle and drift angle against K value and wind attack angle （D/d=1.2）

| CTNR | Counter Rudder | | Wind direction(degree) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| K | 0 | 15 | 30 | 45 | 60 | 75 | 90 | 105 | 120 | 135 | 150 | 165 | 180 |
| K=1 | 0.0 | 0.1 | 0.1 | 0.2 | 0.3 | 0.3 | 0.4 | 0.4 | 0.4 | 0.4 | 0.3 | 0.2 | 0.0 |
| K=2 | 0.0 | 0.2 | 0.5 | 0.8 | 1.0 | 1.3 | 1.5 | 1.7 | 1.7 | 1.5 | 1.2 | 0.6 | 0.0 |
| K=3 | 0.0 | 0.5 | 1.1 | 1.7 | 2.3 | 2.9 | 3.4 | 3.8 | 3.8 | 3.4 | 2.6 | 1.4 | 0.0 |
| K=4 | 0.0 | 1.0 | 2.0 | 3.0 | 4.1 | 5.2 | 6.1 | 6.7 | 6.8 | 6.1 | 4.7 | 2.5 | 0.0 |
| K=5 | 0.0 | 1.5 | 3.1 | 4.7 | 6.4 | 8.1 | 9.5 | 10.5 | 10.6 | 9.5 | 7.3 | 4.0 | 0.0 |
| K=6 | 0.0 | 2.2 | 4.4 | 6.8 | 9.2 | 11.6 | 13.7 | *15.1 | *15.2 | 13.7 | 10.5 | 5.7 | 0.1 |
| K=7 | 0.0 | 3.0 | 6.0 | 9.2 | 12.6 | *15.8 | *18.7 | *20.6 | *20.7 | *18.7 | 14.2 | 7.8 | 0.1 |
| CTNR | Drift angle | | Wind direction(degree) | | | | | | | | | | |
| K | 0 | 15 | 30 | 45 | 60 | 75 | 90 | 105 | 120 | 135 | 150 | 165 | 180 |
| K=1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| K=2 | 0.0 | 0.1 | 0.1 | 0.2 | 0.2 | 0.2 | 0.2 | 0.1 | 0.1 | 0.1 | 0.1 | 0.0 | 0.0 |
| K=3 | 0.0 | 0.1 | 0.3 | 0.3 | 0.4 | 0.4 | 0.4 | 0.3 | 0.3 | 0.2 | 0.1 | 0.1 | 0.0 |
| K=4 | 0.0 | 0.2 | 0.5 | 0.6 | 0.7 | 0.7 | 0.6 | 0.6 | 0.5 | 0.4 | 0.3 | 0.1 | 0.0 |
| K=5 | 0.0 | 0.4 | 0.7 | 0.9 | 1.1 | 1.1 | 1.0 | 0.9 | 0.7 | 0.6 | 0.4 | 0.2 | 0.0 |
| K=6 | 0.0 | 0.6 | 1.0 | 1.4 | 1.5 | 1.6 | 1.5 | 1.3 | 1.1 | 0.8 | 0.6 | 0.3 | 0.0 |
| K=7 | 0.0 | 0.8 | 1.4 | 1.9 | 2.1 | 2.1 | 2.0 | 1.8 | 1.5 | 1.1 | 0.8 | 0.4 | 0.0 |

* Counter rudder angle is over 15 degrees

| TANKER | Counter Rudder | | Full load | | | | Wind direction(degree) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| K | 0 | 15 | 30 | 45 | 60 | 75 | 90 | 105 | 120 | 135 | 150 | 165 | 180 |
| K=1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.0 | 0.0 |
| K=2 | 0.0 | 0.0 | 0.1 | 0.2 | 0.3 | 0.5 | 0.6 | 0.6 | 0.5 | 0.4 | 0.3 | 0.1 | 0.0 |
| K=3 | 0.0 | 0.1 | 0.2 | 0.4 | 0.8 | 1.1 | 1.2 | 1.3 | 1.1 | 0.9 | 0.6 | 0.3 | 0.0 |
| K=4 | 0.0 | 0.1 | 0.4 | 0.8 | 1.3 | 1.9 | 2.2 | 2.3 | 2.0 | 1.6 | 1.1 | 0.5 | 0.0 |
| K=5 | 0.0 | 0.2 | 0.6 | 1.2 | 2.1 | 2.9 | 3.5 | 3.5 | 3.2 | 2.5 | 1.6 | 0.8 | 0.0 |
| K=6 | 0.0 | 0.3 | 0.8 | 1.8 | 3.0 | 4.2 | 5.0 | 5.1 | 4.6 | 3.6 | 2.4 | 1.2 | 0.0 |
| K=7 | 0.0 | 0.4 | 1.1 | 2.4 | 4.1 | 5.7 | 6.8 | 6.9 | 6.2 | 4.9 | 3.2 | 1.6 | 0.0 |
| TANKER | Drift angle | | Full load | | | | Wind direction(degree) | | | | | | |
| K | 0 | 15 | 30 | 45 | 60 | 75 | 90 | 105 | 120 | 135 | 150 | 165 | 180 |
| K=1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| K=2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| K=3 | 0.0 | 0.0 | 0.0 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 |
| K=4 | 0.0 | 0.0 | 0.1 | 0.1 | 0.2 | 0.2 | 0.2 | 0.2 | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 |
| K=5 | 0.0 | 0.1 | 0.1 | 0.2 | 0.3 | 0.3 | 0.3 | 0.3 | 0.2 | 0.1 | 0.1 | 0.0 | 0.0 |
| K=6 | 0.0 | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.5 | 0.4 | 0.3 | 0.2 | 0.1 | 0.0 | 0.0 |
| K=7 | 0.0 | 0.1 | 0.2 | 0.4 | 0.5 | 0.6 | 0.6 | 0.5 | 0.4 | 0.2 | 0.1 | 0.0 | 0.0 |

| TANKER | Counter Rudder |  | Ballast |  |  |  | Wind direction(degree) |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| K | 0 | 15 | 30 | 45 | 60 | 75 | 90 | 105 | 120 | 135 | 150 | 165 | 180 |
| K=1 | 0.0 | 0.0 | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.5 | 0.5 | 0.4 | 0.3 | 0.2 | 0.0 |
| K=2 | 0.0 | 0.1 | 0.4 | 0.8 | 1.2 | 1.7 | 2.1 | 2.2 | 2.0 | 1.7 | 1.2 | 0.6 | 0.0 |
| K=3 | 0.0 | 0.3 | 0.8 | 1.7 | 2.8 | 3.8 | 4.6 | 4.9 | 4.6 | 3.8 | 2.7 | 1.4 | 0.0 |
| K=4 | 0.0 | 0.6 | 1.5 | 3.0 | 4.9 | 6.8 | 8.2 | 8.7 | 8.2 | 6.8 | 4.8 | 2.4 | 0.0 |
| K=5 | 0.0 | 0.9 | 2.4 | 4.7 | 7.7 | 10.7 | 12.8 | 13.6 | 12.8 | 10.6 | 7.4 | 3.8 | 0.0 |
| K=6 | 0.0 | 1.3 | 3.4 | 6.8 | 11.1 | *154 | *18.5 | *19.6 | *18.4 | *15.2 | 10.7 | 5.5 | 0.1 |
| K=7 | 0.0 | 1.7 | 4.6 | 9.2 | *15.1 | *20.9 | *25.1 | *26.6 | *25.0 | *20.6 | 14.6 | 7.5 | 0.1 |
| TANKER | Drift angle |  | Ballast |  |  |  | Wind direction(degree) |  |  |  |  |  |  |
| K | 0 | 15 | 30 | 45 | 60 | 75 | 90 | 105 | 120 | 135 | 150 | 165 | 180 |
| K=1 | 0.0 | 0.0 | 0.1 | 0.1 | 0.2 | 0.2 | 0.2 | 0.2 | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 |
| K=2 | 0.0 | 0.2 | 0.3 | 0.5 | 0.6 | 0.7 | 0.7 | 0.6 | 0.5 | 0.3 | 0.2 | 0.1 | 0.0 |
| K=3 | 0.0 | 0.4 | 0.8 | 1.1 | 1.4 | 1.6 | 1.6 | 1.4 | 1.0 | 0.7 | 0.4 | 0.2 | 0.0 |
| K=4 | 0.0 | 0.7 | 1.4 | 2.0 | 2.6 | 2.9 | 2.8 | 2.5 | 1.9 | 1.2 | 0.7 | 0.3 | 0.0 |
| K=5 | 0.0 | 1.1 | 2.1 | 3.2 | 4.0 | 4.5 | 4.4 | 3.8 | 2.9 | 1.9 | 1.0 | 0.4 | 0.0 |
| K=6 | 0.0 | 1.5 | 3.1 | 4.6 | 5.8 | 6.4 | 6.3 | 5.5 | 4.2 | 2.7 | 1.5 | 0.6 | 0.0 |
| K=7 | 0.0 | 2.1 | 4.2 | 6.2 | 7.9 | 8.8 | 8.6 | 7.5 | 5.7 | 3.7 | 2.0 | 0.8 | 0.0 |

* Counter rudder angle is over 15 degrees

| BULKER | Counter Rudder |  |  |  |  |  | Wind direction(degree) |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| K | 0 | 15 | 30 | 45 | 60 | 75 | 90 | 105 | 120 | 135 | 150 | 165 | 180 |
| K=1 | 0.0 | 0.0 | 0.0 | 0.1 | 0.1 | 0.1 | 0.2 | 0.2 | 0.2 | 0.1 | 0.1 | 0.0 | 0.0 |
| K=2 | 0.0 | 0.1 | 0.1 | 0.3 | 0.4 | 0.6 | 0.7 | 0.7 | 0.6 | 0.5 | 0.3 | 0.2 | 0.0 |
| K=3 | 0.0 | 0.1 | 0.3 | 0.6 | 0.9 | 1.2 | 1.5 | 1.5 | 1.4 | 1.1 | 0.8 | 0.4 | 0.0 |
| K=4 | 0.0 | 0.2 | 0.5 | 1.0 | 1.6 | 2.2 | 2.6 | 2.7 | 2.5 | 2.0 | 1.4 | 0.7 | 0.0 |
| K=5 | 0.0 | 0.3 | 0.8 | 1.6 | 2.6 | 3.5 | 4.1 | 4.2 | 3.9 | 3.1 | 2.1 | 1.1 | 0.0 |
| K=6 | 0.0 | 0.5 | 1.2 | 2.3 | 3.7 | 5.0 | 5.9 | 6.1 | 5.5 | 4.5 | 3.1 | 1.5 | 0.0 |
| K=7 | 0.0 | 0.6 | 1.6 | 3.1 | 5.0 | 6.8 | 8.0 | 8.3 | 7.5 | 6.1 | 4.2 | 2.1 | 0.0 |
| BULKER | Drift angle |  |  |  |  |  | Wind direction(degree) |  |  |  |  |  |  |
| K | 0 | 15 | 30 | 45 | 60 | 75 | 90 | 105 | 120 | 135 | 150 | 165 | 180 |
| K=1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| K=2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| K=3 | 0.0 | 0.0 | 0.0 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 |
| K=4 | 0.0 | 0.0 | 0.1 | 0.1 | 0.2 | 0.2 | 0.2 | 0.2 | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 |
| K=5 | 0.0 | 0.1 | 0.1 | 0.2 | 0.3 | 0.3 | 0.3 | 0.3 | 0.2 | 0.1 | 0.1 | 0.0 | 0.0 |
| K=6 | 0.0 | 0.1 | 0.2 | 0.3 | 0.4 | 0.4 | 0.4 | 0.4 | 0.3 | 0.2 | 0.1 | 0.0 | 0.0 |
| K=7 | 0.0 | 0.1 | 0.3 | 0.4 | 0.5 | 0.6 | 0.6 | 0.5 | 0.4 | 0.2 | 0.1 | 0.1 | 0.0 |

| LNG | Counter Rudder |  |  |  |  |  | Wind direction(degree) |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| K | 0 | 15 | 30 | 45 | 60 | 75 | 90 | 105 | 120 | 135 | 150 | 165 | 180 |
| K=1 | 0.0 | 0.1 | 0.2 | 0.3 | 0.5 | 0.7 | 0.8 | 0.9 | 0.8 | 0.7 | 0.5 | 0.3 | 0.0 |
| K=2 | 0.0 | 0.3 | 0.8 | 1.3 | 2.0 | 2.6 | 3.2 | 3.4 | 3.4 | 3.0 | 2.2 | 1.2 | 0.0 |
| K=3 | 0.0 | 0.7 | 1.7 | 2.9 | 4.4 | 5.9 | 7.1 | 7.8 | 7.6 | 6.7 | 4.9 | 2.6 | 0.0 |
| K=4 | 0.0 | 1.3 | 3.0 | 5.2 | 7.8 | 10.5 | 12.6 | 13.8 | 13.6 | 11.9 | 8.8 | 4.7 | 0.0 |
| K=5 | 0.0 | 2.1 | 4.7 | 8.1 | 12.2 | *16.3 | *19.7 | *21.6 | *21.2 | *18.6 | 13.7 | 7.3 | 0.1 |
| K=6 | 0.0 | 3.0 | 6.8 | 11.7 | *17.6 | *23.5 | *28.4 | *31.0 | *30.6 | *26.7 | *19.8 | 10.6 | 0.1 |
| K=7 | 0.0 | 4.1 | 9.2 | *15.9 | *23.9 | *32.0 | *38.7 | *42.2 | *41.6 | *36.4 | *26.9 | 14.4 | 0.1 |
| LNG | Drift angle |  |  |  |  |  | Wind direction(degree) |  |  |  |  |  |  |
| K | 0 | 15 | 30 | 45 | 60 | 75 | 90 | 105 | 120 | 135 | 150 | 165 | 180 |
| K=1 | 0.0 | 0.0 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 |
| K=2 | 0.0 | 0.1 | 0.3 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.3 | 0.2 | 0.1 | 0.1 | 0.0 |
| K=3 | 0.0 | 0.3 | 0.6 | 0.8 | 0.9 | 1.0 | 0.9 | 0.8 | 0.7 | 0.5 | 0.3 | 0.1 | 0.0 |
| K=4 | 0.0 | 0.5 | 1.0 | 1.4 | 1.7 | 1.8 | 1.7 | 1.5 | 1.2 | 0.8 | 0.5 | 0.2 | 0.0 |
| K=5 | 0.0 | 0.8 | 1.6 | 2.2 | 2.6 | 2.7 | 2.6 | 2.3 | 1.8 | 1.3 | 0.8 | 0.4 | 0.0 |
| K=6 | 0.0 | 1.2 | 2.3 | 3.2 | 3.7 | 3.9 | 3.8 | 3.3 | 2.6 | 1.9 | 1.2 | 0.5 | 0.0 |
| K=7 | 0.0 | 1.6 | 3.1 | 4.3 | 5.1 | 5.4 | 5.1 | 4.5 | 3.6 | 2.5 | 1.6 | 0.7 | 0.0 |

* Counter rudder angle is over 15 degrees

| PCC | Counter Rudder | | Wind direction(degree) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| K | 0 | 15 | 30 | 45 | 60 | 75 | 90 | 105 | 120 | 135 | 150 | 165 | 180 |
| K=1 | 0.0 | 0.1 | 0.2 | 0.4 | 0.6 | 0.7 | 0.9 | 1.0 | 1.0 | 0.9 | 0.7 | 0.4 | 0.0 |
| K=2 | 0.0 | 0.4 | 0.9 | 1.5 | 2.2 | 2.9 | 3.5 | 3.9 | 3.9 | 3.5 | 2.6 | 1.4 | 0.0 |
| K=3 | 0.0 | 1.0 | 2.1 | 3.4 | 5.0 | 6.5 | 7.9 | 8.8 | 8.8 | 7.9 | 5.9 | 3.2 | 0.0 |
| K=4 | 0.0 | 1.7 | 3.7 | 6.1 | 8.8 | 11.6 | 14.1 | *15.6 | *15.7 | 14.0 | 10.5 | 5.7 | 0.1 |
| K=5 | 0.0 | 2.7 | 5.7 | 9.5 | 13.8 | *18.2 | *22.0 | *24.4 | *24.5 | *21.8 | *16.5 | 8.9 | 0.1 |
| K=6 | 0.0 | 3.8 | 8.3 | 13.6 | *19.8 | *26.2 | *31.7 | *35.1 | *35.2 | *31.4 | *23.7 | 12.8 | 0.1 |
| K=7 | 0.0 | 5.2 | 11.3 | *18.6 | *27.0 | *35.6 | *43.1 | *47.7 | *47.9 | *42.8 | *32.3 | *17.4 | 0.2 |
| PCC | Drift angle | | Wind direction(degree) | | | | | | | | | | |
| K | 0 | 15 | 30 | 45 | 60 | 75 | 90 | 105 | 120 | 135 | 150 | 165 | 180 |
| K=1 | 0.0 | 0.1 | 0.1 | 0.1 | 0.2 | 0.2 | 0.1 | 0.1 | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 |
| K=2 | 0.0 | 0.2 | 0.4 | 0.5 | 0.6 | 0.6 | 0.6 | 0.5 | 0.4 | 0.3 | 0.2 | 0.1 | 0.0 |
| K=3 | 0.0 | 0.5 | 0.9 | 1.2 | 1.4 | 1.4 | 1.3 | 1.2 | 0.9 | 0.7 | 0.4 | 0.2 | 0.0 |
| K=4 | 0.0 | 0.8 | 1.6 | 2.1 | 2.4 | 2.5 | 2.4 | 2.1 | 1.7 | 1.2 | 0.8 | 0.4 | 0.0 |
| K=5 | 0.0 | 1.3 | 2.4 | 3.3 | 3.8 | 4.0 | 3.7 | 3.3 | 2.6 | 1.9 | 1.2 | 0.6 | 0.0 |
| K=6 | 0.0 | 1.9 | 3.5 | 4.8 | 5.5 | 5.7 | 5.4 | 4.7 | 3.8 | 2.7 | 1.8 | 0.8 | 0.0 |
| K=7 | 0.0 | 2.5 | 4.8 | 6.5 | 7.5 | 7.8 | 7.3 | 6.4 | 5.1 | 3.7 | 2.4 | 1.2 | 0.0 |

* Counter rudder angle is over 15 degrees

### ② Calculation of drift angle due to current effect

The drift angle due to current effect can be calculated by the following formula with ship speed and cross current velocity.

$$\beta 2 = \mathrm{Arctan}\,(Vc / V)$$

$\beta 2$ : Drift angle due to current effect

Vc : Cross current velocity V : Ship speed

### ③ Calculation of drift angle due to wind and current effect

The total drift angle due to wind and current effect can be calculated by the following formula.

$$\beta = \beta 1 + \beta 2$$

$$W(\beta) = Loa \cdot \sin\beta + B \cdot \cos\beta$$

$W(\beta)$ : Drift due to wind and current

Loa : Length over all of design ship

B : Breadth of design ship $\beta$ : Drift angle due to wind and current effect

### ④ Calculation for drift sideway due to ship yaw

The drift sideway due to ship yaw can be calculated by the following formula.

$$W(y) = V \int \sin\psi(t)dt \qquad (t = 0 \sim Ty/4)$$

$$= VTy \cdot \sin\psi_0 / 4$$

$W(y)$ : Drift sideway due to ship yaw

V : Ship speed

Ty : Yawing period

$\psi_0$ : Max yawing angle

$\psi(t)$ : Yawing at time of (t) $= \psi 0 \cdot \sin(2\pi t / T)$

⑤ Calculation of necessary basic manoeuvring lane against the effect of wind, current and etc.

$$Wm(\beta,y) = W(\beta)+W(y)$$

$$= Loa \cdot \sin\beta + B \cdot \cos\beta + VTy \cdot \sin\psi_0/2$$

$Wm(\beta,y)$ : Manoeuvring lane against the effect of wind, current and etc.

$W(\beta)$ : Drift due to wind and current

$W(y)$ : Drift sideway due to ship yaw
$Loa$ : Length over all of design ship
$B$ : Breadth of design ship

$\beta$ : $\beta 1+\beta 2$

$\beta 1$ : Drift angle due to wind effect

$\beta 2$ : Drift angle due to current effect

$V$ : Ship speed
$Ty$ : Yawing period

$\psi_0$ : Max yawing angle

3) $Wm(\alpha)$ (Manoeuvring lane for detection of drift) can be calculated by the following formula.

3-1) Basic idea for calculation

Ship handlers intend to keep ship on the planed course line except when in emergency, but sometimes a ship drifts away from the course line due to various reasons. In such a case, the drift that makes ship handlers detect off course is defined as [manoeuvring lane for detection of drift].

Well-experienced ship handlers in defined water can handle and navigate ships observing land mark, but generally the following method to detect the drift of ship are adopted.

Fixing position by observing sidewalls like canal
Fixing position by observing leading post or leading light
Fixing position by observing structure such as breakwater
Fixing position by observing light buoys on both sides of fairway
Fixing position by RADAR, GPS

Here, the lane for detection of drift shall be calculated by the method of fixing position by light buoys on both sides of fairway.

3-2) Practical calculation method and formula to be used

① Calculation for lane (unit of angle : degree)

The lane for detection of drift can be calculated by the following formula.

$$\theta = 2\,\mathrm{Arctan}\,(Wbuoy / (2 \cdot LF))$$

$\alpha r \quad = 0.00044 \cdot \theta^2 + 0.0002 \cdot \theta + 0.55343$

$\alpha\mathrm{max} \quad = 4\alpha r$

$\mathrm{Wm}(\alpha) \quad = \mathrm{LF} \cdot \tan(\alpha\mathrm{max})$ (Formula by West Japan port operation study group)

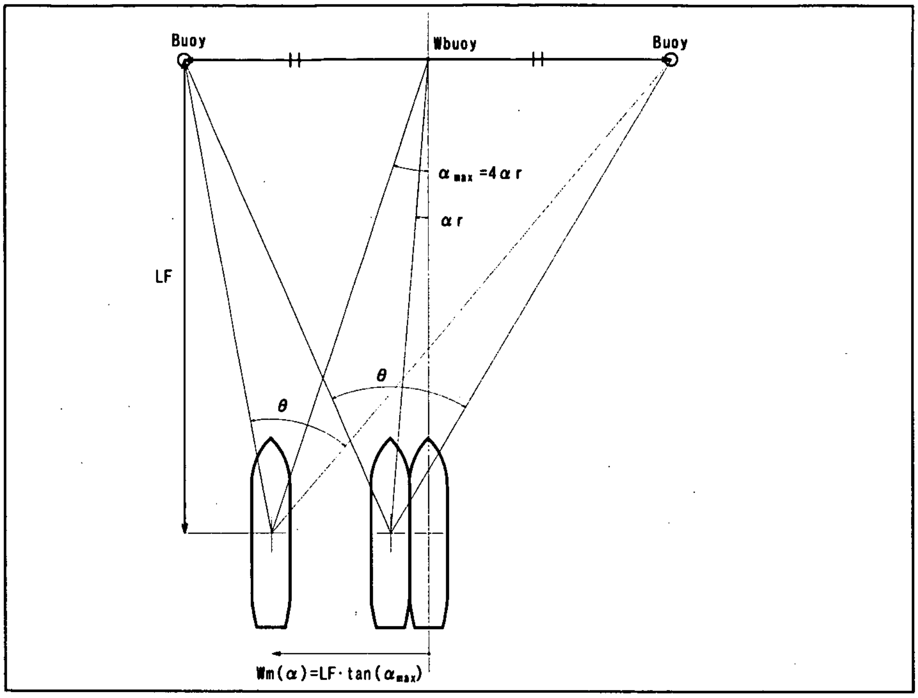


Figure 3-6 Manoeuvring lane for detection of drift

$\theta$ : Angle between ship and two buoys on both sides

Wbuoy : Clearance between two buoys forward

LF : Distance from the ship to light buoy forward

$\mathrm{Wm}(\alpha)$ : Basic lane for detection of drift

Ar : Observation error of middle point $=0.00044 \cdot \theta^2 + 0.0002 \cdot \theta + 0.55343$

$\alpha\mathrm{max}$ : Max observation error of center point (Max error that ship handlers of 99.8% can recognize the drift)

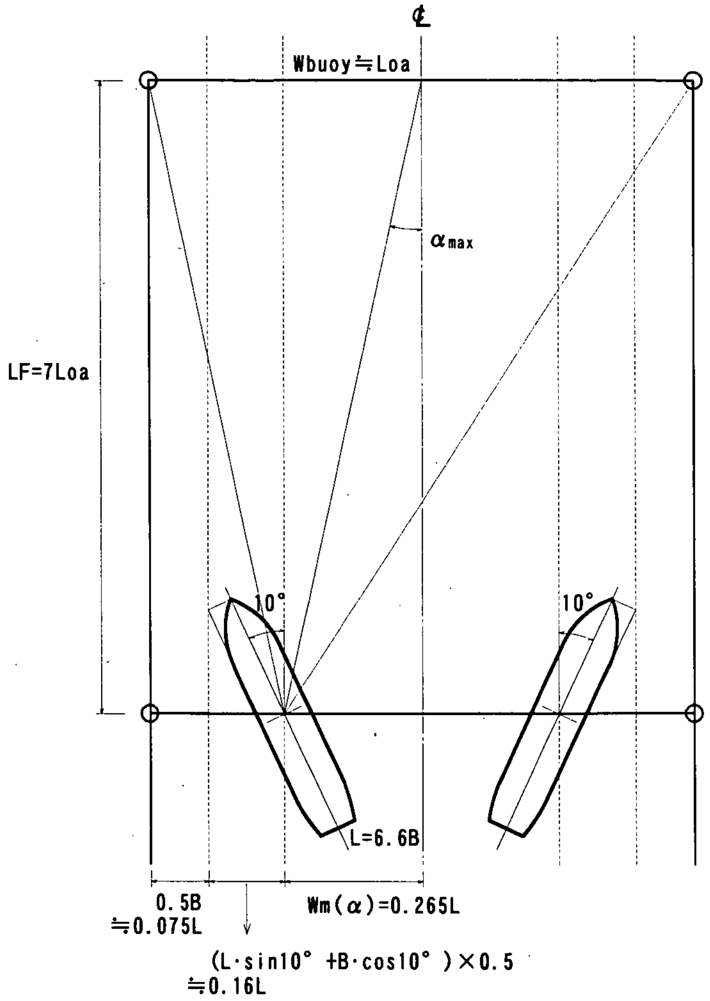
- Formula by West Japan port operation study group: West Japan port operation study group, Fairway design study (Decision method for the width of long fairways) , 1977

### ② Set up of distance between buoy and ship (LF)

LF can be set up as follows, based on the idea shown in Figure 3-7, according to the present standard ( Wbuoy ≒Loa)

Here, in case of two-way fairway, two ships navigate in one-way fairway respectively and meet at middle point shown in Figure 3-8.
In case of the existing fairway, the distance between buoys along the fairway should be used.

| | |
|---|---|
| One-way waterway | LF = 7Loa |
| Two-way waterway | LF = 3.5Loa |



Breadth of one way fairway≒Loa

Wm( $\alpha$)=(0.5-0.075-0.016)L=0.265L

→ $\alpha$ max opposite calculation

→ $\alpha$ opposite calculation

→ $\theta$ opposite calculation

→LF≒7Loa

*Drift angle was set as 10 degrees that is allowed for mariners

Figure 3-7 Idea for LF ≒Loa

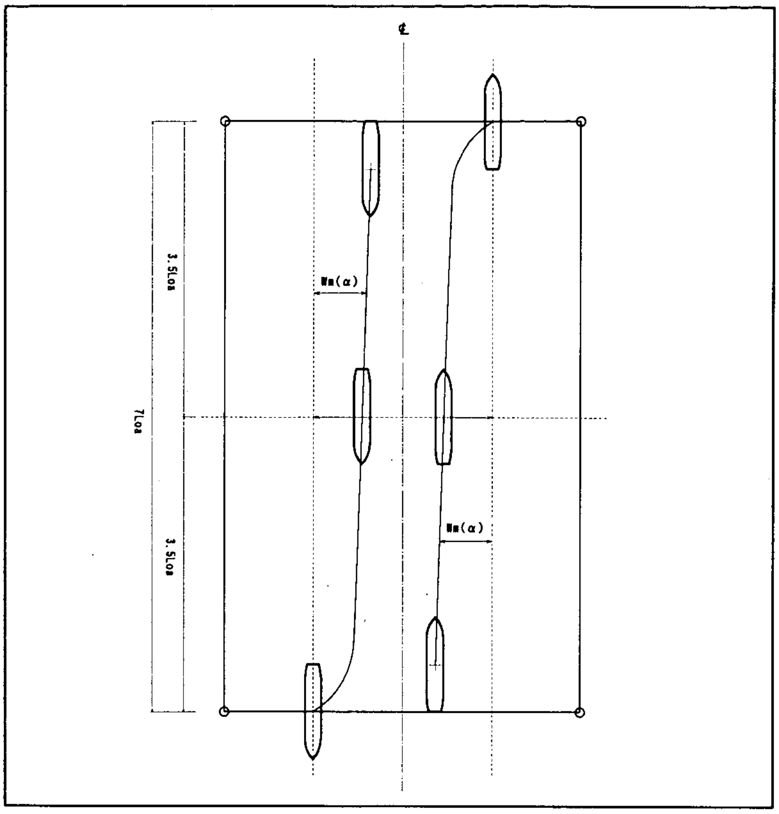


Figure 3-8 Idea of meeting

4) Wmi （Basic manouevring lane） can be calculated by the following formula.

Max. basic manoeuvring lane for one side can be calculated by the following formula.

$0.5 \cdot \mathrm{Wmi} = \mathrm{Wm}(\alpha) + 0.5 \cdot \mathrm{Wm}(\beta, y)$

Therefore the basic manoeuvring lane can be calculated as follows.

$\mathrm{Wmi} = 2 \cdot \mathrm{Wm}(\alpha) + \mathrm{Wm}(\beta, y)$

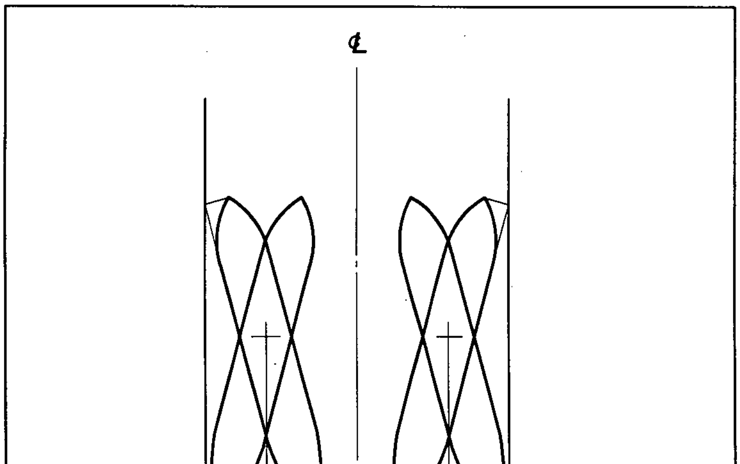


Figure3-9 Idea for basic manoeuvring lane

5) Wbi（Bank clearance）can be calculated by the following procedure

5-1) Basic idea for calculation

Counter rudder angle for bank suction effect is limited to max 5 degrees. Bank clearance is calculated as the distance from wall to absorb bank suction effect using the limited amount (Max 5 degrees) of rudder angle.

5-2) Practical calculation method and formula used

① Calculation of the bank clearance in case of straight bank wall

a : Set up of ship particulars, ship speed , natural condition and etc.
b : Calculation of thrust and moment acting on ship hull due to the bank suction effect of straight bank wall
c : Calculation of counter rudder angle according to the equation of ship motion
d : Repeat calculations to obtain the counter ruder of 5-degrees to absorb bank suction effect

Wbi0 : Repeat calculation of bank clearance to require 5-degrees counter rudder against bank suction effect

② Correction based on the shape of bank wall and the ratio of water depth and ship draft

a : Calculation of correction coefficient based on the ratio of depth of fairway and depth of outer water. (In case of sloping bank wall, coefficient of straight bank wall shall be applied) (Pro Kijima Figure-1)
b : Calculation of bank clearance depending on the shape of cross section of fairway and the ratio of depth of fairway and depth of outer water, that is calculated by applying correction coefficient based on straight bank wall.

$$Wbi = Wbi0 \times h1$$

$$hf = \exp(-2(h1/(1-h1))$$

Wbi : Bank clearance in case of the designed cross-section geometry of fairway and depth /draft ratio
Wbi0 : Bank clearance required allowable counter rudder of 5 degrees in case of steep wall
h1 : Correction ratio for the cross-section geometry of fairway
hf : Correction ratio for the cross-section geometry of fairway

Figure of Dr. Kijima: Kijima, Qing: Manoeuvrung Motion of a Ship in the Proximity of Bank Wall(Fig.4) Journal of The Society of Naval Architects of Japan No.162, 1987
Formula of Dr. Kijima: Kijima, Nonaka: Ship's manoeuvrability in restricted water, The Society of Naval Architects of Japan 3rd Manoeuvrability of ship Symposium, 1981

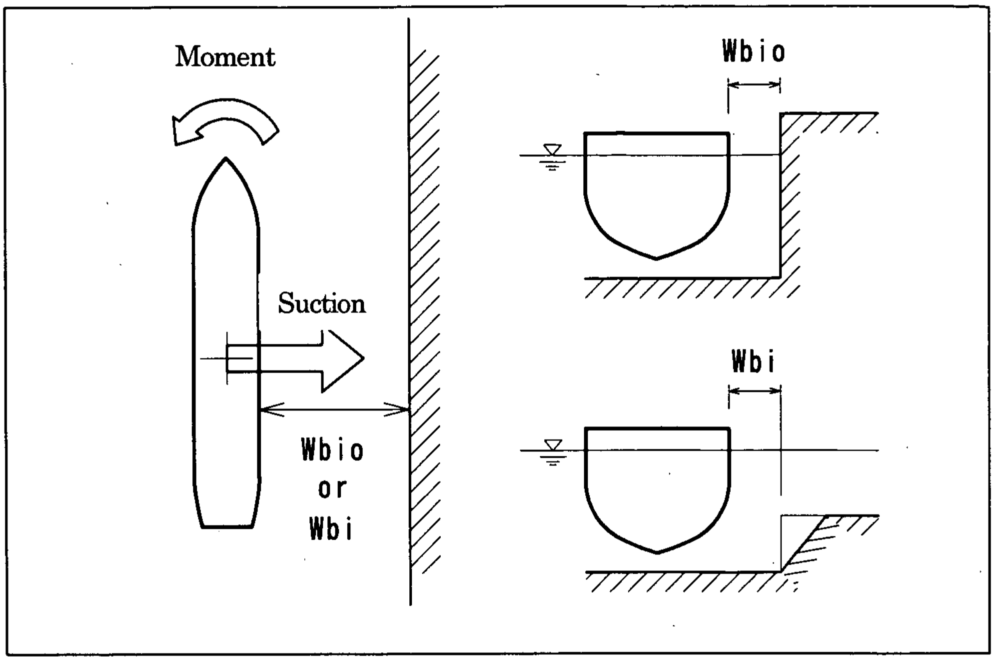
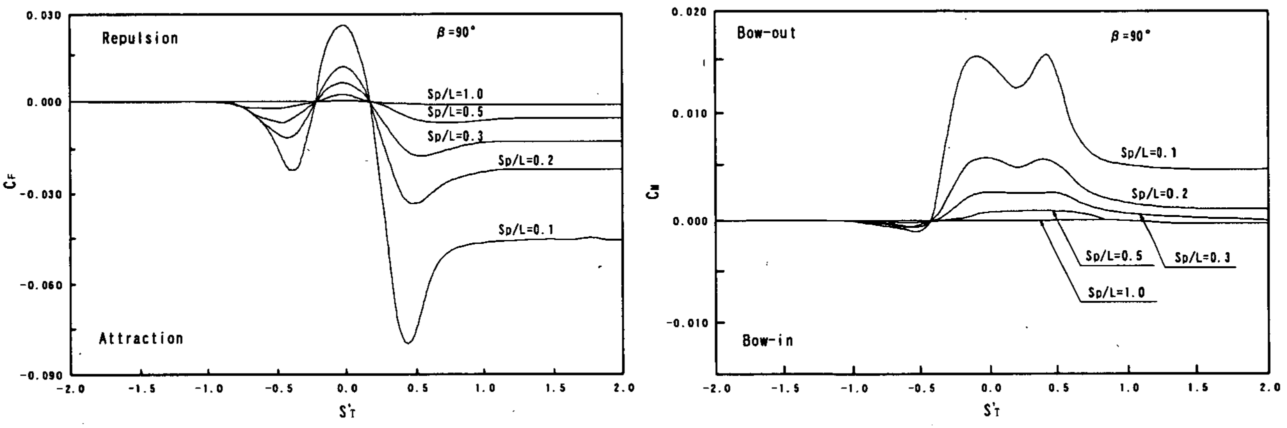


Figure 3-10 Idea for bank clearance



(a) (b)

The effect of Sp on lateral force and yaw moment acting on a ship in the proximity of bank wall with wedge angle $\beta$=90°

Fig.3-11 Ship manoeuvring navigating along wall (Dr. Kijima Figure-1)

The calculation result of bank clearance for ships shown in Table 3-2 is shown in Table 3-4.

This table can be used to obtain rough Wbi0 (Bank clearance required allowable counter rudder angle of 5 degrees in case of straight wall) . This value is free from ship speed.

Table 3-4 Wbi0

(Bank clearance required allowable counter rudder angle of 5 degrees in case of straight wall) (D/d=1.2)

| | LNG | CTNR | TANKER (Full load) | TANKER (Ballast) | BULKER | PCC |
|---|---|---|---|---|---|---|
| Wbi0 | 0.93B | 1.52B | 0.58B | 0.67B | 1.01B | 0.63B |

6) Wc (Width for passing distance) can be calculated by the following formula.

6-1) Basic idea for calculation

Max counter rudder for passing distance is assumed as 5 degrees. The width is calculated as the distance to absorb the effect of meeting ships with 5-degrees counter rudder angle.

6-2) Practical calculation method and used formula

a : Set up of the particulars of passing ships and ship speed
b : Calculation of side thrust and moment underway in the fairway
c : Calculation of counter rudder angle according to the equation of ship motion
d : Repeat calculations to obtain counter ruder of 5-degrees to absorb the suction effect due to meeting ships

The ship proceeds obliquely against the centerline of fairway shown in Figure 3-12, but in this case, dangerous condition drawn with dotted line is taken into consideration.

- Figure of Dr. Kijima: Kijima, Yasukawa Manoeuvrability of Ships in Narrow Waterway, Journal of The Society of Naval Architects of Japan (Fig.2,3) No.156, 1984

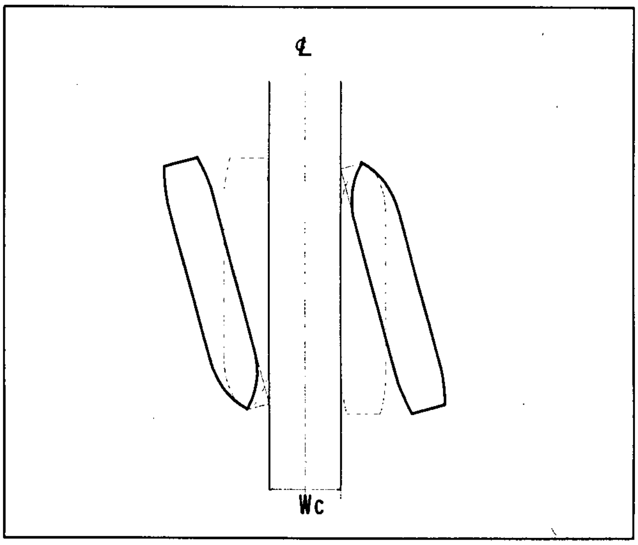
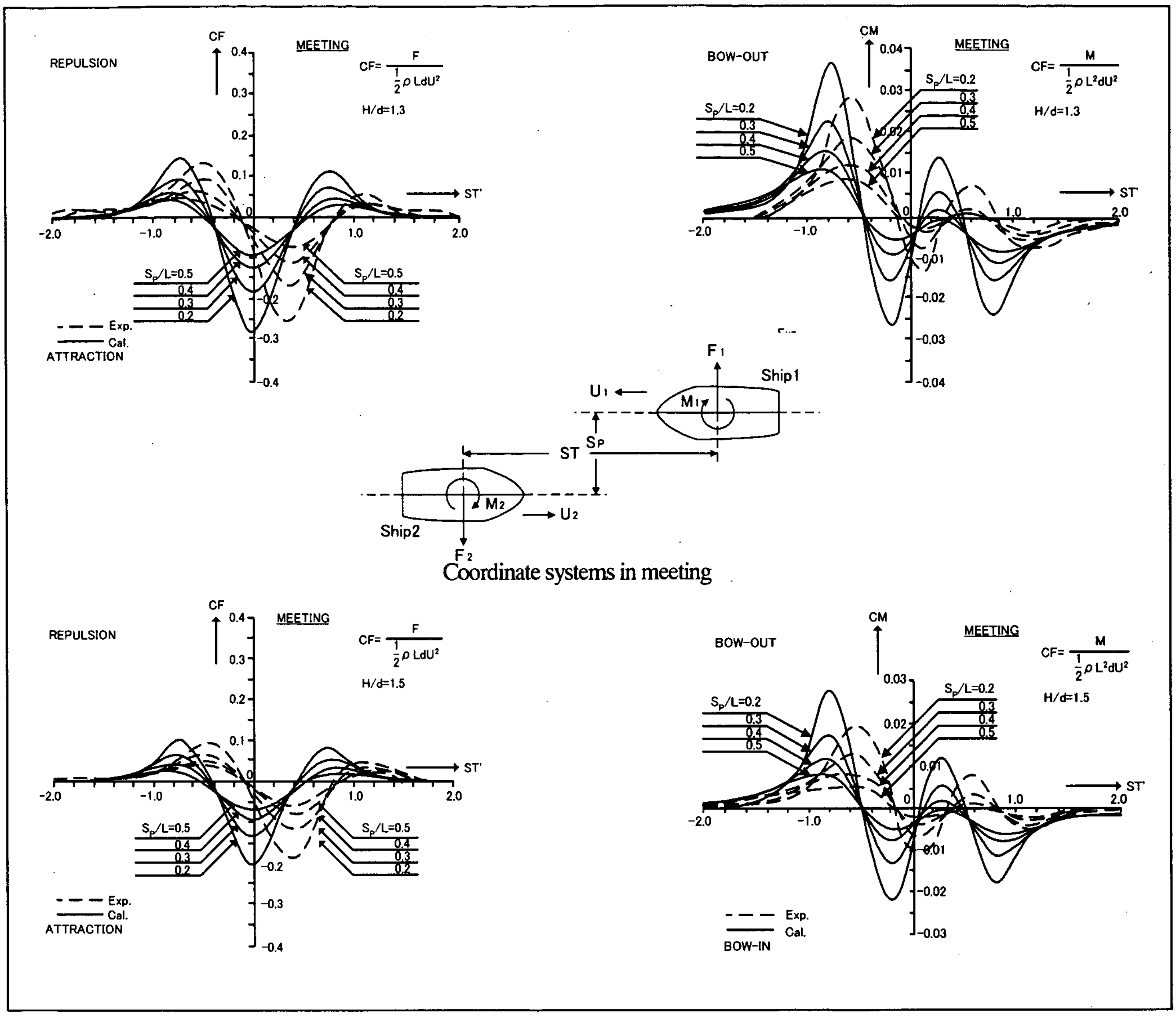


Figure 3-12 Idea of passing distance



Coordinate systems in meeting

Figure 3-13 Lateral force and yaw moment acting on ship 1 in meeting（Kijima-2）

The calculation result of meeting distance for ships shown in Table 3-2 is shown in Table 3-5. This table can be used to obtain rough Wc (Passing distance). This value is free from ship speed.

Table 3-5　Wc（Passing distance）（D/d＝1.3）

| | LNG | CTNR | TANKER<br>(Full load) | TANKER<br>(Ballast) | BULKER | PCC |
|---|---|---|---|---|---|---|
| Wc | 0.96B | 1.95B | 0.67B | 0.77B | 1.27B | 0.71B |

7) Repeat calculation for basic manoeuvring lane

On calculation of Wmi (basic manoeuvring lane) that is the basic element for calculation of W (Width of fairway) ,Wbuoy (distance between buoys forward) is used for initial value. Therefore, it is necessary to carry out repeat calculation until initial value of Wbuoy reaches to the same value of W (Width of fairway) that is calculated by the following formula.

- One-way fairway $W = Wm0 + Wb1 + Wb2$
- Two-way fairway $W = Wm1 + Wm2 + Wc + Wb1 + Wb2$

Here, in case of existing fairway the distance between buoys forward is set as initial value and repeat calculation is carried out. It is understood that the existing width of fairway is reasonable if calculate result is smaller than the distance between buoys. On the contrary, it is desirable to study again operation criteria and the width of fairway if calculate result is bigger than the distance between buoys

W : Width of fairway
Wm0 : Basic manouevring lane for one-way fairway
Wb1, Wb2 : Bank clearance (Necessary lane against bank suction)
(Each basic manoeuvring lane when two ships meet)
Wm1, Wm2 : Basic manoeuvring lane for two-way fairway (in case of meeting)
Wc : Passing distance (necessary lane for passing ship each other)

$\beta 1$ : Drift angle due to wind effect

$\beta 2$ : Drift angle due to current effect

Vc : Cross current velocity
V : Ship speed

W($\beta$) : Drift due to the effect of wind, current and etc.

Loa : Length over all of design ship
B : Breadth of design ship

$\beta$ : Drift due to wind and current

$\beta$ : $\beta 1 + \beta 2$

$\beta 1$ : Drift angle due to wind effect

$\beta 2$ : Drift angle due to current effect

$\Theta$w : Wind angle between bow and wind direction

Ax : Transverse wind area
Ay : Longitudinal wind area
XG : Distance between F.P. and center of wind area

Rx : Longitudinal wind force
Ry : Lateral wind force
Na : Wind force moment
U : Wind velocity

$\rho$ : Density of air

W(y) : Drift sideway due to ship yaw
Ty : Yawing period

$\psi 0$ : Max yawing angle

$\psi(t)$ : Yawing at time of $(t)=\psi 0\cdot\sin(2\pi t/T)$

Wm($\beta$,y): Manoeuvring lane against wind and current effect

Wm($\alpha$) : Manoeuvring lane for detection of drift

$\theta$ : Angle between ship and two buoys on both sides

Wbuoy : Clearance between two buoys forward

Ar : Observation error of middle point$=0.00044\cdot\theta 2+0.0002\cdot\theta+0.55343$

Amax : Observation error of center point（Max error that ship handlers of 99.8%）

LF : Distance from the ship to light buoy forward
Wbi0 : Bank clearance to require d allowable 5-degrees counter rudder in case of steep wall
Wbi : Bank clearance in case of the designed cross-section geometry of fairway and depth/draft ratio

h1 : Depth ratio ( = Depth of outside of fairway／Depth of fairway, Cannel:0, No wall : 1 )

Hf : Correction ratio for the cross-section geometry of fairway

# Calculation Example 3-1 ( CTNR ship, Under severe navigation conditions)

| | | | |
|---|---|---|---|
| ******** One-way fairway ******** | | | |
| <<ship condition >> | | A: Basic manoeuvring lane for one-way fairway | |
| Kind of ship Large CTNR ship | | 1.Manoeuvring lane for detection of drift | 0.59 |
| Loa: ship length(m) | 288.0 | αr: Observation error of middle point(degree) | 4.0 |
| B: ship breadth(m) | 32.2 | k: Correction ratio | 2.36 |
| V: ship speed (knot) | 7.5 | αmax: Max observation error of center point(degre | 83.1 |
| V: ship speed (m/s) | 3.9 | Manoeuvring lane for detection of drift(m) | |
| | | | |
| << Natural condition>> | | 2.Drift due to wind and current | |
| Wind velocity (m/s) | 15.0 | Drift angle due to wind effect(degree) | 0.6 |
| Cross current (knot) | 0.5 | Drift angle due to current effect(degree) | 3.8 |
| | | Drift angle due to wind and current effect(degree) | 4.4 |
| | | Drift due to wind and current(m) | 27.1 |
| << Fairway condition>> | | | |
| W: Width of fairway (m) | 315 | 3.Drift sideway due to ship yaw | |
| a: Manoeuvring lane for detection of drift (m) | 2016 | Max yawing angle(degree) | 4 |
| (Distance between buoy and ship in terms of Loa) | 7.0 | Ty:Yawing period(second) | 120 |
| θ:Angle between ship and two buoys on both sides | 8.93 | W(y):Drift sideway due to ship yaw(m) | 8.1 |
| | | | |
| | | Half manoeuvring lane for one-way fairway | 118 |
| | | Basic manoeuvring lane for one-way fairway | 237 |
| | | | |
| **** Width of one-way fairway(m) **** | | B: Bank clearance | |
| Basic manoeuvring lane + ( Bank clearance)*2 | 315.0 | e: Coefficient for bank clearance | 1.52 |
| In terms of Loa | 1.1 | h1: Correction ratio (Cannel: 0,No wall: 0.999) | 0.10 |
| In terms of B | 9.8 | Correction coefficient | 0.80 |
| | | Bank clearance = e x correction coefficient x B(m | 39.2 |

| | | | |
|---|---|---|---|
| ******** Two-way fairway ******** | | | |
| <<ship condition >> | | A: Basic manoeuvring lane for one-way fairway | |
| Kind of ship Large CTNR ship | | 1.Manoeuvring lane for detection of drift | 0.59 |
| Loa: ship length(m) | 288.0 | αr: Observation error of middle point(degree) | 4.0 |
| B: ship breadth(m) | 32.2 | k: Correction ratio | 2.36 |
| V: ship speed (knot) | 7.5 | αmax: Max observation error of center point(degre | 83.1 |
| V: ship speed (m/s) | 3.9 | Manoeuvring lane for detection of drift(m) | |
| | | | |
| << Natural condition>> | | 2.Drift due to wind and current | |
| Wind velocity (m/s) | 15.0 | Drift angle due to wind effect(degree) | 0.6 |
| Cross current (knot) | 0.5 | Drift angle due to current effect(degree) | 3.8 |
| | | Drift angle due to wind and current effect(degree) | 4.4 |
| | | Drift due to wind and current(m) | 27.1 |
| << Fairway condition>> | | | |
| W: Width of fairway (m) | 559 | 3.Drift sideway due to ship yaw | |
| a: Manoeuvring lane for detection of drift (m) | 1008 | Max yawing angle(degree) | 4 |
| (Distance between buoy and ship in terms of Loa) | 3.5 | Ty:Yawing period(second) | 120 |
| θ:Angle between ship and two buoys on both sides | 31.00 | W(y):Drift sideway due to ship yaw(m) | 8.1 |
| | | | |
| | | Half manoeuvring lane for one-way fairway | 118 |
| | | Basic manoeuvring lane for one-way fairway | 237 |
| | | | |
| **** Width of two-way frairway (m) **** | | B: Bank clearance | |
| Basic manoeuvring lane + ( Bank clearance)*2 | 559.0 | e: Coefficient for bank clearance | 1.52 |
| In terms of Loa | 1.9 | h1: Correction ratio (Cannel: 0,No wall: 0.999) | 0.10 |
| In terms of B | 17.4 | Correction coefficient | 0.80 |
| | | Bank clearance = e x correction coefficient x B(m | 39.2 |
| | | | |
| | | C: Passing distance for two-way fairway | |
| | | f: Rasio for passing distance | 1.95 |
| | | Passing distance = f x B | 62.8 |

# Calculation Example 3-2 ( CTNR ship, Under fair navigation conditions)

| ******** One-way fairway ******** | | | |
|---|---|---|---|
| <<ship condition >> | | A: Basic manoeuvring lane for one-way fairway | |
| Kind of ship Large CTNR ship | | 1.Manoeuvring lane for detection of drift | 0.57 |
| Loa: ship length(m) | 288.0 | αr: Observation error of middle point(degree) | 4.0 |
| B: ship breadth(m) | 32.2 | k: Correction ratio | 2.28 |
| V: ship speed (knot) | 5.0 | αmax: Max observation error of center point(degre | 57.3 |
| V: ship speed (m/s) | 2.6 | Manoeuvring lane for detection of drift(m) | |
| | | | |
| << Natural condition>> | | 2.Drift due to wind and current | |
| Wind velocity (m/s) | 0.0 | Drift angle due to wind effect(degree) | 0.0 |
| Cross current (knot) | 0.0 | Drift angle due to current effect(degree) | 0.0 |
| | | Drift angle due to wind and current effect(degree) | 0.0 |
| | | Drift due to wind and current(m) | 16.1 |
| << Fairway condition>> | | | |
| W: Width of fairway (m) | 147 | 3.Drift sideway due to ship yaw | |
| a: Manoeuvring lane for detection of drift (m) | 1440 | Max yawing angle(degree) | 0.0 |
| (Distance between buoy and ship in terms of Loa) | 5.0 | Ty:Yawing period(second) | 120 |
| θ:Angle between ship and two buoys on both sides | 5.84 | W(y):Drift sideway due to ship yaw(m) | 0.0 |
| | | | |
| | | Half manoeuvring lane for one-way fairway | 73 |
| | | Basic manoeuvring lane for one-way fairway | 147 |
| | | | |
| **** Width of one-way fairway(m) **** | | B: Bank clearance | |
| Basic manoeuvring lane + ( Bank clearance)*2 | 147.0 | e: Coefficient for bank clearance | 1.45 |
| In terms of Loa | 0.5 | h1: Correction ratio (Cannel: 0,No wall: 0.999) | 0.99 |
| In terms of B | 4.6 | Correction coefficient | 0.00 |
| | | Bank clearance = e x correction coefficient x B(m | 0.00 |

| ******** Two-way fairway ******** | | | |
|---|---|---|---|
| <<ship condition >> | | A: Basic manoeuvring lane for one-way fairway | |
| Kind of ship Large CTNR ship | | 1.Manoeuvring lane for detection of drift | 0.73 |
| Loa: ship length(m) | 288.0 | αr: Observation error of middle point(degree) | 4.0 |
| B: ship breadth(m) | 32.2 | k: Correction ratio | 2.93 |
| V: ship speed (knot) | 5.0 | αmax: Max observation error of center point(degre | 44.2 |
| V: ship speed (m/s) | 2.6 | Manoeuvring lane for detection of drift(m) | |
| | | | |
| << Natural condition>> | | 2.Drift due to wind and current | |
| Wind velocity (m/s) | 0.0 | Drift angle due to wind effect(degree) | 0.0 |
| Cross current (knot) | 0.0 | Drift angle due to current effect(degree) | 0.0 |
| | | Drift angle due to wind and current effect(degree) | 0.0 |
| | | Drift due to wind and current(m) | 16.1 |
| << Fairway condition>> | | | |
| W: Width of fairway (m) | 304 | 3.Drift sideway due to ship yaw | |
| a: Manoeuvring lane for detection of drift (m) | 864 | Max yawing angle(degree) | 0.0 |
| (Distance between buoy and ship in terms of Loa) | 3.0 | Ty:Yawing period(second) | 120 |
| θ:Angle between ship and two buoys on both sides | 19.96 | W(y):Drift sideway due to ship yaw(m) | 0.0 |
| | | | |
| | | Half manoeuvring lane for one-way fairway | 60 |
| | | Basic manoeuvring lane for one-way fairway | 121 |
| | | | |
| **** Width of two-way frairway (m)**** | | B: Bank clearance | |
| Basic manoeuvring lane + ( Bank clearance)*2 | 304.0 | e: Coefficient for bank clearance | 1.52 |
| In terms of Loa | 1.1 | h1: Correction ratio (Cannel: 0,No wall: 0.999) | 0.99 |
| In terms of B | 9.4 | Correction coefficient | 0.00 |
| | | Bank clearance = e x correction coefficient x B(m | 0.0 |
| | | | |
| | | C: Passing distance for two-way fairway | |
| | | f: Rasio for passing distance | 1.95 |
| | | Passing distance = f x B | 62.8 |

# Calculation example 4-1 (TANKER: Full load, Under severe navigation conditions)

| ******** One-way fairway ******** | |
|---|---|
| <<ship condition >> | |
| Kind of ship VLCC | |
| Loa: ship length(m) | 333.0 |
| B: ship breadth(m) | 60.0 |
| V: ship speed (knot) | 7.5 |
| V: ship speed (m/s) | 3.9 |
| | |
| << Natural condition>> | |
| Wind velocity (m/s) | 15.0 |
| Cross current (knot) | 0.5 |
| | |
| << Fairway condition>> | |
| W: Width of fairway (m) | 346 |
| a: Manoeuvring lane for detection of drift (m) | 2331 |
| (Distance between buoy and ship in terms of Loa) | 7.0 |
| θ:Angle between ship and two buoys on both sides | 8.49 |
| | |
| **** Width of one-way fairway (m) **** | |
| Basic manoeuvring lane + ( Bank clearance)*2 | 346.0 |
| *in terms of Loa* | 1.0 |
| in terms of B | 5.8 |

| | |
|---|---|
| *A: Basic manoeuvring lane for one-way fairway* | |
| 1.Manoeuvring lane for detection of drift | 0.59 |
| αr: Observation error of middle point(degree) | 4.0 |
| k: Correction ratio | 2.35 |
| αmax: Max observation error of center point(degre | 95.6 |
| Manoeuvring lane for detection of drift(m) | |
| | |
| 2.Drift due to wind and current | |
| Drift angle due to wind effect(degree) | 0.2 |
| Drift angle due to current effect(degree) | 3.8 |
| Drift angle due to wind and current effect(degree) | 4 |
| Drift due to wind and current(m) | 41.6 |
| | |
| 3.Drift sideway due to ship yaw | |
| Max yawing angle(degree) | 4 |
| Ty:Yawing period(second) | 120 |
| W(y):Drift sideway due to ship yaw(m) | 8.1 |
| | |
| Half manoeuvring lane for one-way fairway | 145 |
| Basic manoeuvring lane for one-way fairway | 290 |
| | |
| B: Bank clearance | |
| e: Coefficient for bank clearance | 0.58 |
| h1: Correction ratio (Cannel: 0,No wall: 0.999) | 0.10 |
| Correction coefficient | 0.80 |
| Bank clearance = e x correction coefficient x B(m | 27.9 |

| ******** Two-way fairway ******** | |
|---|---|
| <<ship condition >> | |
| Kind of ship VLCC | |
| Loa: ship length(m) | 333.0 |
| B: ship breadth(m) | 60.0 |
| V: ship speed (knot) | 7.5 |
| V: ship speed (m/s) | 3.9 |
| | |
| << Natural condition>> | |
| *Wind velocity (m/s)* | 15.0 |
| Cross current (knot) | 0.5 |
| | |
| << Fairway condition>> | |
| W: Width of fairway (m) | 594 |
| a: Manoeuvring lane for detection of drift (m) | 1166 |
| *(Distance between buoy and ship in terms of Loa)* | 3.5 |
| θ:Angle between ship and two buoys on both sides | 28.59 |
| | |
| **** Width of two-way fairway (m) **** | |
| Basic manoeuvring lane + ( Bank clearance)*2 | 594.0 |
| In terms of Loa | 1.8 |
| In terms of B | 9.9 |

| | |
|---|---|
| A: Basic manoeuvring lane for one-way fairway | |
| 1.Manoeuvring lane for detection of drift | 0.92 |
| αr: Observation error of middle point(degree) | 4.0 |
| k: Correction ratio | 3.68 |
| αmax: Max observation error of center point(degre | 74.9 |
| Manoeuvring lane for detection of drift(m) | |
| | |
| 2.Drift due to wind and current | |
| Drift angle due to wind effect(degree) | 0.2 |
| Drift angle due to current effect(degree) | 3.8 |
| Drift angle due to wind and current effect(degree) | 4 |
| Drift due to wind and current(m) | 41.6 |
| | |
| 3.Drift sideway due to ship yaw | |
| Max yawing angle(degree) | 4 |
| Ty:Yawing *period(second)* | 120 |
| W(y):Drift sideway due to ship yaw(m) | 8.1 |
| | |
| Half manoeuvring lane for one-way fairway | 125 |
| Basic manoeuvring lane for one-way fairway | 249 |
| | |
| B: Bank clearance | |
| *e: Coefficient for bank clearance* | 0.58 |
| h1: Correction ratio (Cannel: 0,No wall: 0.999) | 0.10 |
| Correction coefficient | 0.80 |
| Bank clearance = e x correction coefficient x B(m | 27.9 |
| | |
| C: Passing distance for two-way fairway | |
| f: Rasio for passing distance | 0.97 |
| *Passing distance = f x B* | 40.2 |

# Calculation example 4-2 (TANKER: Full load, Under fair navigation conditions)

| | | | |
|---|---|---|---|
| ******** One-way fairway ******** | | | |
| <<ship condition >> | | A: Basic manoeuvring lane for one-way fairway | |
| Kind of ship VLCC | | 1.Manoeuvring lane for detection of drift | 0.59 |
| Loa: ship length(m) | 333.0 | αr: Observation error of middle point(degree) | 4.0 |
| B: ship breadth(m) | 60.0 | k: Correction ratio | 2.35 |
| V: ship speed (knot) | 5.0 | αmax: Max observation error of center point(degre | 68.4 |
| V: ship speed (m/s) | 2.6 | Manoeuvring lane for detection of drift(m) | |
| | | | |
| << Natural condition>> | | 2.Drift due to wind and current | |
| Wind velocity (m/s) | 0.0 | Drift angle due to wind effect(degree) | 0.0 |
| Cross current (knot) | 0.0 | Drift angle due to current effect(degree) | 0.0 |
| | | Drift angle due to wind and current effect(degree) | 0.0 |
| | | Drift due to wind and current(m) | 30.0 |
| << Fairway condition>> | | | |
| W: Width of fairway (m) | 253 | 3.Drift sideway due to ship yaw | |
| a: Manoeuvring lane for detection of drift (m) | 1665 | Max yawing angle(degree) | 0 |
| (Distance between buoy and ship in terms of Loa) | 5.0 | Ty:Yawing period(second) | 120 |
| θ:Angle between ship and two buoys on both sides | 8.69 | W(y):Drift sideway due to ship yaw(m) | 0.0 |
| | | | |
| | | Half manoeuvring lane for one-way fairway | 98 |
| | | Basic manoeuvring lane for one-way fairway | 197 |
| | | | |
| **** Width of one-way fairway (m) **** | | B: Bank clearance | |
| Basic manoeuvring lane + ( Bank clearance)*2 | 253.0 | e: Coefficient for bank clearance | 0.58 |
| in terms of Loa | 0.8 | h1: Correction ratio (Cannel: 0,No wall: 0.999) | 0.10 |
| in terms of B | 4.2 | Correction coefficient | 0.80 |
| | | Bank clearance = e x correction coefficient x B(m | 27.9 |

| | | | |
|---|---|---|---|
| ******** Two-way fairway ******** | | | |
| <<ship condition >> | | A: Basic manoeuvring lane for one-way fairway | |
| Kind of ship VLCC | | 1.Manoeuvring lane for detection of drift | 0.75 |
| Loa: ship length(m) | 333.0 | αr: Observation error of middle point(degree) | 4.0 |
| B: ship breadth(m) | 60.0 | k: Correction ratio | 3.01 |
| V: ship speed (knot) | 5.0 | αmax: Max observation error of center point(degre | 52.4 |
| V: ship speed (m/s) | 2.6 | Manoeuvring lane for detection of drift(m) | |
| | | | |
| << Natural condition>> | | 2.Drift due to wind and current | |
| Wind velocity (m/s) | 0.0 | Drift angle due to wind effect(degree) | 0.0 |
| Cross current (knot) | 0.0 | Drift angle due to current effect(degree) | 0.0 |
| | | Drift angle due to wind and current effect(degree) | 0 |
| | | Drift due to wind and current(m) | 30.0 |
| << Fairway condition>> | | | |
| W: Width of fairway (m) | 370 | 3.Drift sideway due to ship yaw | |
| a: Manoeuvring lane for detection of drift (m) | 999 | Max yawing angle(degree) | 0.0 |
| (Distance between buoy and ship in terms of Loa) | 3.0 | Ty:Yawing period(second) | 120 |
| θ:Angle between ship and two buoys on both sides | 20.98 | W(y):Drift sideway due to ship yaw(m) | 0.0 |
| | | | |
| | | Half manoeuvring lane for one-way fairway | 82 |
| | | Basic manoeuvring lane for one-way fairway | 165 |
| | | | |
| **** Width of two-way fairway (m) **** | | B: Bank clearance | |
| Basic manoeuvring lane + ( Bank clearance)*2 | 370.0 | e: Coefficient for bank clearance | 0.58 |
| In terms of Loa | 1.1 | h1: Correction ratio (Cannel: 0,No wall: 0.999) | 0.99 |
| In terms of B | 6.2 | Correction coefficient | 0.00 |
| | | Bank clearance = e x correction coefficient x B(m | 0.0 |
| | | | |
| | | C: Passing distance for two-way fairway | |
| | | f: Rasio for passing distance | 0.67 |
| | | Passing distance = f x B | 40.2 |

# Calculation example 5-1 ( PCC: Full load, Under severe navigation conditions)

| ******** One-way fairway ******** | |
|---|---|
| <<ship condition >> | |
| Kind of ship PCC | |
| Loa: ship length(m) | 180.0 |
| B: ship breadth(m) | 32.2 |
| V: ship speed (knot) | 7.5 |
| V: ship speed (m/s) | 3.9 |
| | |
| << Natural condition>> | |
| Wind velocity (m/s) | 15.0 |
| Cross current (knot) | 0.5 |
| | |
| << Fairway condition>> | |
| W: Width of fairway (m) | 205 |
| a: Manoeuvring lane for detection of drift (m) | 1260 |
| (Distance between buoy and ship in terms of Loa) | 7.0 |
| θ:Angle between ship and two buoys on both sides | 9.30 |
| | |
| **** Width of one-way fairway (m) **** | |
| Basic manoeuvring lane + ( Bank clearance)*2 | 205.0 |
| In terms of Loa | 1.1 |
| In terms of B | 6.4 |

| | |
|---|---|
| A: Basic manoeuvring lane for one-way fairway | |
| 1.Manoeuvring lane for detection of drift | 0.59 |
| αr: Observation error of middle point(degree) | 4.0 |
| k: Correction ratio | 2.37 |
| αmax: Max observation error of center point(degre | 52.2 |
| Manoeuvring lane for detection of drift(m) | |
| | |
| 2.Drift due to wind and current | |
| Drift angle due to wind effect(degree) | 2.4 |
| Drift angle due to current effect(degree) | 3.8 |
| Drift angle due to wind and current effect(degree) | 6.2 |
| Drift due to wind and current(m) | 25.7 |
| | |
| 3.Drift sideway due to ship yaw | |
| Max yawing angle(degree) | 4 |
| Ty:Yawing period(second) | 120 |
| W(y):Drift sideway due to ship yaw(m) | 8.1 |
| | |
| Half manoeuvring lane for one-way fairway | 86 |
| Basic manoeuvring lane for one-way fairway | 172 |
| | |
| B: Bank clearance | |
| e: Coefficient for bank clearance | 0.63 |
| h1: Correction ratio (Cannel: 0,No wall: 0.999) | 0.10 |
| Correction coefficient | 0.80 |
| Bank clearance = e x correction coefficient x B(m | 16.2 |

| ******** Two-way fairway ******** | |
|---|---|
| <<ship condition >> | |
| Kind of ship PCC | |
| Loa: ship length(m) | 180.0 |
| B: ship breadth(m) | 32.2 |
| V: ship speed (knot) | 7.5 |
| V: ship speed (m/s) | 3.9 |
| | |
| << Natural condition>> | |
| Wind velocity (m/s) | 15.0 |
| Cross current (knot) | 0.5 |
| | |
| << Fairway condition>> | |
| W: Width of fairway (m) | 374 |
| a: Manoeuvring lane for detection of drift (m) | 630 |
| (Distance between buoy and ship in terms of Loa) | 3.5 |
| θ:Angle between ship and two buoys on both sides | 33.06 |
| | |
| **** One-way width (m) **** | |
| Basic manoeuvring lane + ( Bank clearance)*2 | 374.0 |
| In terms of Loa | 2.1 |
| In terms of B | 11.6 |

| | |
|---|---|
| A: Basic manoeuvring lane for one-way fairway | |
| 1.Manoeuvring lane for detection of drift | 1.04 |
| αr: Observation error of middle point(degree) | 4.0 |
| k: Correction ratio | 4.16 |
| αmax: Max observation error of center point(degre | 45.9 |
| Manoeuvring lane for detection of drift(m) | |
| | |
| 2.Drift due to wind and current | |
| Drift angle due to wind effect(degree) | 2.4 |
| Drift angle due to current effect(degree) | 3.8 |
| Drift angle due to wind and current effect(degree) | 6.2 |
| Drift due to wind and current(m) | 25.7 |
| | |
| 3.Drift sideway due to ship yaw | |
| Max yawing angle(degree) | 4 |
| Ty:Yawing period(second) | 120 |
| W(y):Drift sideway due to ship yaw(m) | 8.1 |
| | |
| Half manoeuvring lane for one-way fairway | 80 |
| Basic manoeuvring lane for one-way fairway | 159 |
| | |
| B: Bank clearance | |
| e: Coefficient for bank clearance | 0.63 |
| h1: Correction ratio (Cannel: 0,No wall: 0.999) | 0.10 |
| Correction coefficient | 0.80 |
| Bank clearance = e x correction coefficient x B(m | 16.2 |
| | |
| C: Passing distance for two-way fairway | |
| f: Rasio for passing distance | 0.71 |
| Passing distance = f x B | 22.9 |

# Calculation example 5-2 ( PCC: Full load, Under fair navigation conditions)

| ******** One-way fairway ******** | |
|---|---|
| <<ship condition >> | |
| Kind of ship PCC | |
| Loa: ship length(m) | 180.0 |
| B: ship breadth(m) | 32.2 |
| V: ship speed (knot) | 5.0 |
| V: ship speed (m/s) | 2.6 |
| | |
| << Natural condition>> | |
| Wind velocity (m/s) | 0.0 |
| Cross current (knot) | 0.0 |
| | |
| << Fairway condition>> | |
| W: Width of fairway (m) | 104 |
| a: Manoeuvring lane for detection of drift (m) | 900 |
| (Distance between buoy and ship in terms of Loa) | 5.0 |
| θ:Angle between ship and two buoys on both sides | 6.61 |
| | |
| **** Width of one-way fairway (m)**** | |
| Basic manoeuvring lane + ( Bank clearance)*2 | 104.0 |
| In terms of Loa | 0.6 |
| In terms of B | 3.2 |

| | |
|---|---|
| A: Basic manoeuvring lane for one-way fairway | |
| 1.Manoeuvring lane for detection of drift | 0.57 |
| αr: Observation error of middle point(degree) | 4.0 |
| k: Correction ratio | 2.30 |
| αmax: Max observation error of center point(degre | 36.1 |
| Manoeuvring lane for detection of drift(m) | |
| | |
| 2.Drift due to wind and current | |
| Drift angle due to wind effect(degree) | 0.0 |
| Drift angle due to current effect(degree) | 0.0 |
| Drift angle due to wind and current effect(degree) | 0.0 |
| Drift due to wind and current(m) | 16.1 |
| | |
| 3.Drift sideway due to ship yaw | |
| Max yawing angle(degree) | 0.0 |
| Ty:Yawing period(second) | 120 |
| W(y):Drift sideway due to ship yaw(m) | 0.0 |
| | |
| Half manoeuvring lane for one-way fairway | 52 |
| Basic manoeuvring lane for one-way fairway | 104 |
| | |
| B: Bank clearance | |
| e: Coefficient for bank clearance | 0.63 |
| h1: Correction ratio (Cannel: 0,No wall: 0.999) | 0.99 |
| Correction coefficient | 0.00 |
| Bank clearance = e x correction coefficient x B(m | 0.0 |

| ******** Two-way fairway ******** | |
|---|---|
| <<ship condition >> | |
| Kind of ship PCC | |
| Loa: ship length(m) | 180.0 |
| B: ship breadth(m) | 32.2 |
| V: ship speed (knot) | 5.0 |
| V: ship speed (m/s) | 2.6 |
| | |
| << Natural condition>> | |
| Wind velocity (m/s) | 0.0 |
| Cross current (knot) | 0.0 |
| | |
| << Fairway condition>> | |
| W: Width of fairway (m) | 232 |
| a: Manoeuvring lane for detection of drift (m) | 540 |
| (Distance between buoy and ship in terms of Loa) | 3.0 |
| θ:Angle between ship and two buoys on both sides | 24.75 |
| | |
| **** One-way width (m)**** | |
| Basic manoeuvring lane + ( Bank clearance)*2 | 232.0 |
| In terms of Loa | 1.3 |
| In terms of B | 7.2 |

| | |
|---|---|
| A: Basic manoeuvring lane for one-way fairway | |
| 1.Manoeuvring lane for detection of drift | 0.82 |
| αr: Observation error of middle point(degree) | 4.0 |
| k: Correction ratio | 3.27 |
| αmax: Max observation error of center point(degre | 30.8 |
| Manoeuvring lane for detection of drift(m) | |
| | |
| 2.Drift due to wind and current | |
| Drift angle due to wind effect(degree) | 0.0 |
| Drift angle due to current effect(degree) | 0.0 |
| Drift angle due to wind and current effect(degree) | 0.0 |
| Drift due to wind and current(m) | 16.1 |
| | |
| 3.Drift sideway due to ship yaw | |
| Max yawing angle(degree) | 4 |
| Ty:Yawing period(second) | 120 |
| W(y):Drift sideway due to ship yaw(m) | 5.4 |
| | |
| Half manoeuvring lane for one-way fairway | 52 |
| Basic manoeuvring lane for one-way fairway | 105 |
| | |
| B: Bank clearance | |
| e: Coefficient for bank clearance | 0.63 |
| h1: Correction ratio (Cannel: 0,No wall: 0.999) | 0.99 |
| Correction coefficient | 0.00 |
| Bank clearance = e x correction coefficient x B(m | 0.0 |
| | |
| C: Passing distance for two-way fairway | |
| f: Rasio for passing distance | 0.71 |
| Passing distance = f x B | 22.9 |

## 4 . Alignment (Bend)

### First step

The intersection angle of centerlines of fairway at bend ideally should not exceed 30 degrees.

When it exceeds 30 degrees, the centerlines at bend of fairway should be a circular arc with the radius of fore times or more of ship length between perpendiculars.

Width of fairway at bend should be wider than standard width and it is necessary for the fairway with width to widen inner corner according to the figure below.

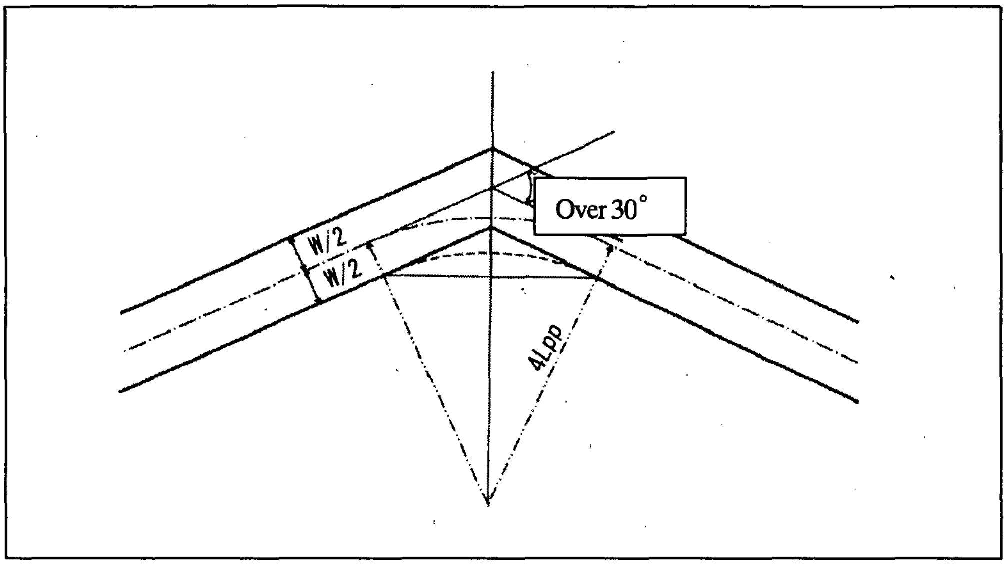


Figure 4-1

### Second step

The intersection angle of centerlines of fairway at bent ideally should not exceed 30 degrees.

When cross angle is larger than 30 degrees and design ship is specified, the radius of turning calculating by manoeuvrability index that indicates the ability of turning. Also width of fairway should be wider than standard.

Other shapes of bend in addition to widening inner corner can be introduced considering installation of light buoys based on the study with mariners concerned. Especially when the radius of turning is large, the study of shape of curve is important because it is not effective to widen the inner corner.

### (Explanation)

1) Radius of turning circle depending on the manoeuvrability index can be calculated by the following formula.

$$R = Lpp / (K' \cdot \delta) = V / (K \cdot \delta)$$

| | | |
|---|---|---|
| R(m) | : Radius of turning circle of bend of waterway | |
| K | : Manoeuvrability index for turning | |
| K’ | : Non dimensional manoeuvrability index of turning | $[K' = K / (V / Lpp)]$ |
| Lpp(m) | : Ship length between perpendiculars | |
| $\delta$ (radian) | : Rudder angle during underway at bend | |
| V(m / s) | : Ship speed during underway at bend | |

2) The following value of K' can be referred. This value is obtained by the result of mathematical simulation under no wind condition. In case of PCC and Container ship with large wind area under strong wind condition, further study is required to get proper K' value.

Deep sea K'=0.75 (For all types of ship)

Shallow water (D/d≒1.2)

VLCC K'=0.70
Container ship K'=0.35
Bulk ship K'=0.55
LNG carrier K'=0.45

3) [Approach Channels A Guide for Design(PIANC, IAPH, IMPA, IALA)] can be referred for design method of shape of bend. And also the existing channels in overseas (Pot of Tanjung Pelapas and etc.) can be referred as actual design example.

---

$\alpha$ : Intersection angle of center line of fairway

$\delta$ : Rudder angle during underway at bend

V : Ship speed during underway at bend
D : Depth of fairway

d : Max. draft

Lpp : Length between perpendicular
R : Radius of center line of fairway

# Reference:

## The result of course changing simulation of various types of ships

### 1. Outline of the simulation

The simulation of VLCC, large container ship, large bulk ship and LNG ship were carried out under the condition of calm and wind speed of 15m/s.

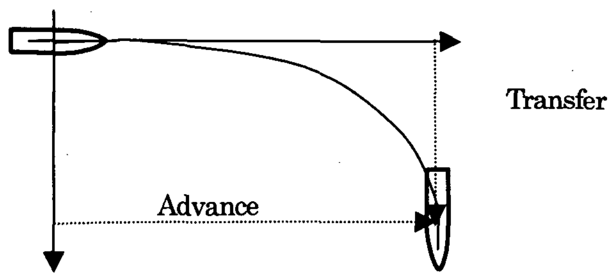
### 2. Ship's particulars

| | VLCC | CONT.C | BULK | LNG |
|---|---|---|---|---|
| L (m) | 316 | 273 | 279 | 269 |
| B (m) | 60 | 32.2 | 45 | 44.5 |
| d (m) | 20.4 | 13.25 | 17.81 | 10.8 |
| Cb | 0.7941 | 0.6665 | 0.8042 | 0.7028 |
| L/B | 5.267 | 8.478 | 6.200 | 6.045 |
| B/d | 2.941 | 2.430 | 2.527 | 4.120 |
| Cb*B/d | 2.336 | 1.620 | 2.032 | 2.896 |
| $A_R$/Ld | 1/52.35 | 1/50 | 1/6.7 | 1/44.6 |
| $\Lambda$ | 2.00 | 1.87 | 1.8462 | 1.4857 |
| Dp(m) | 10.44 | 8.20 | 9.40 | 8.31 |
| P/Dp | 0.6662 | 1.0053 | 0.6503 | 0.7996 |
| MCR(ps) | 36,960 | 35,100 | 19,100 | 40,000 |
| rpm | 74 | 90 | 72 | 103 |

### 3. Condition on the simulation

1) Mathematical model: MMG Model
2) Coefficient of hydrodynamic force: Formula obtained by experiments
3) Shallow effect:
   Added mass: average experimental data
   Hull resistance: modified formula by Dr. Kinoshita
   Propulsion: same value as data in deep water
   Rudder force: same value as data in deep water
   Liner hydrodynamic derivatives: Formula by Dr. Kijima (except Y'r, Y'r is corrected by an average experimental data)
   Non-liner hydrodynamic derivatives: same value as data in deep water
   Wind force coefficient: Formula by Dr. Yamano
4) Propeller specification: estimated by standard design method
5) Rudder angle: 20 degrees

### 4. Result of the simulation of 90 degrees change course

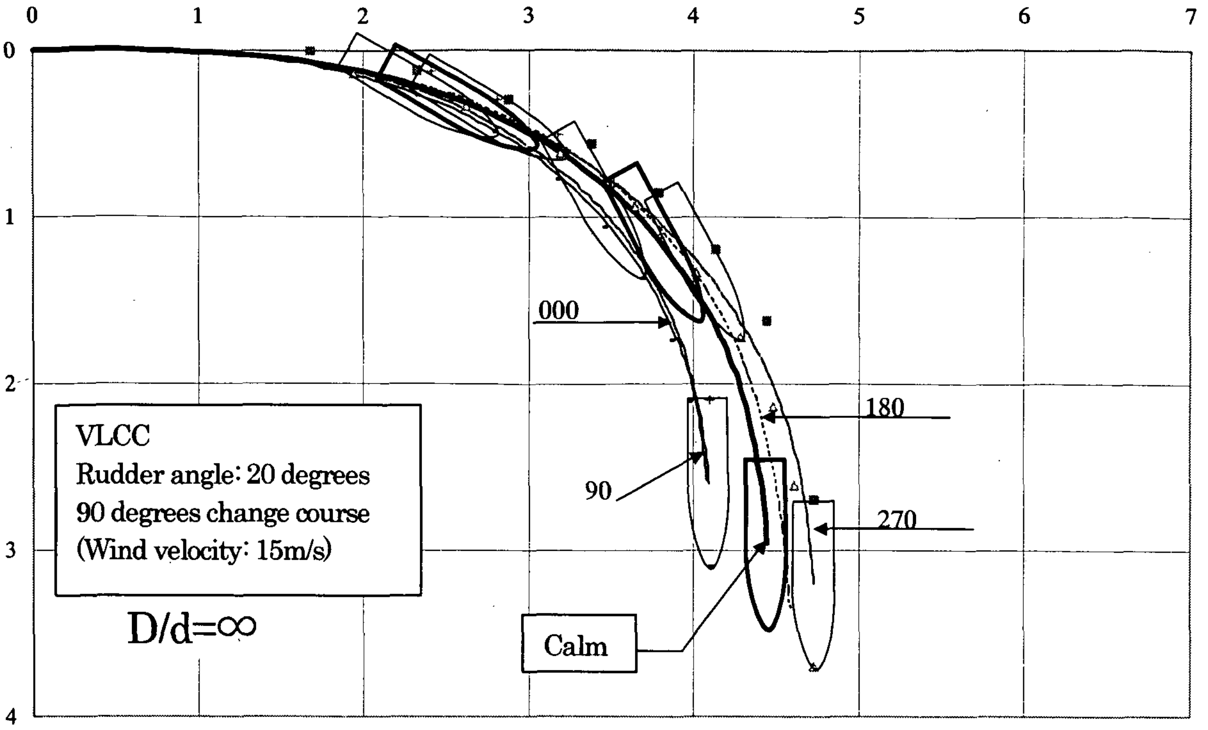


unit: x Lpp

| | VLCC | CONT.C | BULK | LNG |
|---|---|---|---|---|
| D/d=∞ | | | | |
| Advance | 4.45 | 4.54 | 4.61 | 4.24 |
| Transfer | 2.96 | 3.28 | 3.19 | 2.67 |
| Average | 3.70 | 3.91 | 3.90 | 3.46 |
| D/d=1.2 | | | | |
| Advance | 4.26 | 8.97 | 5.71 | 6.54 |
| Transfer | 3.49 | 7.53 | 4.70 | 5.99 |
| Average | 3.88 | 8.24 | 5.20 | 6.26 |

*The trucks of each ship are shown as follows. Thick lines show the result in calm condition and thin lines shows the result under strong wind (4 wind directions).

*Wind direction is true wind direction at initial position.


0
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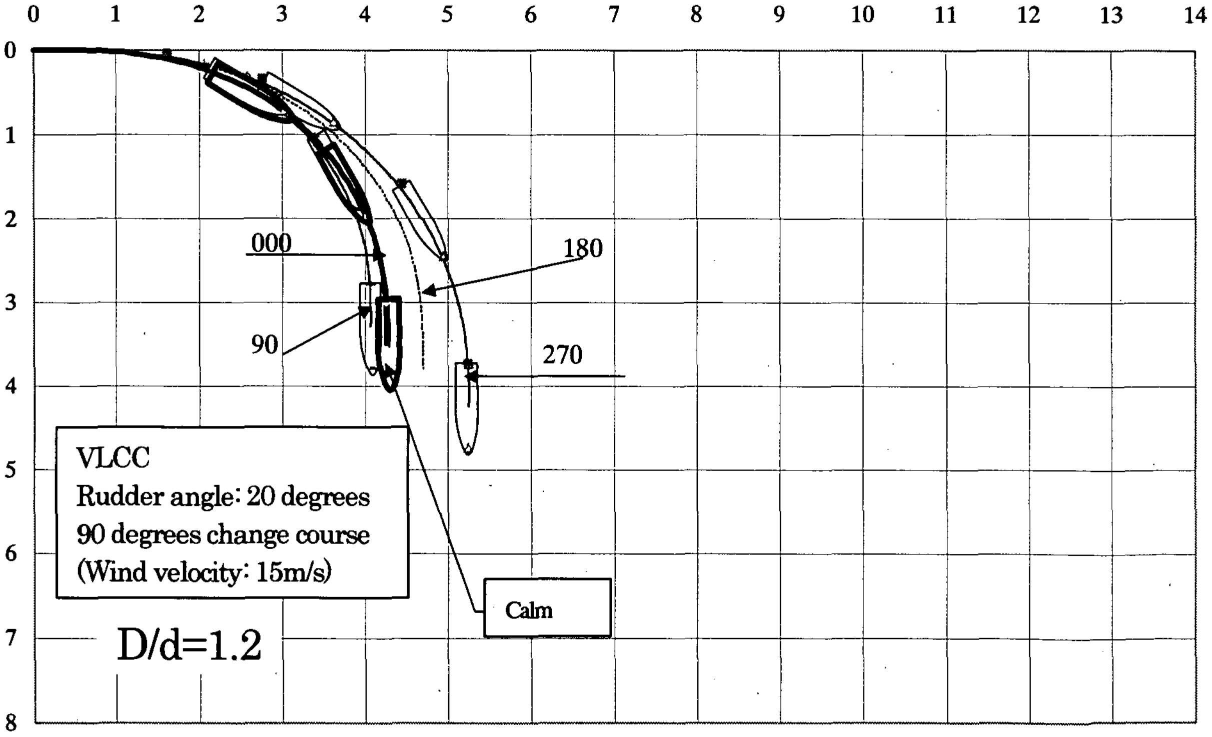
000
180
90
270
Calm
VLCC
Rudder angle: 20 degrees
90 degrees change course
(Wind velocity: 15m/s)
D/d=∞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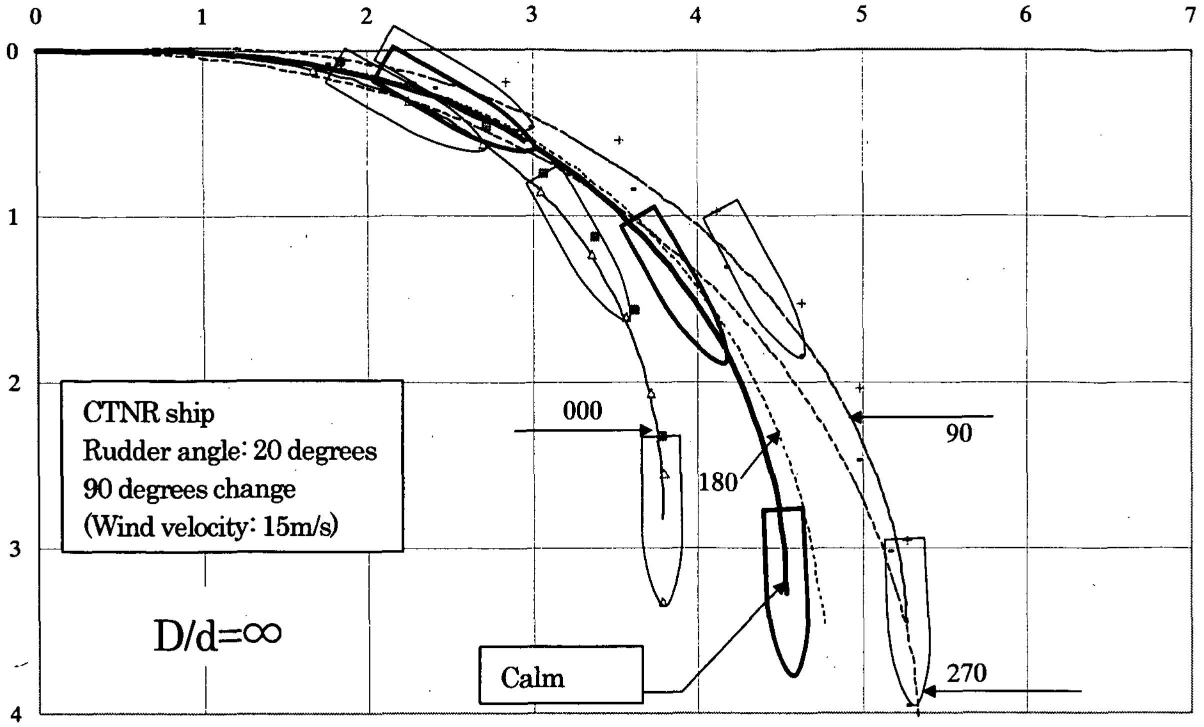
180
90
270
Calm
VLCC
Rudder angle: 20 degrees
90 degrees change course
(Wind velocity: 15m/s)
D/d=1.2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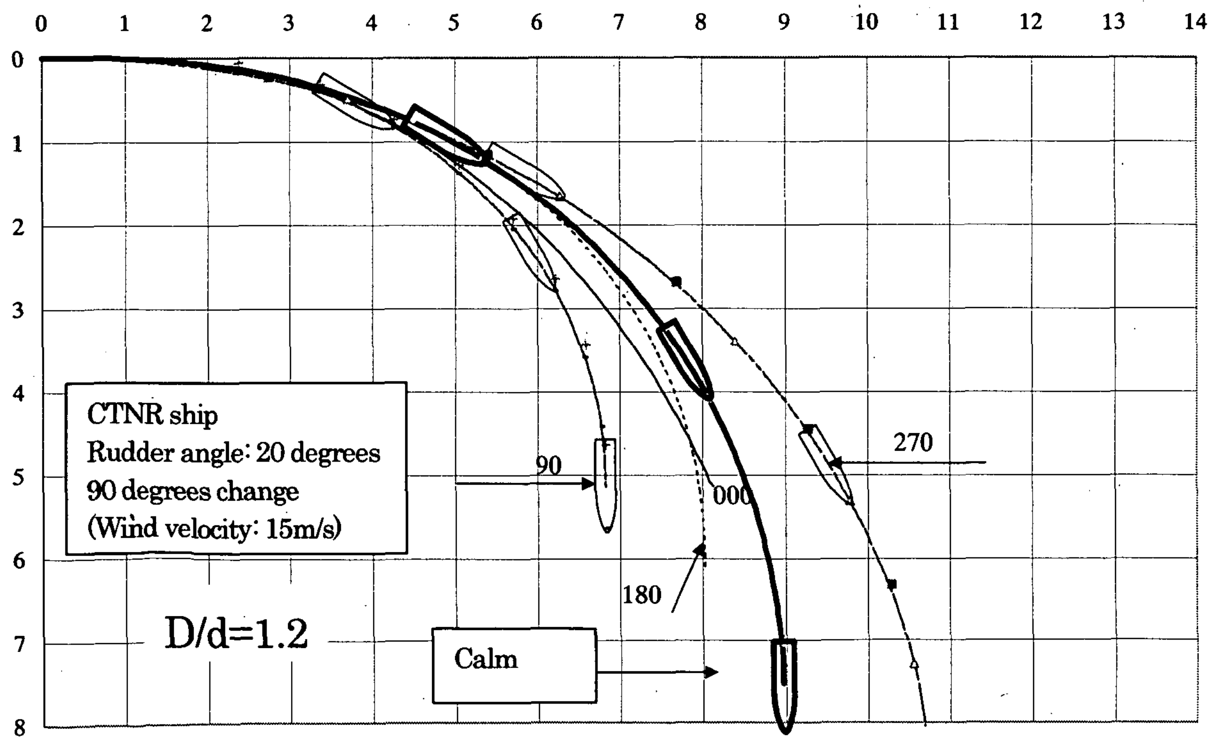
4
CTNR ship
Rudder angle: 20 degrees
90 degrees change
(Wind velocity: 15m/s)
D/d=∞
000
180
90
270
Calm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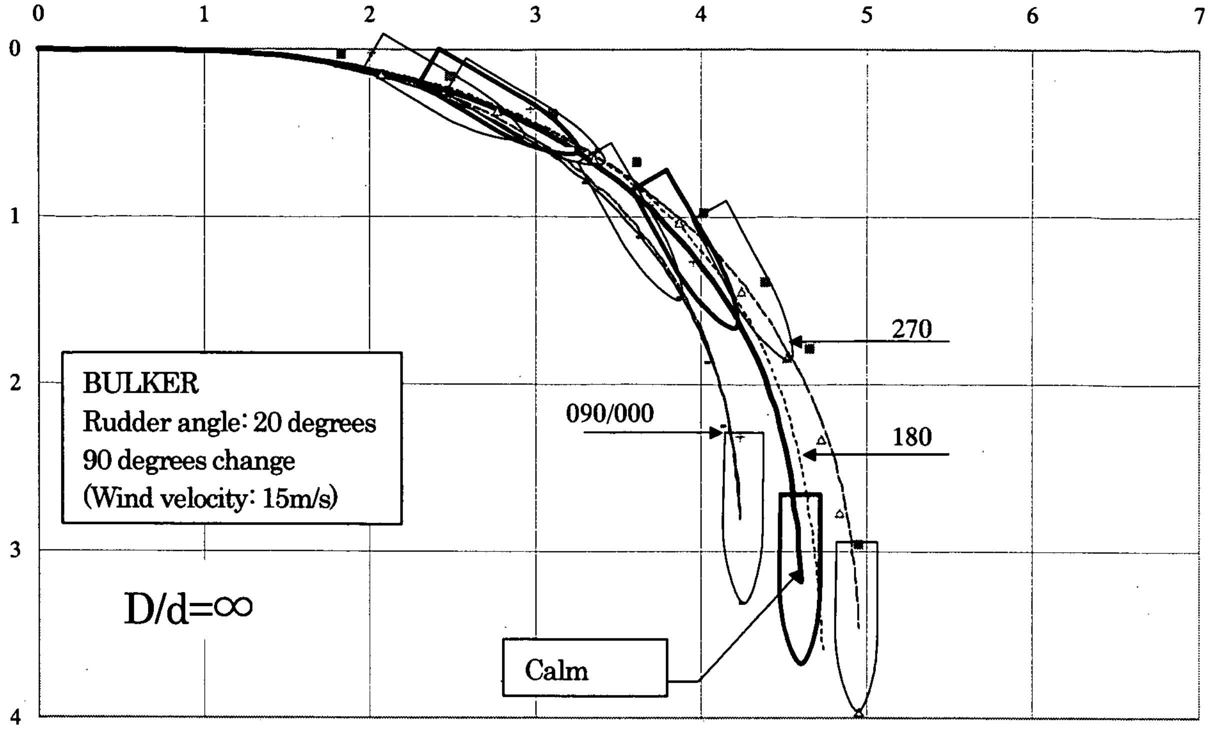
8
CTNR ship
Rudder angle: 20 degrees
90 degrees change
(Wind velocity: 15m/s)
D/d=1.2
90
000
180
270
Calm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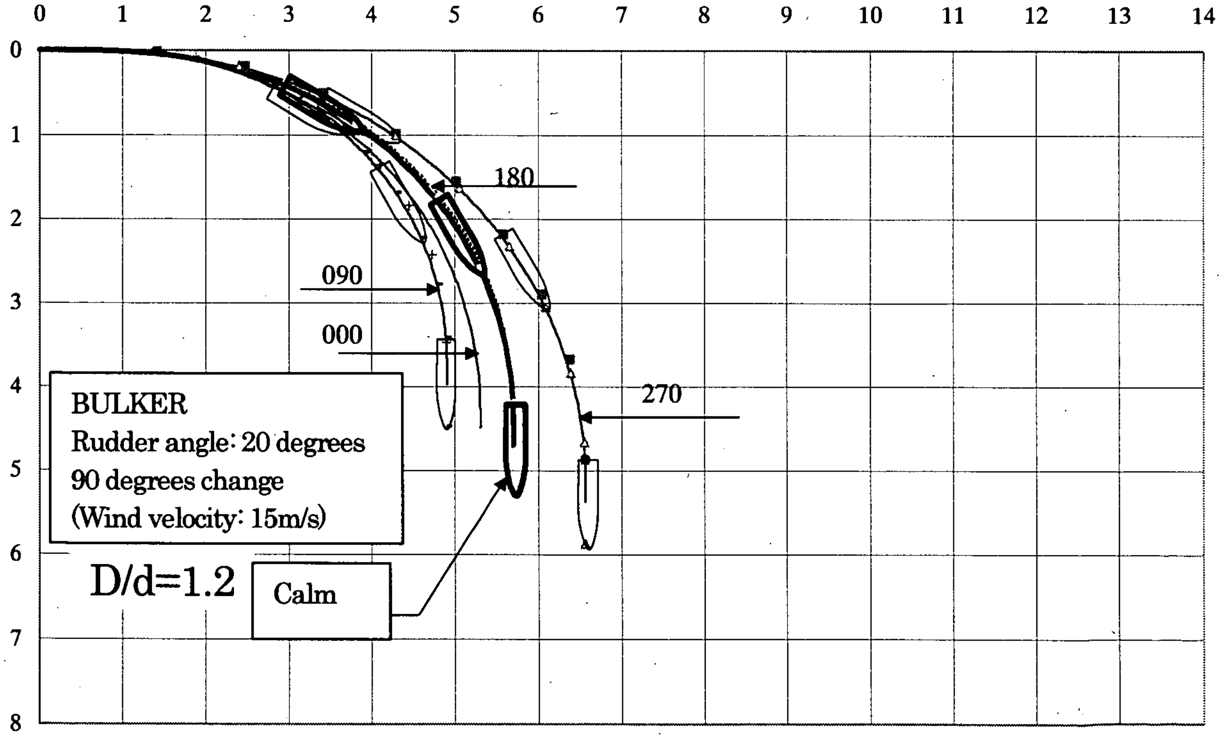
BULKER
Rudder angle: 20 degrees
90 degrees change
(Wind velocity: 15m/s)
D/d=∞
270
090/000
180
Calm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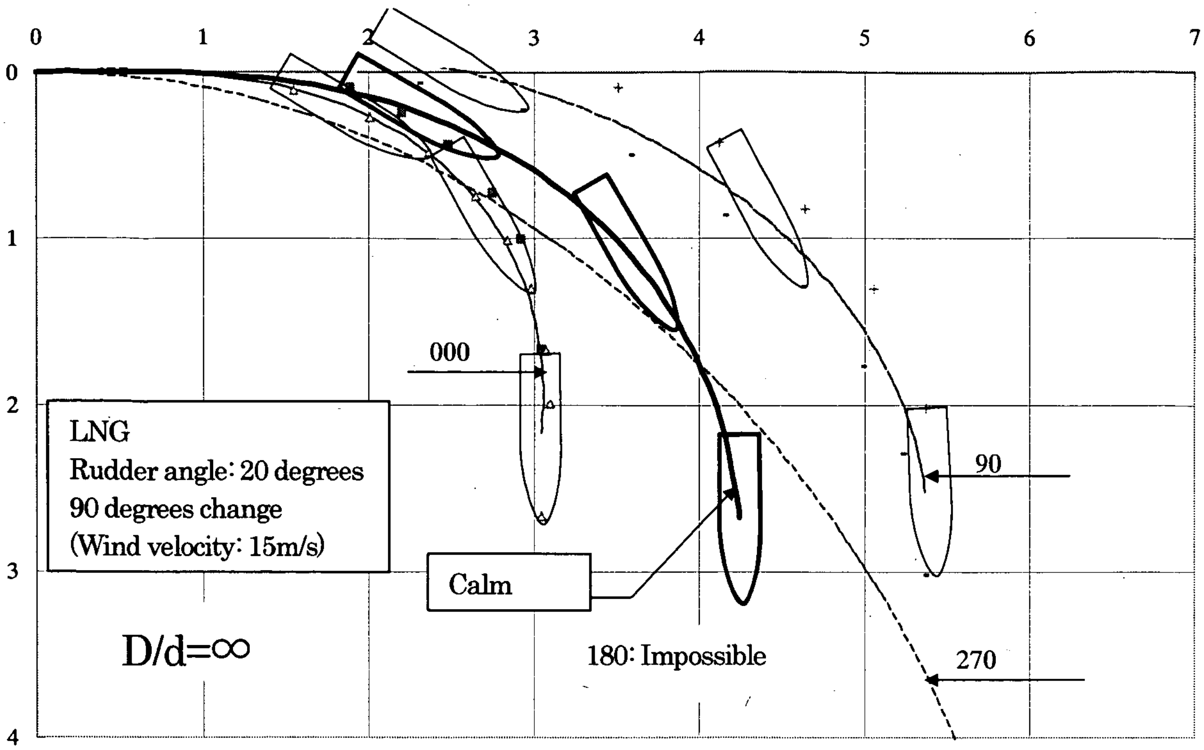
090
000
270
BULKER
Rudder angle: 20 degrees
90 degrees change
(Wind velocity: 15m/s)
D/d=1.2
Calm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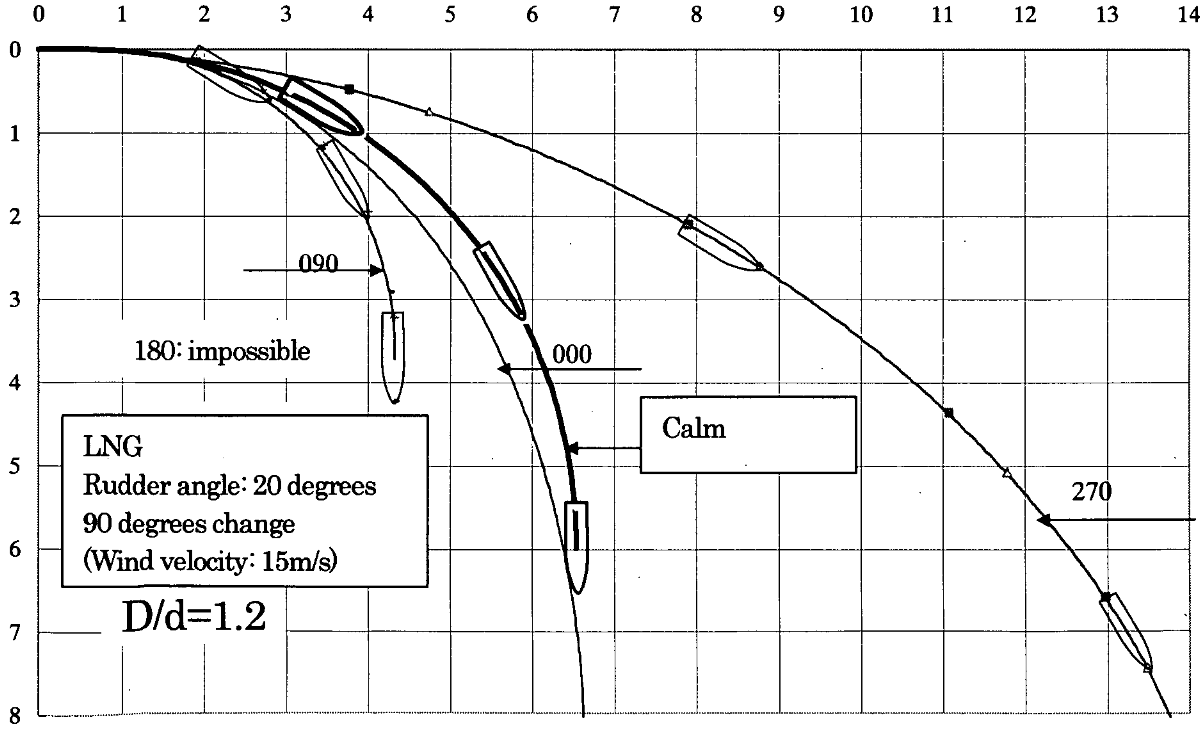
000
LNG
Rudder angle: 20 degrees
90 degrees change
(Wind velocity: 15m/s)
Calm
90
D/d=∞
180: Impossible
270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6
7
8
090
180: impossible
000
Calm
LNG
Rudder angle: 20 degrees
90 degrees change
(Wind velocity: 15m/s)
270
D/d=1.2

## Calculation Example-6 Radius of turning circle in shallow water

| Kind of ship | VLCC | |
|---|---|---|
| Lpp (m) | 316 | |
| K' | 0.7 | |
| Rudder angle | Radius i n shallow water | In terms of Lpp |
| 15 degrees | 1724.3 | 5.5 |
| 20 degrees | 1293.2 | 4.1 |
| 25 degrees | 1034.6 | 3.3 |
| 30 degrees | 862.2 | 2.7 |

| Kind of ship | CTNR | |
|---|---|---|
| Lpp (m) | 273 | |
| K' | 0.35 | |
| Rudder angle | Radius i n shallow water | In terms of Lpp |
| 15 degrees | 2979.4 | 10.9 |
| 20 degrees | 2234.5 | 8.2 |
| 25 degrees | 1787.6 | 6.5 |
| 30 degrees | 1489.7 | 5.5 |

| Kind of ship | BULK | |
|---|---|---|
| Lpp (m) | 279 | |
| K' | 0.55 | |
| Rudder angle | Radius in shallow water | In terms of Lpp |
| 15 degrees | 1937.6 | 6.9 |
| 20 degrees | 1453.2 | 5.2 |
| 25 degrees | 1162.6 | 4.2 |
| 30 degrees | 968.8 | 3.5 |

| Kind of ship | LNG | |
|---|---|---|
| Lpp (m) | 269 | |
| K' | 0.45 | |
| Rudder angle | Radius i n shallow water | In terms of Lpp |
| 15 degrees | 2283.3 | 8.5 |
| 20 degrees | 1712.5 | 6.4 |
| 25 degrees | 1370.0 | 5.1 |
| 30 degrees | 1141.7 | 4.2 |