A Guide to Ship Handling

THE BEST SEAMANSHIP

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Dear friend,

On behalf of the Administrative Committee of the JSU Welfare Fund, please allow us to express our sincere greetings to our non-domiciled special members onboard the vessels, covered by JSU Collective Agreements. This guidebook was designed for training seafarers and fostering their successors. It is crucial process for maritime industry to hand down well-experienced navigation skill to the future International shipping in order to make a significant contribution to the future development and to foster competent seafarers. It is also an asset for maritime industry which should be handed over. However, in the context of the circumstance of the education for seafarers and the initiation of maritime skill, it is not necessarily to say that it is definitely sufficient for us to take advantage of an opportunity to be instructed by well-experienced and competent officers at sea.
In view of this issue, I firmly believe that this book will be effectively-utilized for training and developing of future seafarers, and will make meaningful contributions to these efforts.
Finally, we would like to extend our sincere gratitude and appreciation to everyone involved in this project, especially the International Mariners Management Association of Japan.

Best regards.

Yoji Fujisawa
Chairman,
Administrative Committee of JSU
Welfare Fund and;
President,
All Japan Seamen's Union

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Chapter 1

Maneuvering Capability of Ships

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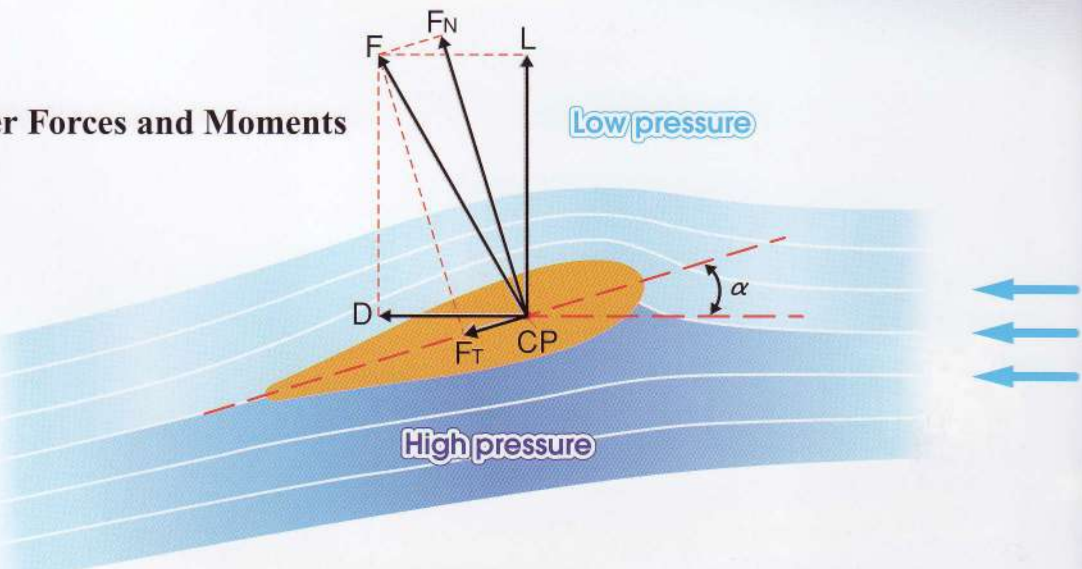
Maneuvering Capability of Ships

1.1 Rudder

General

A rudder is a device to control the horizontal motion of a ship. The control force exerted by a rudder at the stern of a ship creates a moment on the ship that causes the ship to rotate and to orient itself at an angle of attack to the flow.

Rudder Forces and Moments



α : Angle of attack
L : Lift force
D : Drag force
F : Total resultant force
CP: Center of pressure
F_N : Normal force
F_T : Axial force

Fig.1-1 Rudder force components

Let us consider a rudder as a separate body at an angle of attack α to the flow velocity.
The combination of forward velocity and angle of attack will induce a circulation about the rudder that in turn produces a lift force **L** on the rudder due to a difference in the pressure acting on the upper and lower surfaces of the rudder.
In a real fluid, drag force **D** composed of friction and separate forces, acts on the rudder.
As shown in Fig.1-1 the total resultant force **F** acts at a point called the center of pressure **CP**.
This may be resolved into a lift component **L** normal to the direction of motion, into a drag component **D** parallel to the direction of motion, or into a normal force **FN** normal to the center plane of the rudder, into a axial force **FT** parallel to the center plane of the rudder.
Since the axial force **FT** is very small compared to the normal force **FN**, the normal force **FN** is considered to represent rudder force that controls the motion of the ship.
In addition to the rudder area, the geometric properties of the rudder, such as aspect ratio, section shape and profile shape, influence the capability of the rudder to function as a separate body.

Rudder at the Stern

A rudder located at the stern is subject to influence from the hull and the propeller, and the inflow velocity to the rudder is different from ship velocity. Turning motion of a ship also changes the inflow velocity and direction to the rudder. The added velocity of propeller race increases the rudder force both at normal speed and at zero speed. Meanwhile, the wake, disturbed water dragged along with the ship, decreases the inflow velocity to the rudder. In the steady ahead maneuver, the rudder is in propeller race and its effectiveness is good where magnitude of the rudder force is about equal to that of a separate in a uniform flow.

The following cases are often experienced during in-harbor ship handling:

- In the accelerating maneuver (accelerating ahead from zero speed), the rudder of a single screw ship is particularly effective, because in this condition the rudder operates in the discharge jet of the propeller, which has a very high velocity at zero speed resulting from the large slip ratio of the propeller. For this reason, the turning ability is excellent, and thus is often used by the ship's operator when he does not wish to accelerate ahead but rather to change the ship's heading.
- On the other hand, the rudder effectiveness is poor during a coasting maneuver (decelerating the ship without using reverse power). With the propeller wind-milling or locked, the rudder does not benefit from the propeller's discharge jet, and, accordingly, net velocity of flow over the rudder is very small. Fig.1-2 shows the comparison of turning trajectories on each maneuver.

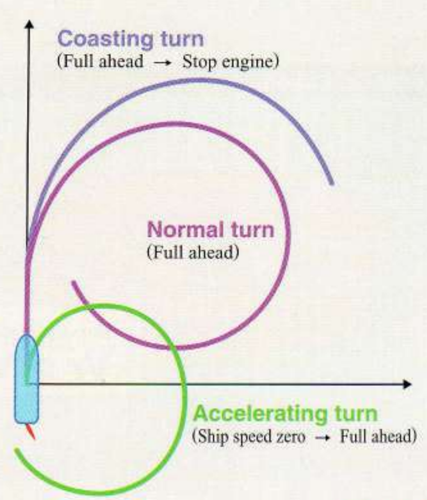


Fig.1-2
Turning trajectories on steady ahead, acceleration and deceleration maneuvers

- In the stopping maneuver (decelerating the ship by use of full reverse power), the rudder effectiveness is exceptionally poor, the propeller discharge jet being opposed in direction by the ship's velocity ahead relative to the water. Hence, the net velocity of flow over the rudder is exceptionally small. Fig.1-3 shows the flow around the stern while stopping.

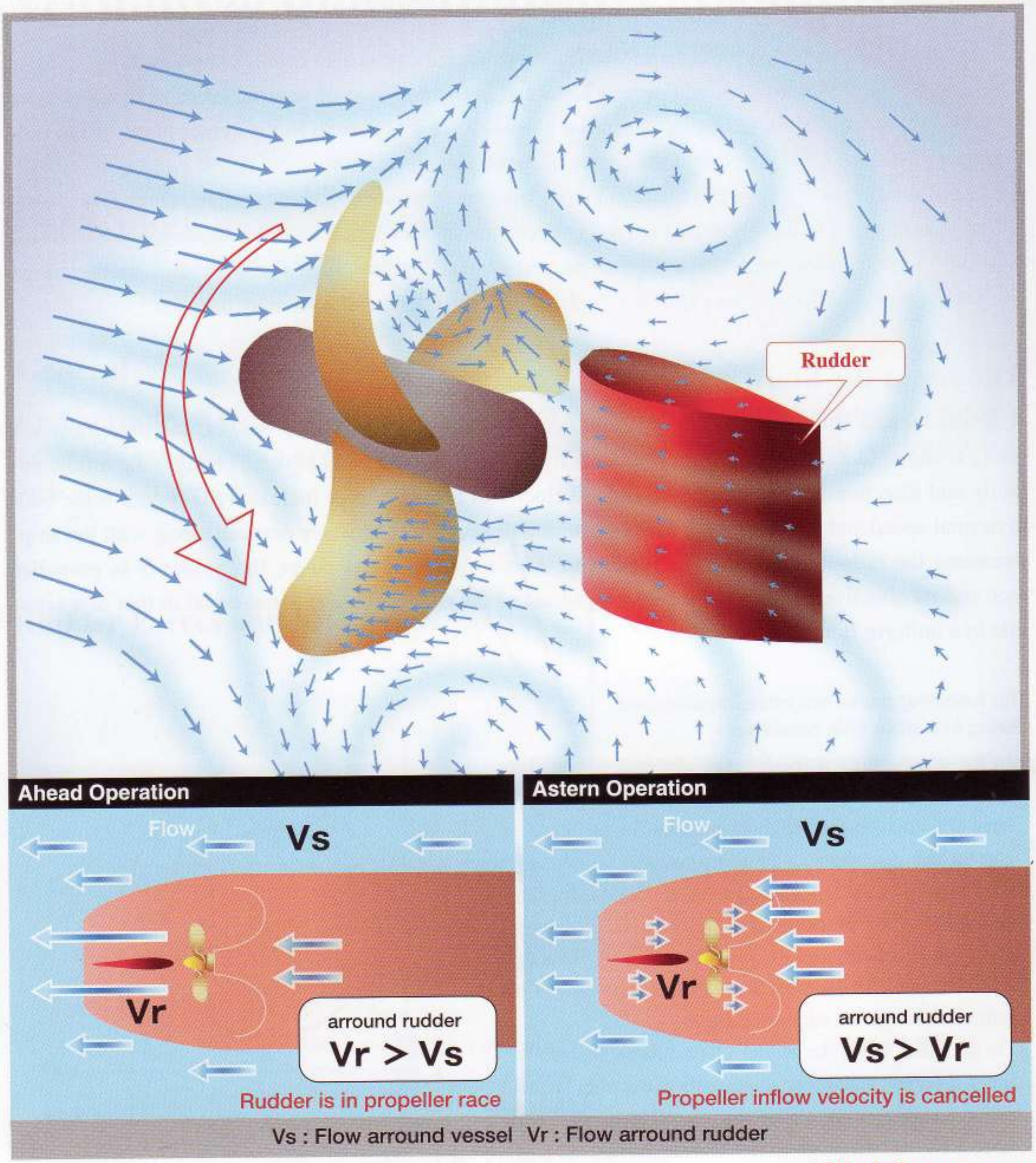


Fig.1-3 Flow pattern

Therefore, it is important to note that the propeller's powerful discharge jet is indispensable for the rudder effectiveness.

1.2 Fundamental Maneuvering Characteristics

Actual ship maneuvering patterns practiced under various navigational environments are classified broadly into two categories -- course keeping and evasive (emergency) maneuvers.

When considering maneuvering procedures, such as course keeping, course changing, and decelerating/stopping, the following maneuvering characteristics are required for ship handling:

1. **Turning ability**
2. **Initial turning ability**
3. **Yaw-checking and course-keeping abilities**
4. **Stopping ability**

Each is briefly defined below:

1. Turning ability

Turning ability is the measure of the ability to turn the ship using hard-over rudder.
The results being a minimum "advance at 90° change of heading" and "tactical diameter" defined by the "transfer at 180° change of heading."

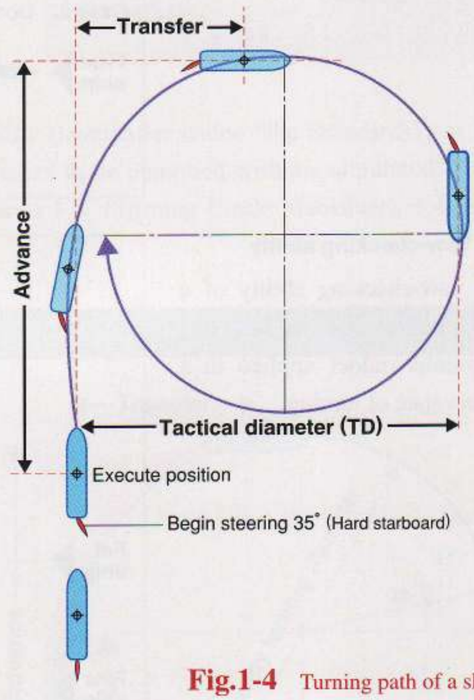
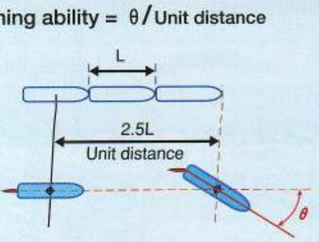


Fig.1-4 Turning path of a ship

2. Initial turning / course changing ability

The initial turning ability is defined by the change-of-heading response to a moderate helm in terms of heading deviation per unit distance sailed.

Initial turning ability = θ / Unit distance



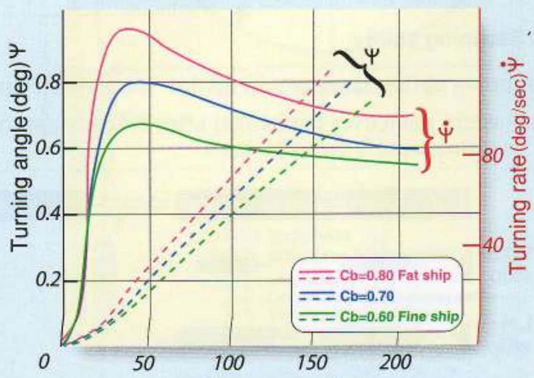


Fig.1-5 Initial turning ability & effect of Cb

3-1. Course-keeping ability

Course-keeping ability is a measure of the ability of the ship to maintain a straight path on a predetermined course without excessive oscillations of rudder or heading.

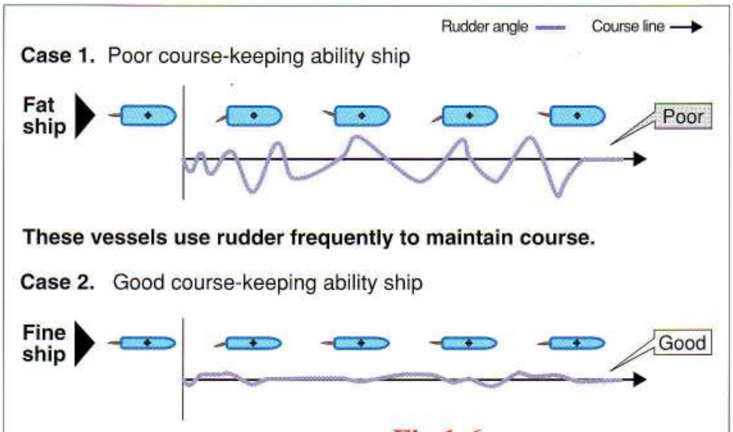


Fig.1-6 Course-keeping ability

3-2. Yaw-checking ability

The yaw-checking ability of a ship is a measure of the response to counter-rudder applied in a certain state of turning.

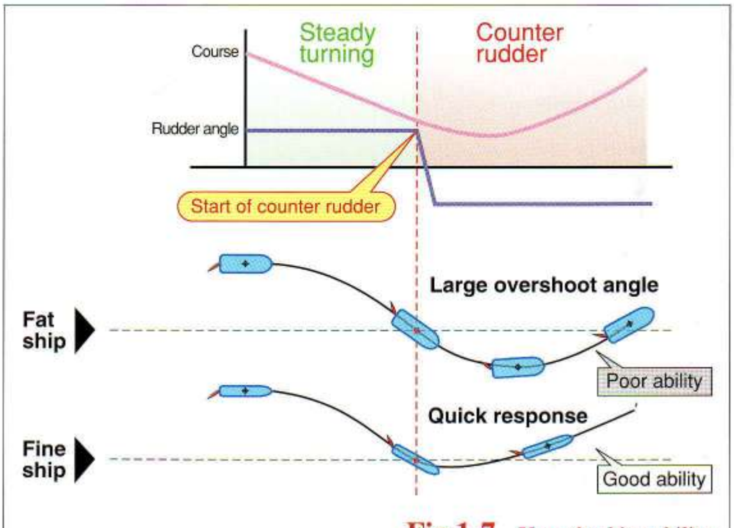


Fig.1-7 Yaw-checking ability

4. Stopping ability

Stopping ability is measured by the "track reach" and "time to dead in water" realized in a stop engine-full astern maneuver performed after a steady approach at full test speed.

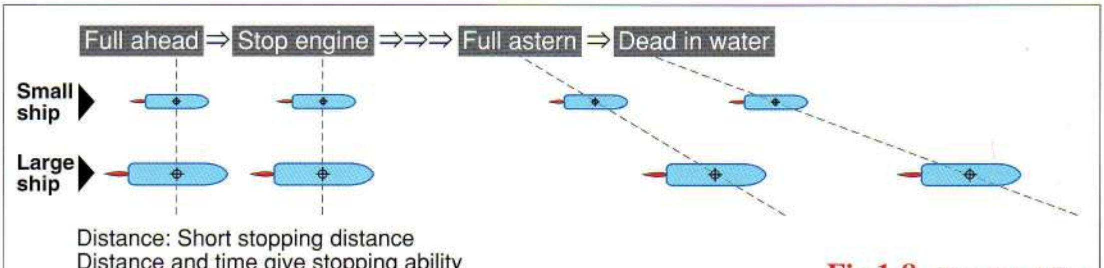


Fig.1-8 Stopping ability

Summary of maneuverability

Shape of ship	Fine ship	Fat ship
Cb (Block Coefficient)	Small	Large
Kind of ship	Container	Tanker Bulk carrier
Initial turning ability	Nearly equal but fat ship turns slightly faster than fine ship.	
Course-keeping ability	Good	Poor
Turning ability	Poor	Good

Note) The above criteria is applied generally except in special cases.

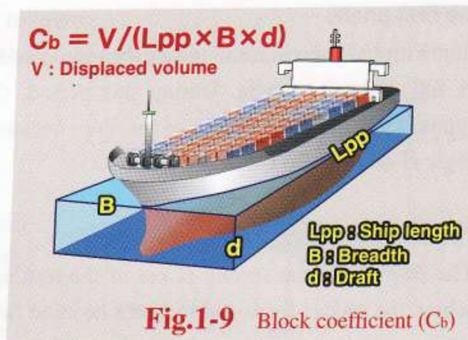


Fig.1-9 Block coefficient (C_b)

The IMO established Standards for Ship Maneuverability (hereinafter called "the Standards") in December 2002, where criteria of maneuvering characteristics to be complied with are stipulated. These criteria will be referred in the following relevant Sections 1.3 (Turning Circle Maneuver), 1.4 (Ship Maneuvering Tests) and 1.5 (Speed Control).

1.3 Turning Circle Maneuver

The turning test remains an important practical maneuver that ships frequently perform. Also it is suitable for analyzing test results because the final phase of the turning path is a steady-state maneuver.

The Three Phases of a Turn

When the rudder is deflected and held at a fixed angle, the turning path of the ship's center of gravity is called the turning circle. The course of the turning motion may be divided into three phases:

Table 1-1

	Phase 1	Phase 2	Phase 3	Remarks
Rudder angle	Increasing	Steady	Steady	δ
Turning rate	Increasing	Increasing	Steady	r
Drift	0	Increasing	Steady	β
Heel	0	Inward	Outward	
Speed	Steady	Decreasing	Steady	(Same RPM)

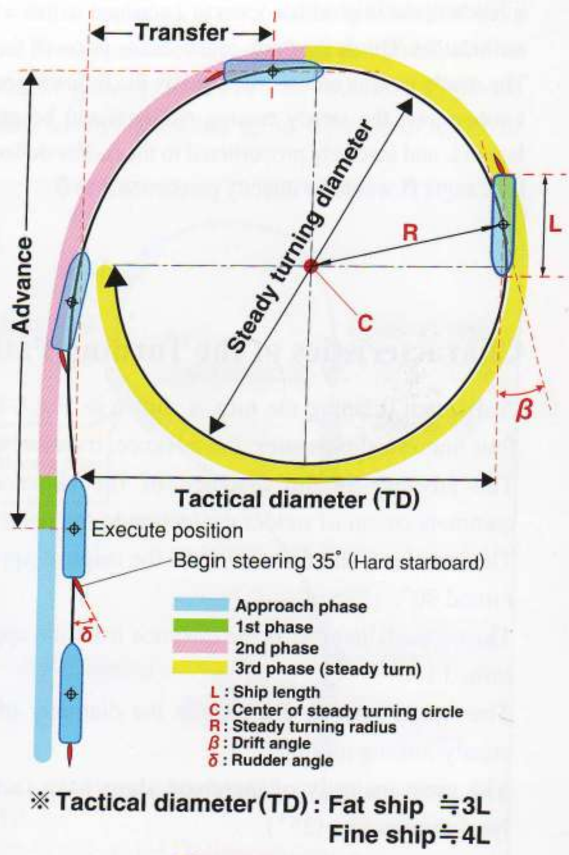


Fig.1-10 Turning path of a ship

The first phase

The first phase starts at the instant that the rudder is laid over and may be over by the time the rudder reaches its full deflection angle. During this period, the rudder force and moment produce acceleration and are opposed solely by the inertia of the ship, because there has not yet been an opportunity for a substantial drift angle β or yaw rate r to develop.

The second phase

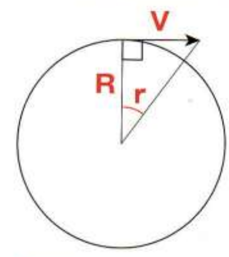
The ship enters the second phase of the turning, with the development of a drift angle β and a yaw rate r where the rudder force and moment become fully operative. The crucial event at the beginning of the second phase is the creation of a inwardly directed force towards the center of the turn, resulting from the drift angle β. Eventually, inwardly directed force caused by the drift angle comes into balance with the outwardly directed centrifugal force of the ship. (The beginning of the steady phase.) However, in the second phase of the turn, as shown in Fig.1-10, the path of the ship's center of gravity at first responds to the rudder force and tends to port before the inwardly directed force grows sufficiently large. In spite of this tendency of the ship's center of gravity, the bow usually remains to starboard of the approach course during the entire entry phase. (Kick.)

The third phase

The second phase of turning ends with the establishment of the new equilibrium of forces. When this equilibrium is reached, the ship settles down to a constant radius with constant drift angle and rotation. This is the third, or the steady phase of the turn.

The steady turning radius is defined by the following relationship: $R=V/r$

Furthermore, the steady turning radius would be proportional to the ship length L and inversely proportional to the rudder deflection angle δ while the drift angle β would be directly proportional to δ.



R : turning radius (m)
V : ship speed (m/sec)
r : yaw rate (radian/sec)

Characteristics of the Turning Path

A diagram defining the turn is shown in Fig.1-10. Generally, a ship's turning path is characterized by four numerical measures: the advance, transfer, tactical diameter and steady turning diameter.

The advance is the distance of the ship's center of gravity along the original course from commencement of rudder deflection to the point when the ship has turned 90°.

The transfer is the distance from the original approach course to the ship's center of gravity when it has turned 90°.

The tactical diameter is the distance from the approach course to the ship's center of gravity when it has turned 180°.

The steady turning diameter is the diameter of the ship's trajectory when it has settled down to the steady turning motion.

The great majority of merchant ships have tactical diameters between three and four ship lengths at hard-over rudder (35°).

IMO Standards stipulate the turning ability of the ship as follows:

The advance should not exceed 4.5 ship lengths (L) and the tactical diameter should not exceed 5 ship lengths in a turning circle maneuver with maximum rudder angle.

IMO Standards : Advance < 4.5L
Tactical diameter < 5L

Fig.1-11 shows the position of the "pivot point" in a steady turn, determined by drawing a perpendicular from the center of the steady turning circle to the centerline of the ship.

To an observer on board a turning ship, it appears as if the ship is pivoting at that point.

The distance between the pivot point **P** and the ship's center of gravity **G** is expressed as $GP = R \sin\beta$.

For most ships the pivot point is somewhere between 1/4 L and 1/3 L forward of the ship's center of gravity.

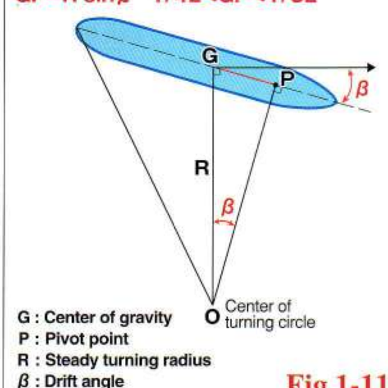


Fig.1-11 Drift angle and pivot point

At the entry stage of the second phase of the turn, the ship's center of gravity tends to skid outwardly from the original path as the result of the rudder force. This phenomenon is known as "kick", and its magnitude is about 1/100 ship length **L** at the center of gravity. However, as shown in Fig.1-12, the stern kick (the magnitude of lateral shift at the stern terminal) reaches up to 1/7 of ship length at the 20° change of heading in hard-over rudder. Care should be taken regarding stern kick.

Now, stern kick can be used to one's advantage -- deflecting the rudder towards a man onboard prevents him from being caught in the propeller.

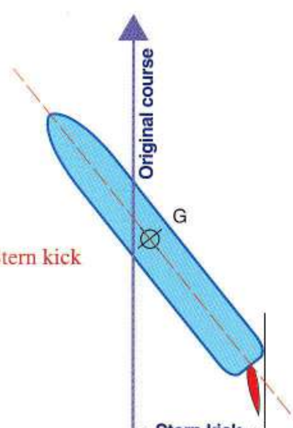


Fig.1-12 Stern kick

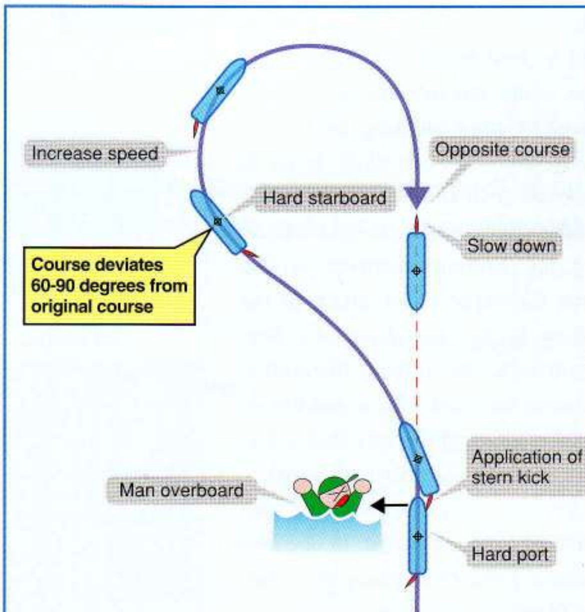


Fig.1-13
Application of stern kick-1 (Williamson turn)

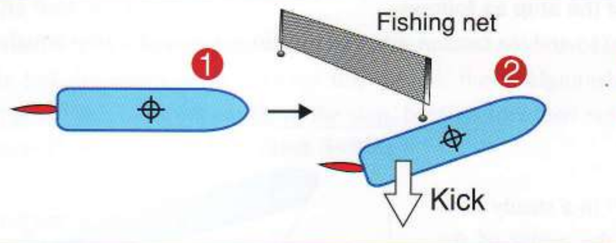
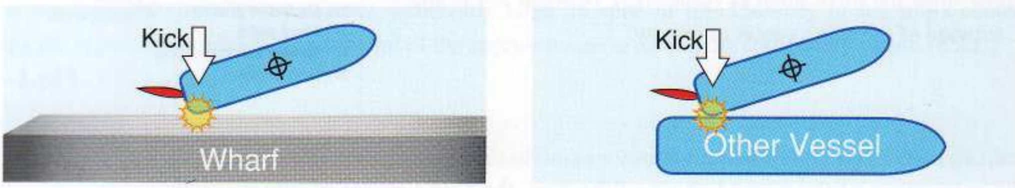


Fig.1-14 Application of stern kick-2

However, abrupt and large rudder deflections should be avoided when passing in close proximity of another ship at berth or at anchor, since stern kick may cause contact with the other ship.

Fig.1-15 Contact caused by stern kick



Coupled Motions in Turning

Heel angle in a turn

The deflection of the rudder is intended to produce motion solely in the yaw plane, but motions are also induced by cross coupling into the roll plane, and these are likely to be of concern. Heel angles induced by the rudder can be estimated by considering the heeling moments arising from the vertical disposition of the forces. In the first phase of a starboard turn, the vertical disposition between the rudder force and the inertial reaction of the ship makes the ship heel to starboard (inward). These heel angles are small and soon finished. Forces acting in the roll plane for the third phase of a starboard turn are shown in **Fig.1-16**.

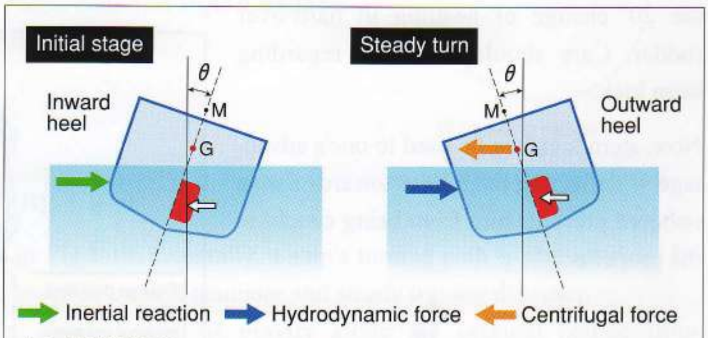


Fig.1-16 Outward heel in a steady turn

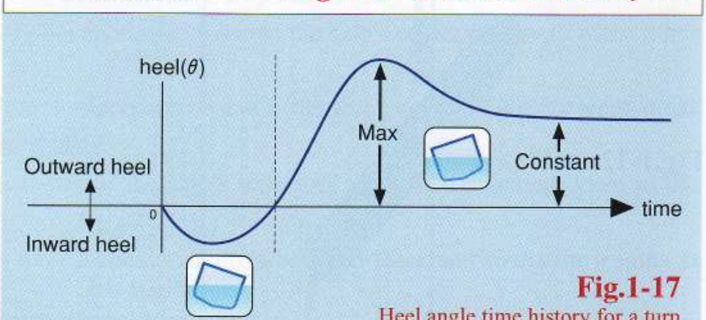


Fig.1-17 Heel angle time history for a turn

Heeling moment arising from the vertical disposition between the centrifugal force and hydrodynamic forces makes the ship heel to port (outward).

Thus, between the first and the third phases of a turn, heel angle of a ship changes.

The second heel (outward heel) involves a large overshoot angle beyond the equilibrium value of the turn's third phase as shown in **Fig.1-17**.

A potentially dangerous situation exists just prior to the completion of the first large heel to port. Care should be taken when operating ships with poor stability, as capsizing may result.

If a transient, large heel occurs in such a ship, the only safe action is to immediately, but slowly and cautiously, reduce the rudder angle and, at the same time, reduce speed as quickly as possible.

Reduction of speed in a turn

Speed reduction in a turn is largely a function of turning circle tightness; that is, hull resistance increase due to the development of drift angle and yaw rate, and propeller efficiency is reduced.

The smaller the turning diameter, the more rapid the rate of speed reduction.

Fig.1-18 shows the speed reduction as a function of turning diameter (TD)/ship length (L). From the figure it is known that the smaller the turning diameter, the greater the rate of speed reduction.

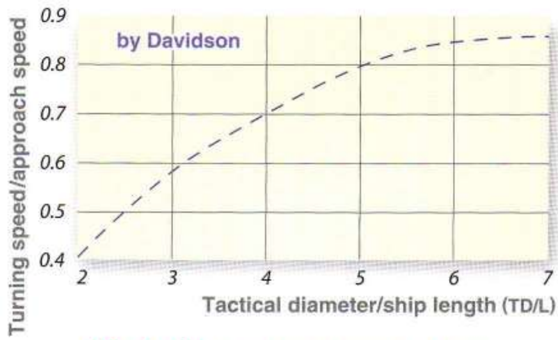


Fig.1-18 Speed reduction vs. final turning diameter (TD/L)

Influential Factors in Turning

Turning ability is influenced by external forces, such as wind and current, and by the depth of water, which will be explained in each relevant chapter. In this section, influential factors are explained in the case of deep, unrestricted water and a calm environment.

Ship configuration

A fat ship with large block coefficient (C_b) has good turning ability compared to a fine ship with small C_b. A schematic diagram is shown in **Fig.1-19**.

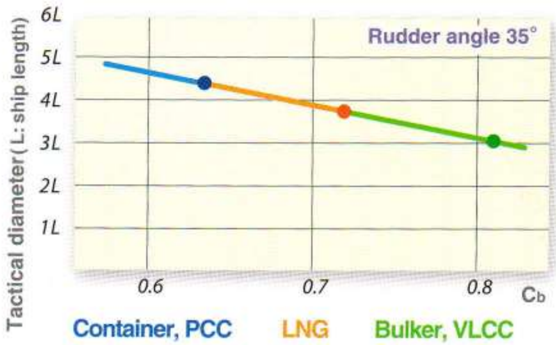


Fig.1-19 Influence of C_b on turning ability

Underwater hull profile

Turning ability is affected considerably by the underwater bow and stern profiles. The cut up at the stern increases turning ability but decreases course-keeping and initial turning ability.
On the contrary, the dead wood at the stern increases course-keeping and initial turning abilities but decreases turning ability.

Trim

The change of trim has the same effect as a change of underwater hull profile. Trim by the head results in a favorable effect on turning ability because of the forward shift of the side force's center of pressure, but an unfavorable effect on course-keeping and initial turning abilities.
On the other hand, trim by the stern results in an unfavorable effect on turning ability, but a favorable effect on course-keeping and initial turning abilities because the side force's center of pressure shifts afterwards. The influence of trim on turning ability is shown in **Fig.1-20**.

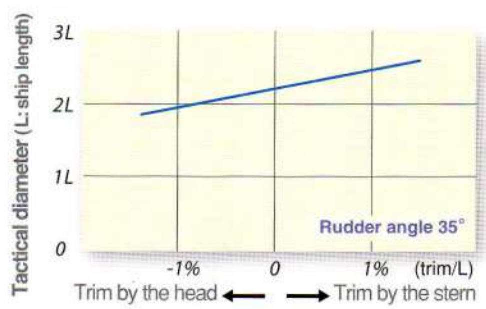


Fig.1-20 Influence of trim on turning ability

Ship speed

When a ship is running steadily at a constant screw rate, there is little reliance on turning ability, and little change in the scale of turning circle.
As shown in **Fig.1-21**, there is little difference between turning ability in Nav.-Full Ahead and that of Slow Ahead.
However, as previously mentioned, during a coasting maneuver with the propeller wind-milling or locked, the ability to steer grows exceptionally worse due to a loss of propeller discharge current over the rudder.
On the other hand, during an accelerating maneuver, turning ability is excellent due to the large slip ratio of the propeller. Turning trajectories for each maneuver are shown in **Fig.1-2**.

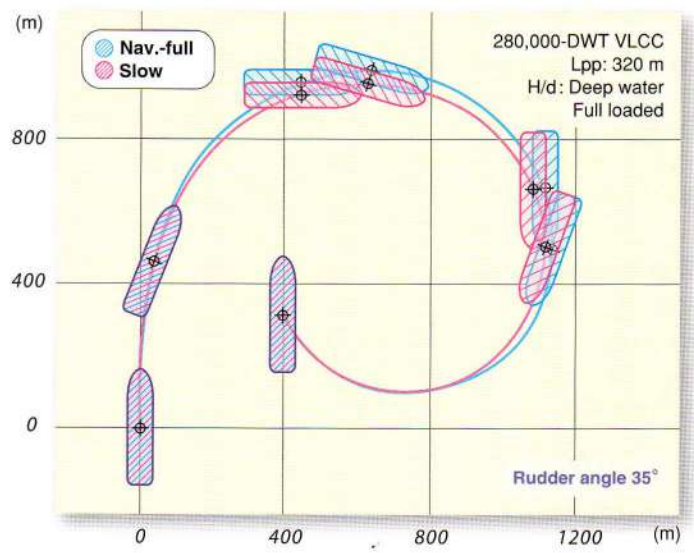


Fig.1-21 Comparison of turning under steady propeller rotation

1.4 Ship Maneuver Tests

The Standards stipulate that a turning test is to be performed to both starboard and port with 35° rudder. Details of the turning circle maneuver are described in Section 1.3. Therefore, ship maneuver tests other than the turning test are discussed in this section.

In the past, the ship maneuver test was limited to a turning test and solely for analyzing turning ability. With the development of large-sized ships with large block coefficients, course-keeping and initial turning abilities have been recognized as important factors in regards to safe navigation.

Zig-zag Maneuver Test

Zig-zag maneuver test is the maneuver where a known amount of helm is applied alternately to either side when a known heading deviation is reached. Although the zig-zag maneuver test is simple, it covers the overall assessment of ship maneuverability due to its proximity to actual ship operations.

Taking the 10°/10° zig-zag maneuver test as an example, the operating procedure of the test is explained as follows: (**Fig.1-22**)

❶ After a steady approach with zero yaw rate, the rudder is put over to 10° to starboard or port (first execute)

❷ When the heading has changed to 10° off the original heading, the rudder is reversed to 10° to port or starboard (second execute)

❸ After the rudder has been turned to port/starboard, the ship will continue turning in the original direction with a decreasing turning rate. In response to the rudder, the ship should then turn to port/starboard. When the ship has reached a heading of 10° to port/starboard of the original course, the rudder is again reversed to 10° to starboard/port (third execute)

Fig.1-22 shows a schematic diagram of the 10°/10° zig-zag test, where the following information obtained from the test is shown:

the first overshoot angle α_1 the additional heading deviation following the second execute; the second overshoot angle α_2 the additional heading deviation following the third execute; the initial turning time to second execute **ta** and the time to check yaw **ts**.

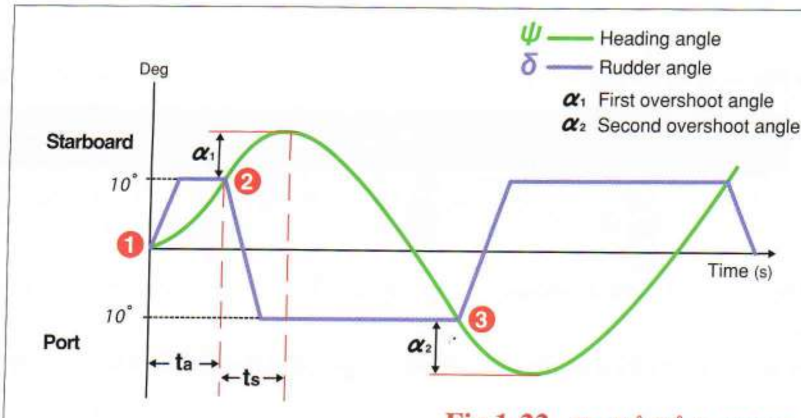


Fig.1-22 The 10°/10° zig-zag test

The 20°/20° zig-zag test is performed using the same procedure as above, using 20° rudder angles and 20° change of heading, instead of 10° rudder angles and 10° change of heading, respectively.
From the zig-zag maneuver tests, essential information regarding ship maneuverability is obtained.
The Standards lay down criteria using the test results for initial turning ability, and yaw-checking and course-keeping abilities as follows:

(1) Initial turning ability

With the application of 10° rudder angles to port/starboard, the ship should not have traveled more than 2.5 ship lengths by the time the heading has changed by 10° from the original heading.

(2) Yaw-checking and course-keeping abilities

- The value of the first overshoot angle in the 10°/10° zig-zag test should not exceed:
  1. 10° if L/V is less than 10 sec;
  2. 20° if L/V is 30 sec or more; and
  3. (5+0.5 L/V) degrees, if L/V is 10 sec or more, but less than 30 sec,

  where L and V are expressed in m and m/sec, respectively.

- The value of the second overshoot angle in the 10°/10° zig-zag test should not exceed:
  1. 25°, if L/V is less than 10 sec;
  2. 40°, if L/V is 30 sec or more; and
  3. (17.5+0.75 L/V) degrees, if L/V is 10 sec or more, but less than 30 sec.

	First overshoot angle α_1	Second overshoot angle α_2
$L/V < 10$ sec	$\alpha_1 < 10^\circ$	$\alpha_2 < 25^\circ$
$10 \text{ sec} < L/V < 30$ sec	$\alpha_1 < (5+0.5\times L/V)^\circ$	$\alpha_2 < (17.5+0.75\times L/V)^\circ$
$L/V > 30$ sec	$\alpha_1 < 20^\circ$	$\alpha_2 < 40^\circ$

- The value of the first overshoot angle in the 20°/20° zig-zag test should not exceed 25°.

First overshoot angle α_1
$\alpha_1 < 25^\circ$

The values of maneuverability indices **K** and **T,** to be discussed below, are calculated from the zig-zag test.
Practical application of the test will be discussed in the section Maneuverability of a Very Large Ship.

Maneuverability Indices K and T

At the steady turning phase, the relation between the ruder angle and the steady turning rate is expressed as shown in **Fig.1-23,** with coefficient **K** known as the turning index "gain". The time needed for the turning rate to develop to 63% of steady turning rate is expressed as **T**. Coefficient **T** is known as the initial turning index, or "time constant". It is said that a large **K** value provides a favorable turning ability. Factors affecting the values of turning indices **K** and **T** are water depth, draft, trim and rudder angle.

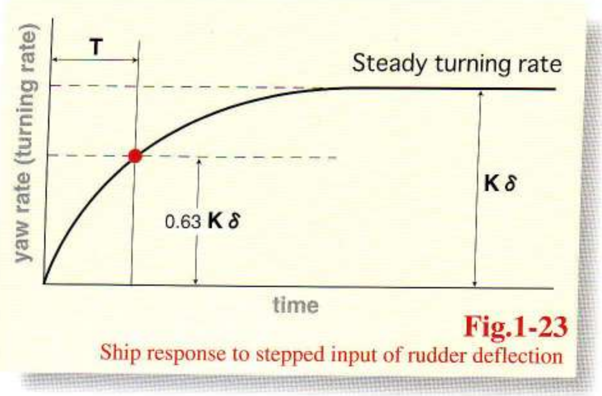


Fig.1-23 Ship response to stepped input of rudder deflection

In combinations of large or small values of **K** and **T**, maneuvering characteristics may be classified in four patterns as shown in **Fig.1-24**. However, because **K** (steady turning ability) and **1/T** (initial turning ability, or responsiveness to the helm) have a countervailing nature to each other, most ships belong to one of the two patterns shown in the figure (i.e., patterns B and C).

Ship A and **Ship D** belong to types where steady turning ability and initial turning (responsiveness to the helm) ability are either good or poor, and ships belonging to the above patterns are very scarce.

Ship B has good initial turning ability but poor steady state turning ability.
Fine high-speed cargo ships, such as container ships, belong to this pattern.

Ship C has poor initial turning ability but good steady state turning ability. Fat ships, such as full-loaded VLCCs and bulk carriers, belong to this pattern.

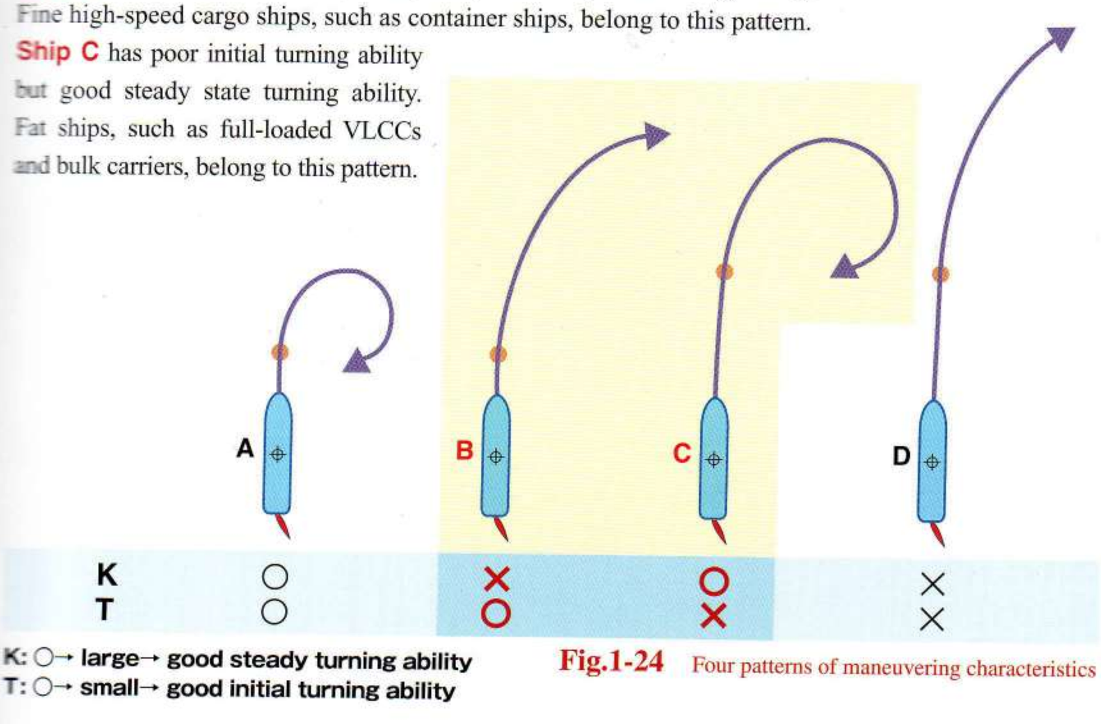


Fig.1-24 Four patterns of maneuvering characteristics

Turning lag to new course

Let us consider a ship is changing course. Due to the turning lag, it is not possible to bring the ship onto the intended course-changing path if the rudder is put over when the ship has reached the course-changing point as shown in **Fig.1-25**.

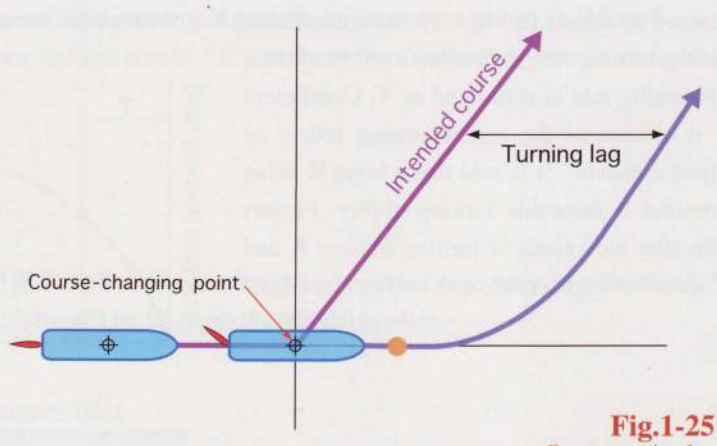


Fig.1-25
Course-turning lag

When changing course, the rudder should be put over before reaching the course-changing point, taking the turning lag into account. The distance to new course is the distance along the original approach course, from the commencement of rudder deflection to the course-changing point. The relationship between the course-changing distance to new course and the course-changing angle is expressed in **Fig.1-26**.

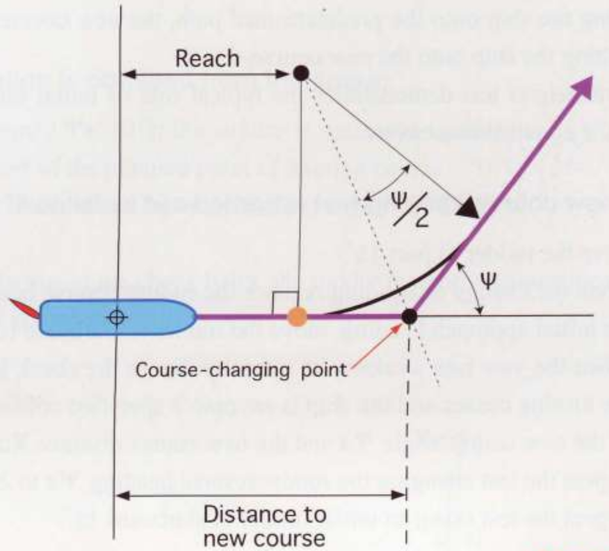
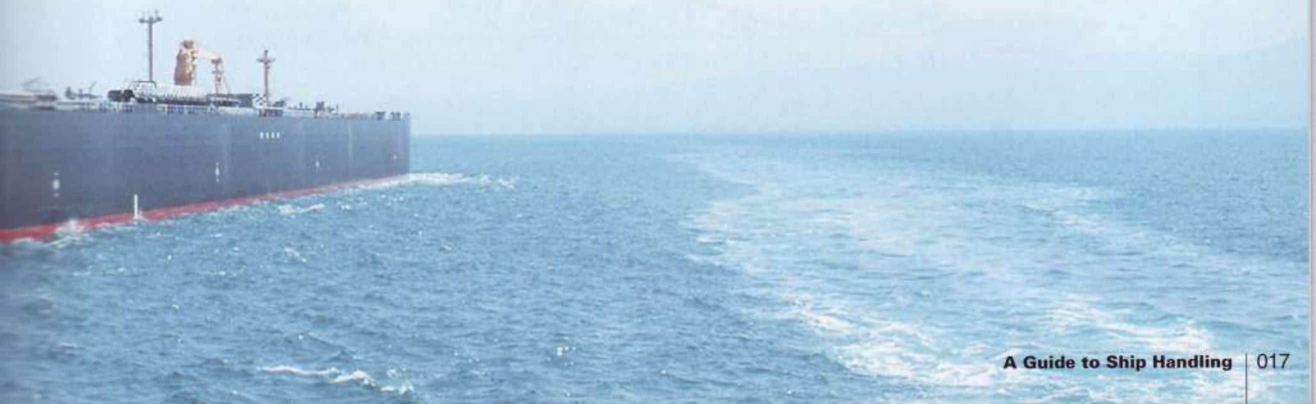


Fig.1-26
Course-changing distance (new course distance)

The distance to a new course is affected by the type of ship, the ship's condition and water depth.



New Course Keeping Test

The new course-keeping test provides information about the timing of the initial rudder deflection for bringing the ship onto the predetermined path, the new course distance, and the timing of check helm for setting the ship onto the new course.

This maneuver test demonstrates the typical role of initial turning and yaw-checking abilities, and is used for practical maneuvers.

The new course-keeping test is carried out as follows:

1. Move the rudder to port 15°.
2. When the change of heading reaches the rudder reverse heading, Ψ_2, (Ψ_2=10°, 20°, 30°・・・) from the initial approach heading, move the rudder to starboard (check helm).
3. When the yaw rate weakens its intensity due to the check helm, return the rudder amidships. When the turning ceases and the ship is set onto a specified course, finish the test with the data acquisition of the new course angle Ψ_4 and the new course distance **Xc**.
4. Repeat the test changing the rudder reverse heading Ψ_2 to 20°, 30° and etc.
5. Repeat the test using an initial rudder of starboard 15°.

Repeat steps 1, 2 and 3 with "starboard" and "port" reversed.

Fig.1-27 shows an example of the new course-keeping test.

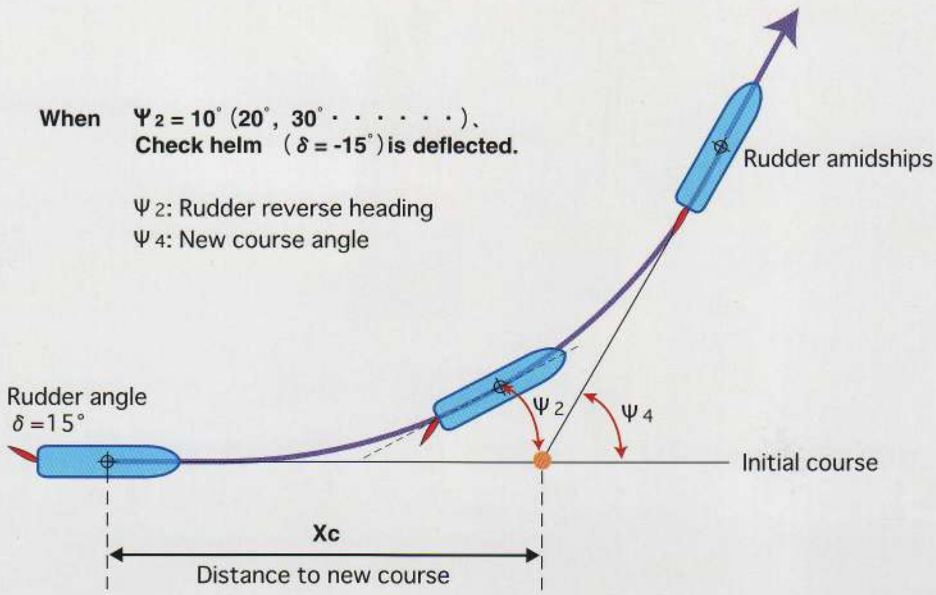


Fig.1-27
Executing procedure of new course-keeping test

The test results are arranged by plotting **Xc** versus Ψ_4 and Ψ_4 versus Ψ_2 curves as shown in **Fig.1-28**, by which the timing of check helm corresponding with the new course angle, and of initial rudder deflection can be predicted.

For example, the following information is obtained from the figure:

- when altering course to 40° to starboard (Ψ_4=40°), the rudder is deflected to starboard 15°, at the position 580 m (**Xc**=580 m: 2.1 L) short of the planned point of altering course
- when the change of heading reaches 22° starboard (reverse heading angle Ψ_2 =22°), the rudder is deflected to port 15°
- when the yaw rate weakens its intensity due to the check helm, the rudder is returned amidships. Thus, the ship is brought onto the new course path.

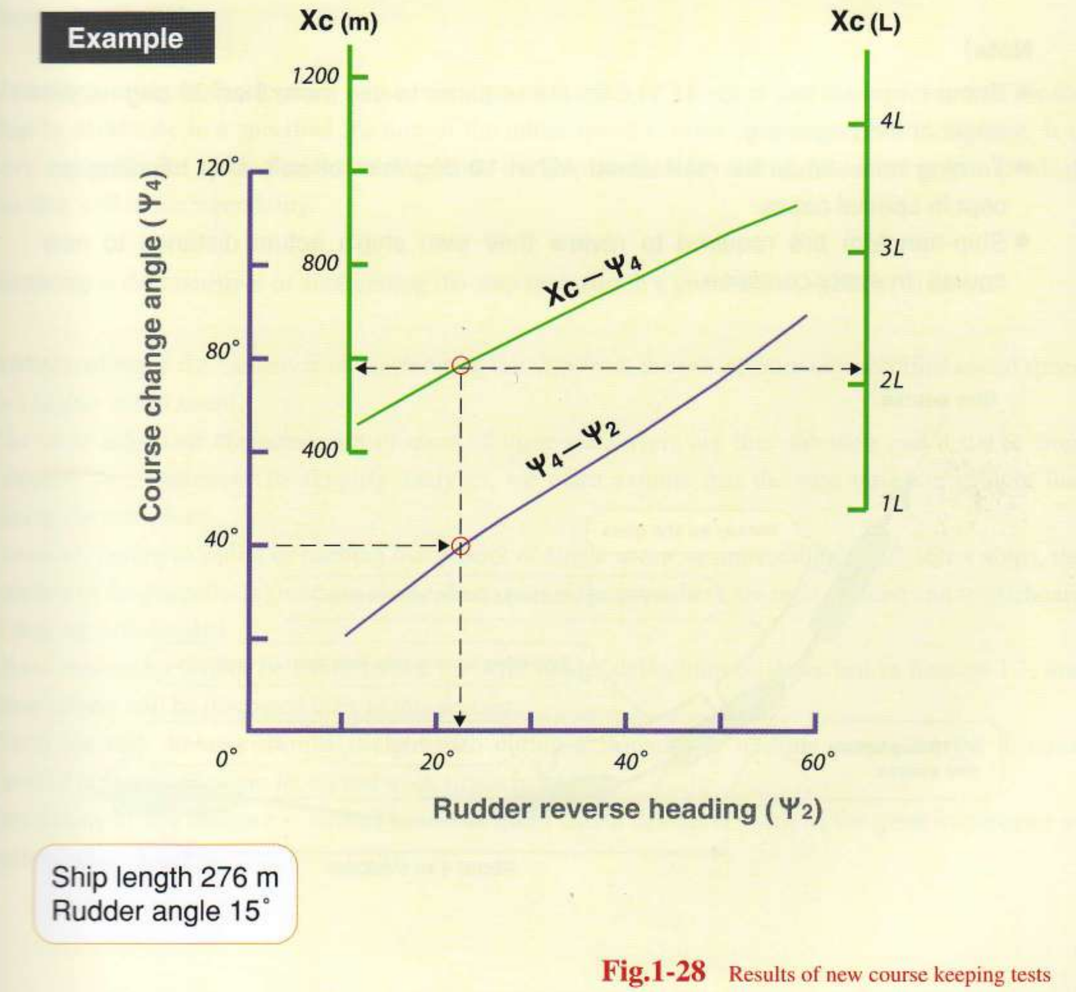


Fig.1-28 Results of new course keeping tests

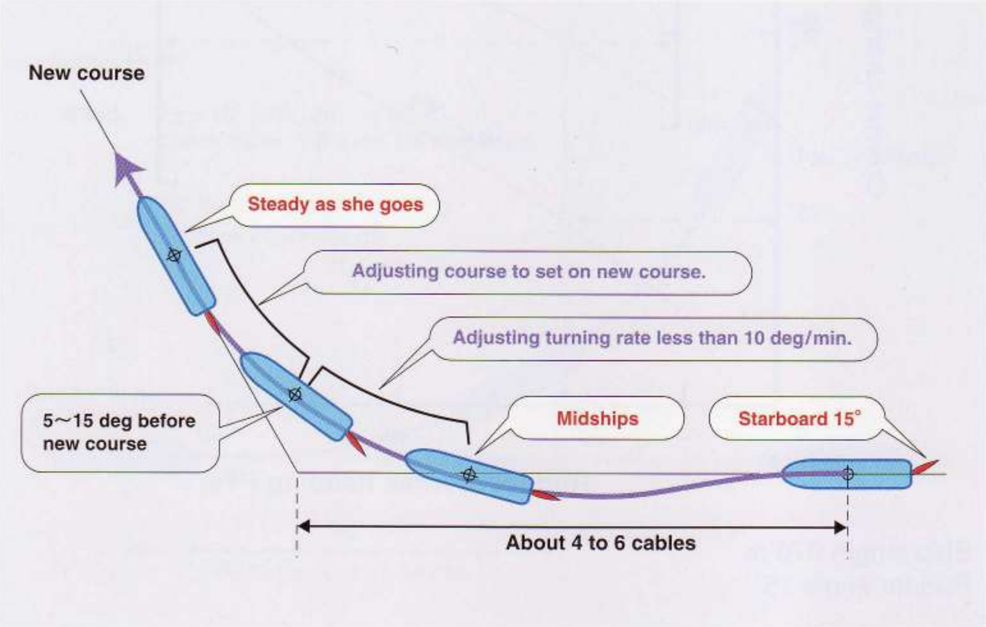
Most navigators use the following procedure to change course safely.

Sample)

Order	Status	Remark
Starboard 15°	4~6 cables before way point	Note
Midships	Suitable turning rate	Turning rate ≦ 10°/ min
Adjust rudder angle	Avoid excessive turning rate	Turning rate ≦ 10°/ min
Adjust rudder angle	Adjust course on new course	5~15 deg before new course
Steady as she goes	Heading on new course	

Note)

- Some large vessels such as VLCCs are required to use more than 20 deg rudder angle at the beginning.
- Turning rate should be maintained within 10 deg/min for safe ship handling except in special cases.
- Ship-handlers are required to review their own ship's actual distance to new course in every condition.



1.5 Speed Control

Introduction

Stopping, coasting, backing and accelerating are important ship maneuvers:
The first three are particularly important for operations in crowded waters or in proximity to fixed structures. However, the interactions between hull and propeller during these maneuvers are quite complex.

Stopping is the maneuver of decelerating the ship by use of full backing power from any given ahead speed until the ship comes to rest. When discussing stopping capabilities, at least two ahead speeds should be considered: a crash stop from "full-ahead sea-speed" and a stop from "harbor speed" of about 12 knots.

Coasting refers to decelerating without using backing power. The time and distance required for the ship to decelerate to a specified fraction of the initial speed is often of interest in ship handling. It is very important for a ship handler to decelerate the ship at the least sustainable ahead power at which the ship will retain steerability.

Backing is the maneuver of accelerating the ship from rest to a given astern speed or distance.

Accelerating is the maneuver of accelerating the ship from the rest or from any specified ahead speed to a higher ahead speed.
The most important characteristics of most of these maneuvers are time duration and distance from initiation to completion. To simplify analyses, we often assume that the ship travels a straight line during the maneuver.
However, during stopping or backing maneuvers of single screw or uni-rotating multi-screw ships, the rotation of the propeller(s) tends to swing the to port if the propellers are right-handed and to starboard if they are left-handed.
These tendencies cannot be compensated for with rudder deflections as described in Section 1.1, and these effects will be discussed later in this section.
When the ship deviates from a straight path during a stopping or backing maneuver, the distance traveled is measured along its curved track (track reach).
Projections of this distance -- termed head reach and lateral deviation -- are of the great importance as performance characteristics. (Fig.1-29)

Stopping

Introduction

Stopping is a maneuver of interest primarily from the point of view of avoiding collision. When decelerating the ship by use of full backing power from "full ahead sea-speed" until the ship comes to rest, the length of the track (track reach) is called "crash stopping distance" or "short stopping distance", which indicates the most important index for stopping ability. The Standards define the terminology used in stopping tests as shown in Fig.1-29. Stopping ability is measured by the "track reach" and "time to dead in water" realized in a stop engine-full astern maneuver performed after a steady approach at full test speed. Lateral deviations are also of interest, but they are very sensitive to initial conditions and wind disturbances.

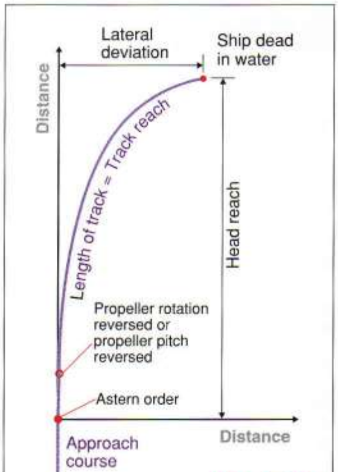


Fig.1-29
Definitions used in stopping test

The IMO Standards stipulate the following stopping ability criterion to be complied with:

The track reach in the full astern stopping test should not exceed 15 ship lengths.
However, this value may be modified by the Administration where ships of large displacement make this criterion impracticable, but should in no case exceed 20 ship lengths.

Operating elements and ship response during stopping maneuver

The time history records of propeller thrust, ship speed, propeller rpm and distance traveled during a stopping maneuver are shown in Fig.1-30.

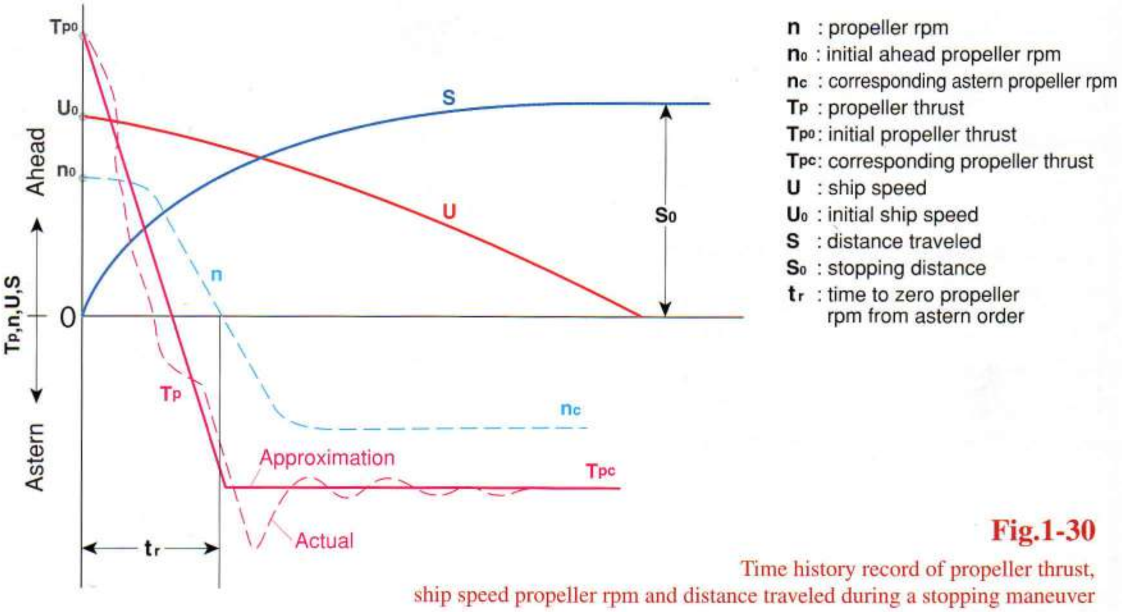


Fig.1-30
Time history record of propeller thrust, ship speed propeller rpm and distance traveled during a stopping maneuver

As seen in the figure, the decrease of propeller rpm **n** and propeller thrust **Tp** is relatively quick, and settles down to the corresponding astern propeller rpm **nc** and backing thrust **Tpc**, whereas ship speed **U** decelerates gradually and needs a considerable time to reach zero after the generation of steady backing thrust.

Accordingly, the rate of increase of distance traveled **S** is slow and reaches to the stopping distance **So** when the ship comes to rest.

Fig.1-31 shows an example of the measured and computed stopping distances at several initial speeds of a tanker in full load and in ballast conditions.

It is known that these stopping distances are calculated very accurately.

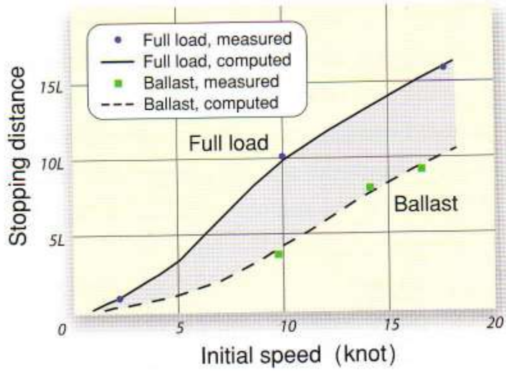


Fig.1-31 Measured and computed stopping distance of a tanker

Influential factors on stopping ability

1. Coefficient of fineness (Cb)

When assuming the two types of ships having the same displacement, fat ships with large Cb, such as tankers or bulk carriers, constitute characteristic features with longer stopping distances compared to fine ships with small Cb, such as container ships, because the ship with large Cb increases added mass in a longitudinal direction.

2. Astern thrust

Needless to say, the larger the value of constant thrust is, the shorter the stopping distance attained. Fig.1-32 shows stopping distance versus three stages of astern thrust: full astern, half and slow astern thrust.

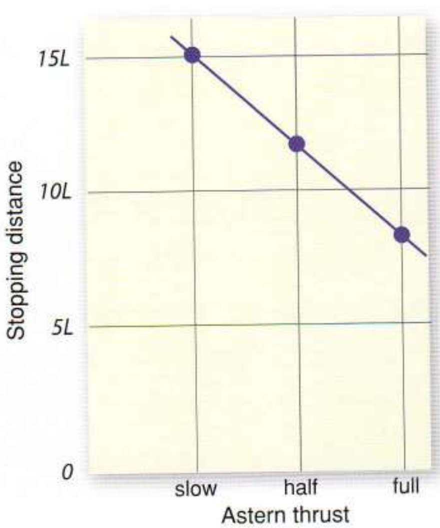


Fig.1-32
Influence of backing thrust

3. Types of power plants and propellers

The time lag in reversing propeller rpm tends to dilute the resulting thrust increase. For large tankers, stopping is relatively insensitive to time lag in reversing the engine. On the other hand, it may be important for relatively light, high-speed ships, where the thrust is large compared to ship's mass. The former explains why there is a slight difference in stopping distance between the large ship installed with a turbine engine and one with diesel engine, without being affected by the difference of time lag in reversing the engines. The latter explains why, for a relatively small ship, the stopping ability of a ship equipped with a controllable pitch propeller (CPP) is superior a ship equipped with a conventional fixed pitch propeller (FPP), because the time required to reverse the notch of CPP is relatively short.

Item	Stopping Distance		Remarks
	Short	Long	
Displacement / ME Output	Large	Small	
Main Propulsion	Diesel	Turbine	Not apparent
Propeller	CPP	FPP	

Table 1-2

4. Displacement and loading condition

Stopping distance and time to stop vary almost directly with a ship's displacement. Fig.1-33 shows the crash stopping distances of VLCCs, from which it is also known that the stopping distance of VLCCs in full-load condition is approximately from 1.5 to 2.0 times as long as that in ballast condition.

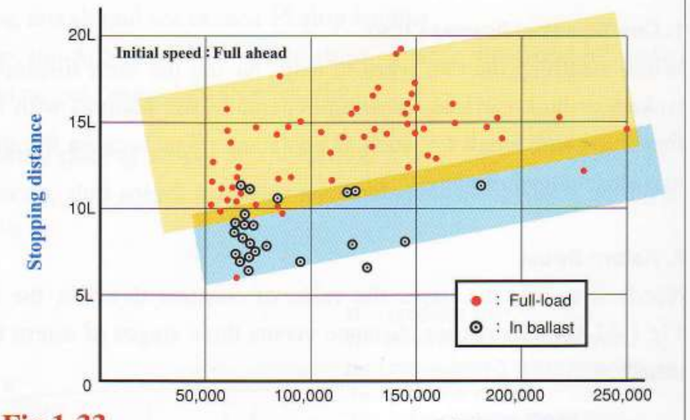


Fig.1-33
Short stopping distances (VLCC)

5. Examples of stopping ability

Table 1-3 shows the results of sea trials on short stopping distances "s".

Ship Type	DWT	Lpp (m)	Draft (m)	Eng.	V (Knot)	S (m)	S/Lpp
Ore Carrier	55,700	211	11.8	Diesel	16.0	1,875	8.9
Car Carrier	21,443	190	10.3	Diesel	20.0	2,568	13.5
Container Ship	81,171	284	14.0	Diesel	25.0	3,620	12.7
LNG Carrier	11,000	124	6.5	Turbine	15.0	1,441	11.6
LNG Carrier	72,571	276	11.4	Turbine	19.5	2,580	9.3
Product Tanker	48,658	180	12.6	Diesel	15.1	2,280	12.6
Product Tanker	105,084	233	14.7	Diesel	15.5	3,658	15.7
VLCC	209,000	326	17.7	Turbine	16.6	4,750	14.6
VLCC	279,989	319	20.3	Diesel	15.5	4,593	14.4
VLCC	310,309	333	21.1	Diesel	15.6	3,600	10.8
VLCC	332,000	320	24.8	Turbine	14.8	3,241	10.1

Table 1-3

6. Turning motion during stopping

In this subsection, turning motion of a single-screw ship with right-handed propeller during stopping maneuver is discussed.

As shown in **Fig.1-34**, when the propeller is reversing, the difference in reaction force exerted between the upper blade and the bottom blade results in a net force to port that tends to cause the ship to turn to starboard. (known as "the direct effect of propeller.")

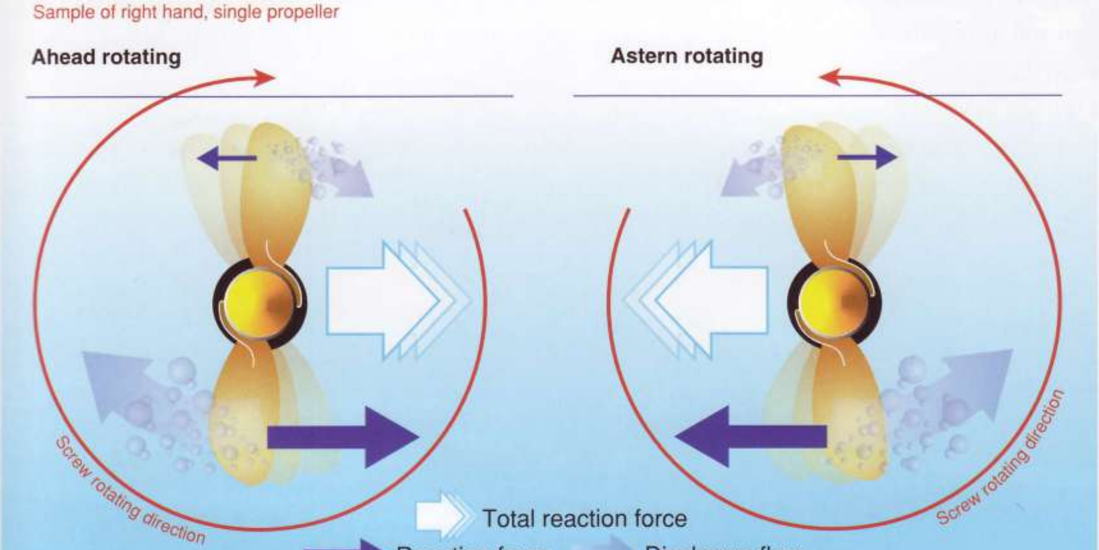


Fig.1-34
Direct effect of propeller

Also, as shown in **Fig.1-35**, the interactions between hull (stern) and propeller discharge currents produces the strong force to port that tends to cause the ship to turn to starboard. (knows as "the indirect effect of propeller on hull.")

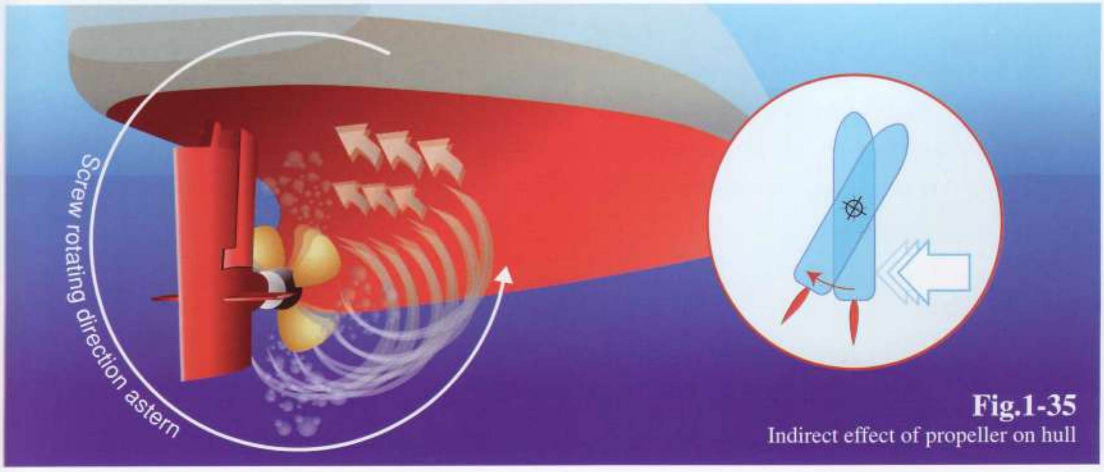


Fig.1-35
Indirect effect of propeller on hull

Furthermore, as stated in Section 1.1, the rudder loses most of its effectiveness during stopping because the net velocity of flow over the rudder is small.
Generally, the ship with right-handed propeller tends to turn to starboard during stopping maneuver due to the above stated direct and indirect effects of the propeller.
In fact, numerous stopping trials indicate that ships tend to turn to starboard.

However, because rudder effectiveness and course stability are lost during stopping, the turning direction and its trajectory are susceptible to such external disturbances as wind and current, and are usually unpredictable.
Fig.1-36 shows the variations of track reach in sea trials of VLCCs.
Particularly, it is noted that many of the ships in ballast condition that are very susceptible to external disturbances tend to turn to port. Therefore, the utmost care should be taken when executing the crash stop maneuver, taking surrounding sea room and traffic conditions into account.

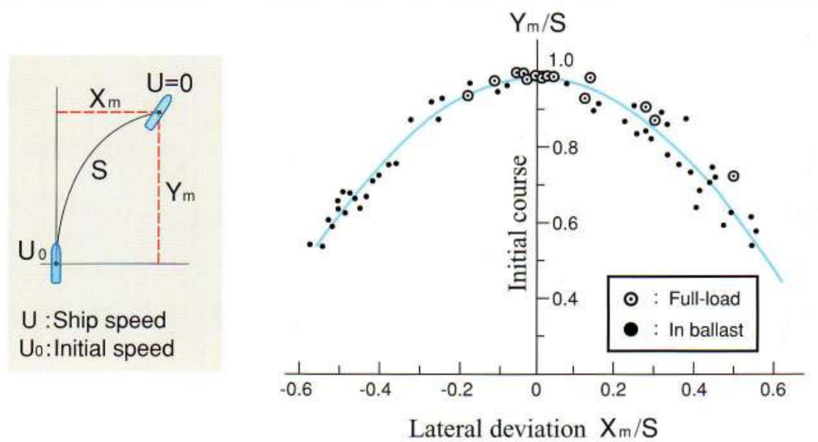
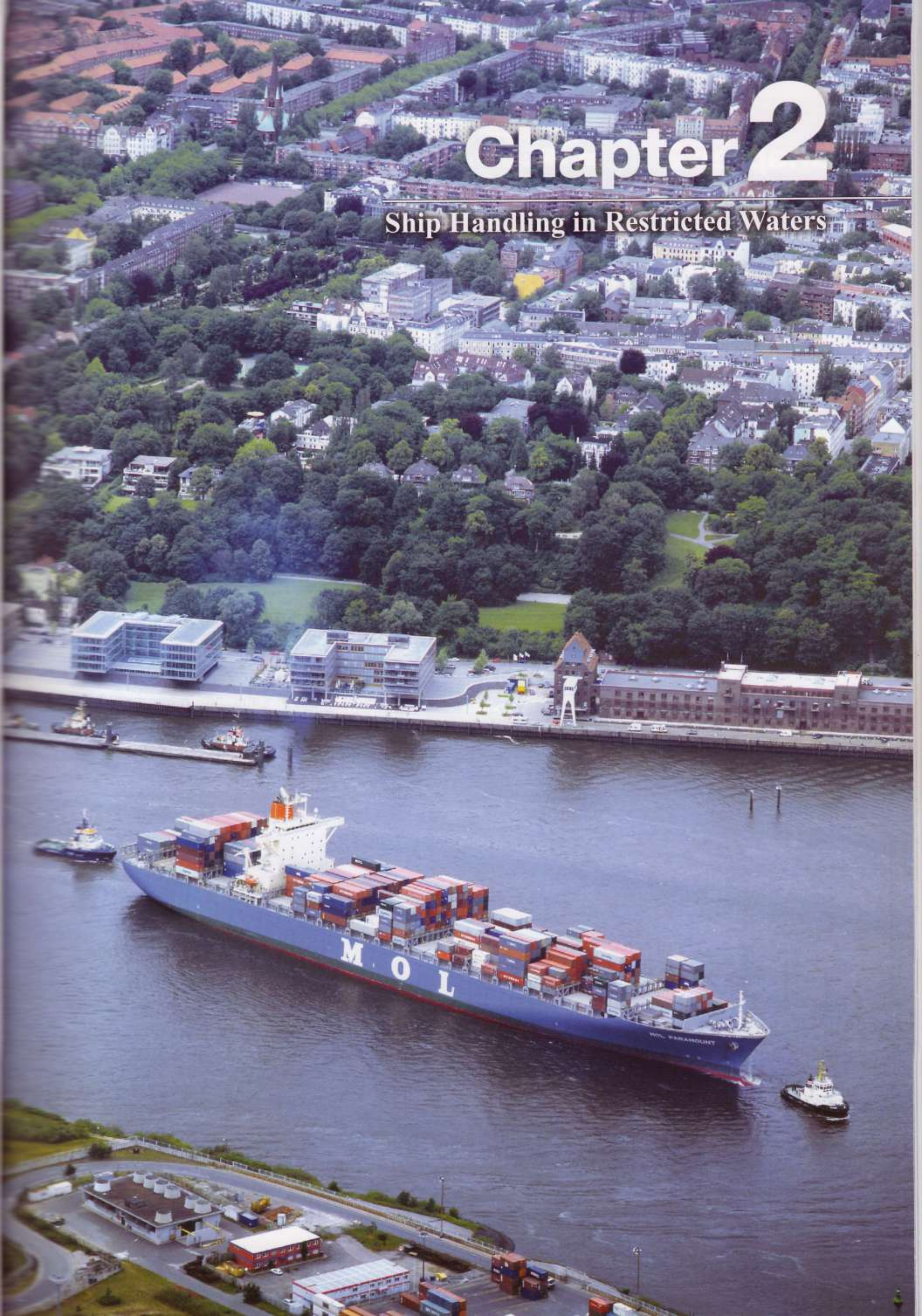


Fig.1-36 Position of ships dead in water in crash stopping trials

At high speeds and sufficient sea room, it is said that turning of a large ship is much superior to stopping for avoiding a hazard.
Advance in a turn is much less than head reach in stopping and directional control is maintained. From a slower speed approach, the stopping maneuver assumes greater importance and the turning maneuver becomes less significant.

Chapter 2

Ship Handling in Restricted Waters



Chapter 2

Ship Handling in Restricted Waters

2.1 General

Ship handling in confined waters, particularly in narrow waterways, has been receiving a great deal of attention in recent years. With the ever-increasing size of ships, as exemplified in tankers and bulk carriers, potential hazards of collision and grounding attract attention, and control errors may results in personal injury and costly damage to both the ship and the surrounding environment. An accident can have far-reaching effects. In regard to maneuvering performance, shallow waters may be defined as those in which the ratio of water depth to ship draft is three or less. At greater ratios, shallow-water effects on maneuvering performance become rapidly less significant as the water deepens. Restricted waters may be defined as narrow channels or canals, waterways with vertical or overhanging banks or areas that include piers and breakwaters which introduce a substantial change in maneuvering characteristics or requirements. Obviously, most restricted waters include shallow water, and many include significant currents and tides. In restricted waters, areas available for navigation are limited, further complicating the problems of maneuvering and control of the ship.

2.2 Parameters Related to Shallow Waters

1) Froude Number (F_n)

The Froude Number is defined as

$$F_n = U/\sqrt{gL}$$

U: Ship speed (m/sec)
g: Acceleration due to gravity (9.8m/sec^2)
L: Ship length (m)

Reference Annex 1, Chart showing Froude Number from ship length and ship speed

The Froude Number is a dimensionless number and has been used for matching the similarity of motion between a model ship in tank tests and an actual ship under way. Hence, this number is used for comparing and arranging the experimental results of ships with various sizes and speeds under the normative method.

2) Froude Depth Number (F_{nh})

In a similar way to the Froude Number, the following dimensionless number is defined as

$$F_{nh} = U/\sqrt{gH}$$

H: Depth of water (m)

This number is called the Froude Depth Number and is used for comparing the experimental results of ships with various speeds and water depths under normative method.

2.3 Shallow-Water Effects

Effects on Hull Sinkage and Change of Trim (Squat)

When a ship is proceeding, surrounding water is displaced towards the sides and the bottom of the ship, exerting the flow of water relative to the moving ship. The pressure distribution that develops around the ship moving through water distorts the water line by raising the level of the high pressure regions ahead of the bow and aft of the stern, while, because of the relative velocity increase, lowering it along the length of the hull, particularly amidships. Fig.2-1 shows an illustration of pressure distribution of water flow around the hull.

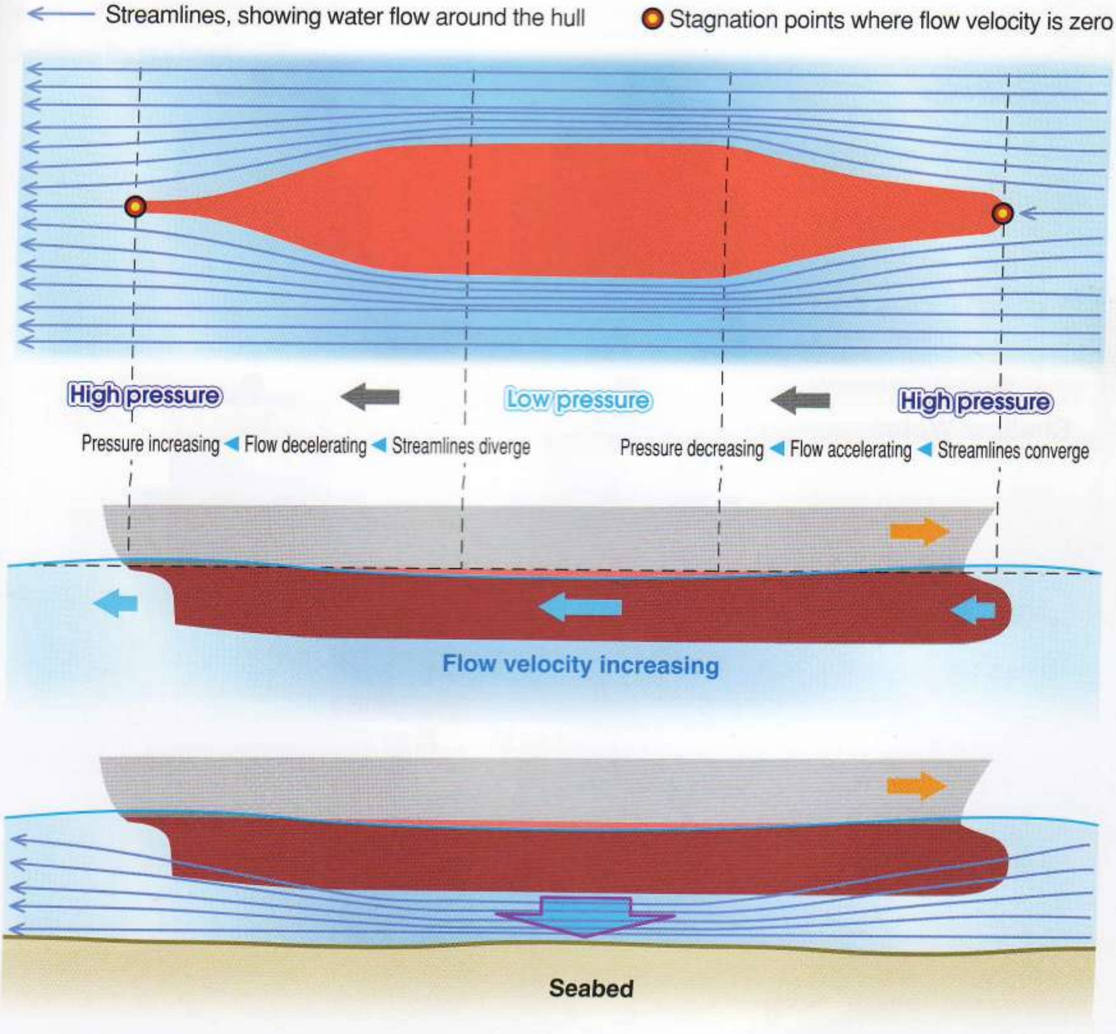


Fig.2-1
Pressure distribution of water flow around the hull

Consequently, the overall effect of the pressure distribution is to create a local depression of the mean level that coincides with the ship and travels along with it. Furthermore, this drop in the water level is concentrated amidships, where immersed hull volume is greatest, and the ship will also move bodily downwards to maintain its full buoyancy, including a change of trim. This effect is imperceptible and irrelevant in deep water, but it becomes significant when the ship moves into shallow water, where the restriction of flow between the hull and the seabed weakens the three-dimensional flow towards the keel and the two-dimensional flow parallel to the hull grows stronger. Therefore, the mean water level around the hull is depressed further accompanied by the change of trim, which results in a significant reduction of under keel clearance. This phenomenon is known as "squat." **Fig.2-2** shows the flow pattern, pressure distribution and water level around the hull in shallow water.

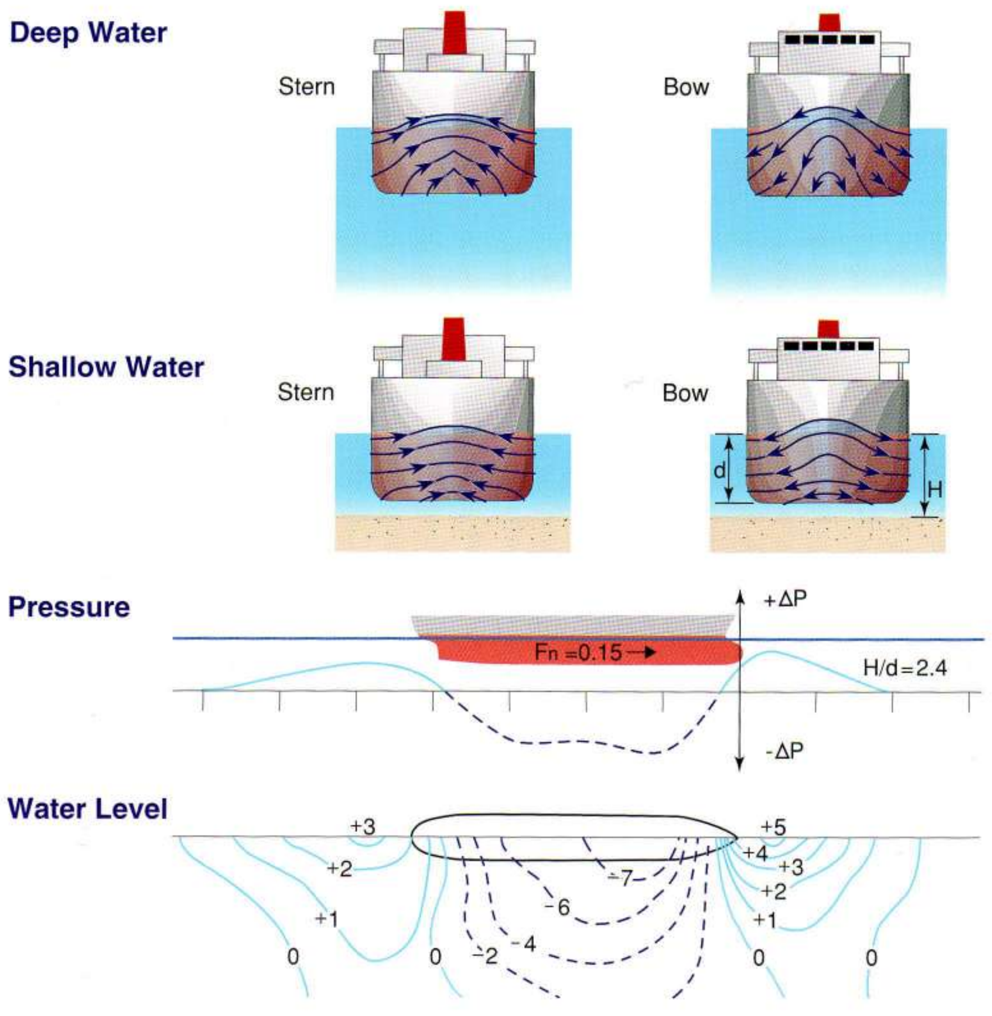


Fig.2-2 Flow pattern, pressure distribution and change of water level in shallow water

Fig.2-3 shows the bow sinkage (F.P.) and stern sinkage (A.P.) when proceeding in deep water (solid line) and in shallow water (chain line).

The squat is conspicuous in shallow water. Trim by the head is prominent in the low speed range, and trim by the stern in the high-speed range. As the Froude Number approaches 0.25 (a ship of 300 m length with its speed about 26 knots), the bow of the ship tends to float, and the stern tends to sink abruptly. However, large-sized ships usually navigate shallow water at stand-by speed, and most ships are considered to be proceeding with the trim by the head. Because the squat is mainly related to large-sized ships with full-load conditions, it is important to obtain the amount of bow sinkage, as most of the ships tend to be trimmed by the head.

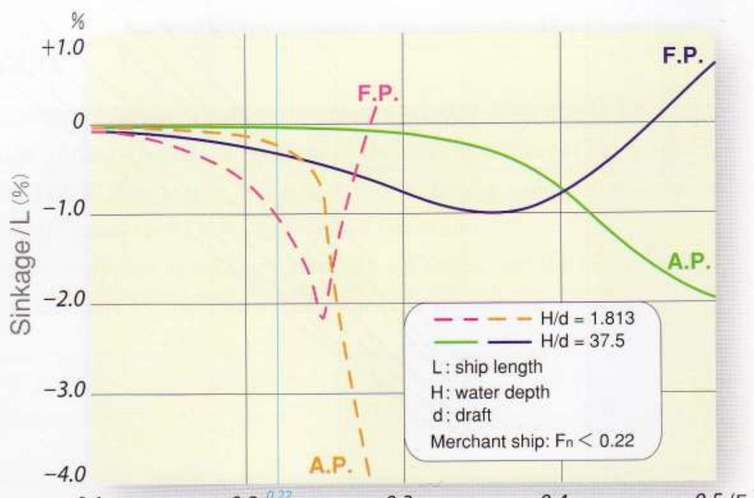


Fig.2-3 Bow and stern sinkage

Fig.2-4 shows the squat estimation chart for a ship in combination with its length (L), and speed (U).

Instructions: (Plotted by broken line: bow sinkage of a 300 meter tanker with 17 meter draft proceeding at 12 knots in water of 22 meter depth.)

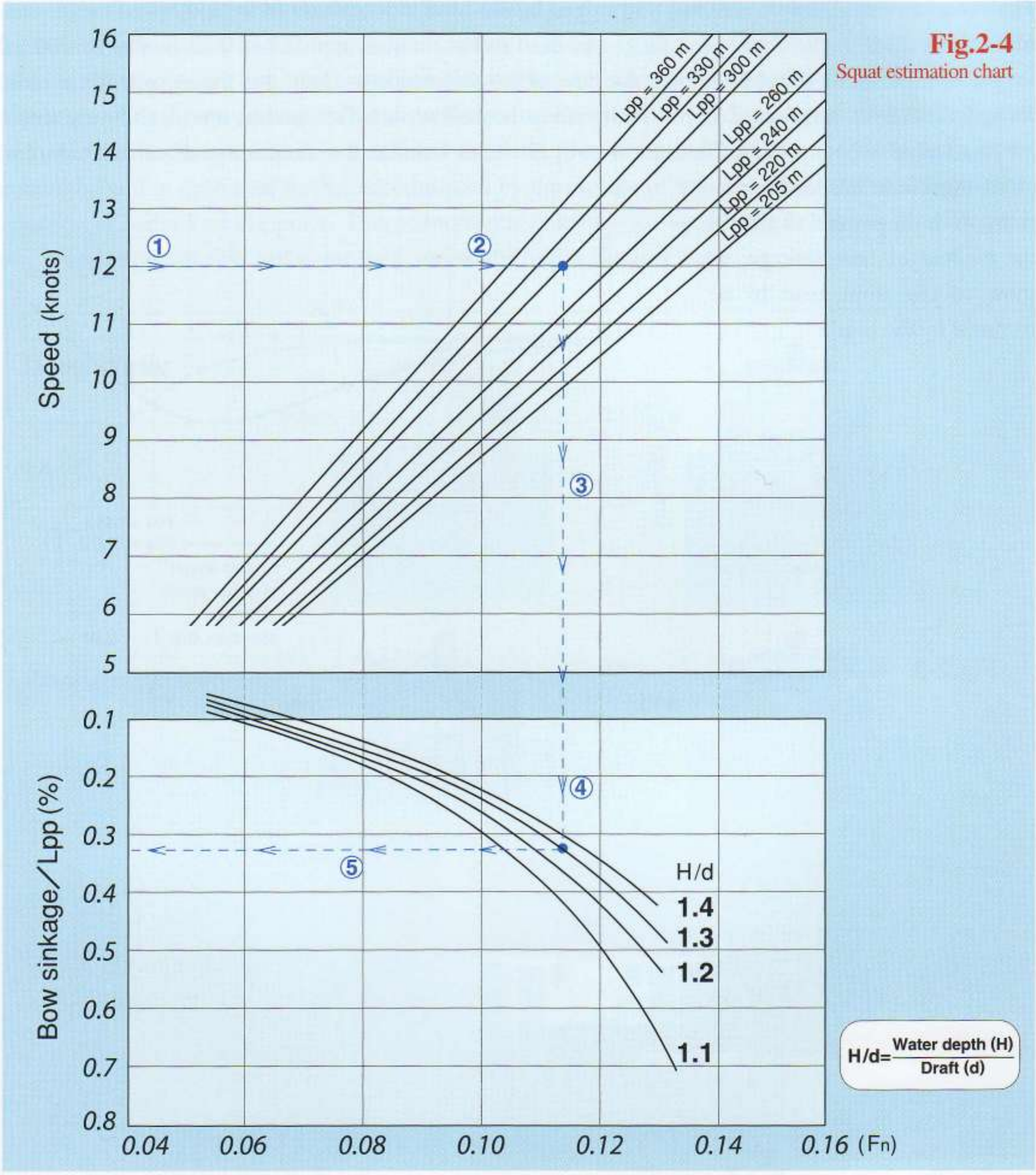


Fig.2-4
Squat estimation chart

① Enter ship speed in knots. (U : 12 knots)

② Draw parallel line to intersect appropriate ship length. (L : 300 m)

③ Drop perpendicular line to intersect abscissa of the upper diagram to obtain the corresponding Froude Number. (Fn : 0.114)

④ Continue to draw perpendicular line to intersect appropriate water depth/ship draft. (H/d=1.3)

⑤ Draw parallel line to intersect bow sinkage/ship length (%) to give bow sinkage as percent of ship length.
(Bow sinkage/ship length (Lpp)=0.32%, i.e., amount of bow sinkage=300 × 0.32%=0.96 m)

Effect on Hull Resistance and Ship Speed

When a ship moves into shallow water, ship speed is reduced due to increased wave making resistance and the deterioration of propulsive efficiency.

From the results of speed trials, the following formula is proposed for the critical water depth affecting hull resistance:

$$H < 3\sqrt{Bd}$$

H: Water depth (m)
B: Ship breadth (m)
d: Ship draft (m)

Effect on Turning Capability

When a ship is turning in shallow water, the turning diameter increases considerably due to the bluntness of hull response at the initial stage of the turn and the increase of the turning moment of resistance. Fig.2-5 shows the results of 280,000-DWT, ship length 320 meter VLCC tanker simulations in water depth1.5 times ship draft (H/d=1.5), ship speed 15.7 knots, full-loaded condition.

In shallow water, the maximum advance increases up to approximately 1.4 times, and the tactical diameter increases up to about 1.3 times as compared to turning in deep water, respectively.

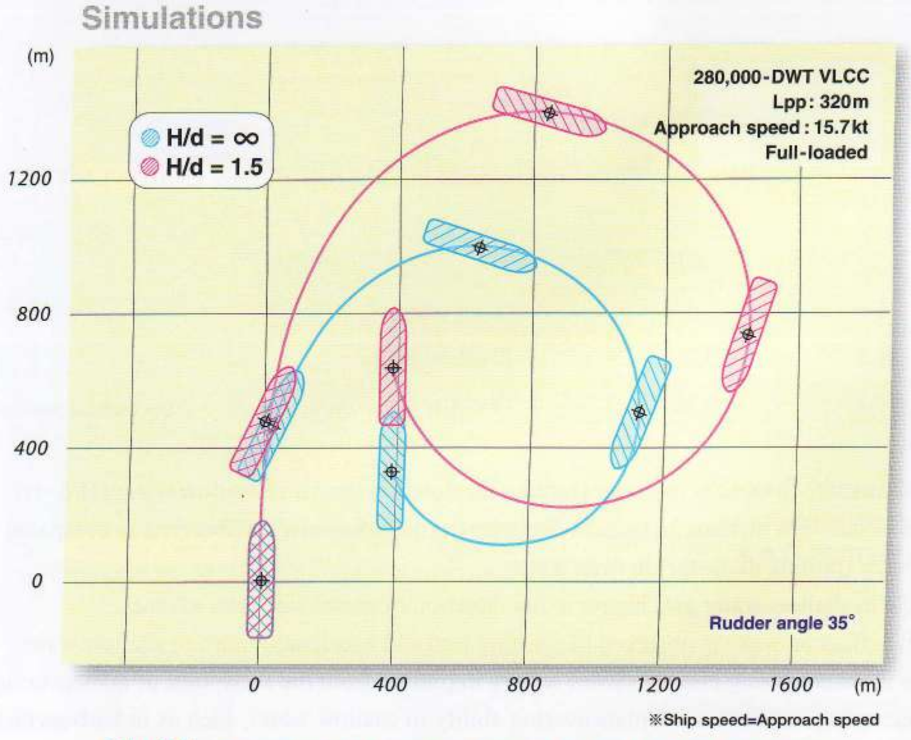


Fig.2-5 Turning circle (comparison between deep and shallow water areas)

Fig.2-6 summarizes experimental data on turning rate.

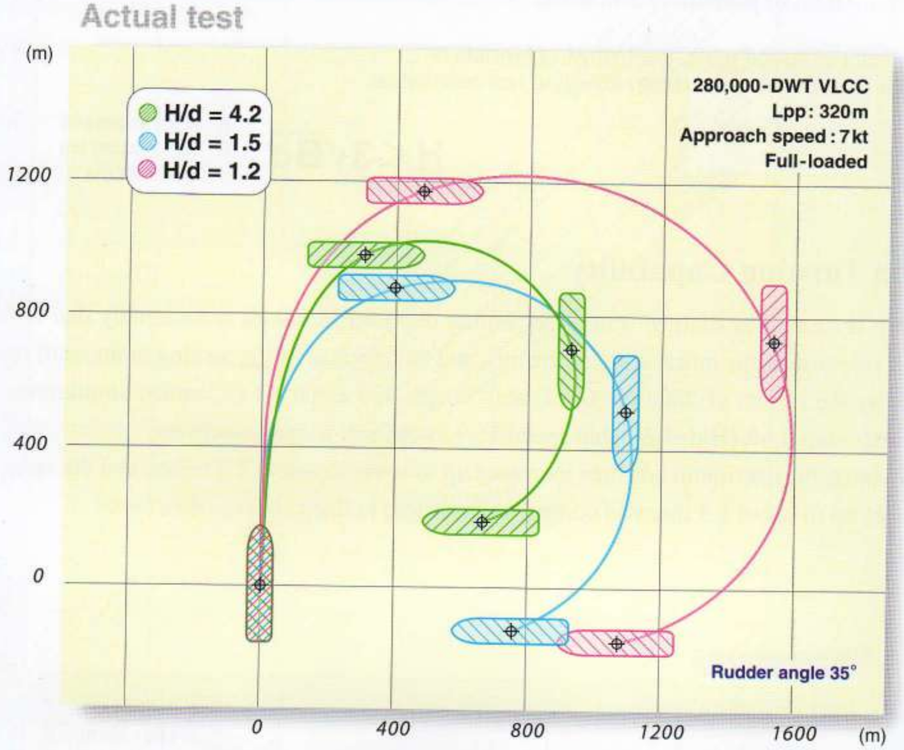


Fig.2-6 Effect of water depth on turning performance (280,000-DWT VLCC)

H/d	TD	
4.2	2.8L	Deep water
1.5	3.3L	Shallow water
1.2	4.9L	Shallow water

(TD=Tactical diameter)

A substantial increase in tactical diameter (turning diameter) is shown in shallow water (H/d=1.2).
In the figure, about 75% increase in tactical diameter (turning diameter) is observed as compared to the tactical diameter (turning diameter) in deep water.
Turning circle in shallow water gets bigger in the direction of vessel side than advance.
And the same effect on wake is observed in coasting turn and acceleration turn in shallow water.
This change in maneuvering characteristics is very important from the viewpoint of maneuvering safety, due to increasing importance of maneuvering ability in shallow water, such as in harbors and other restricted waterways.

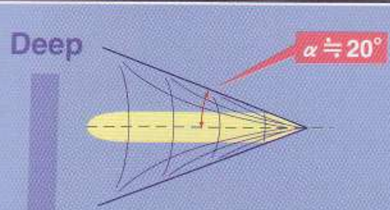
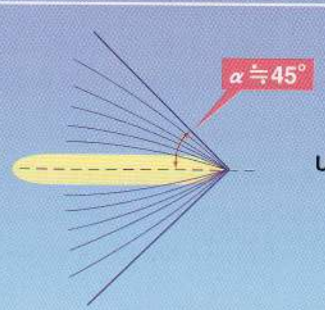
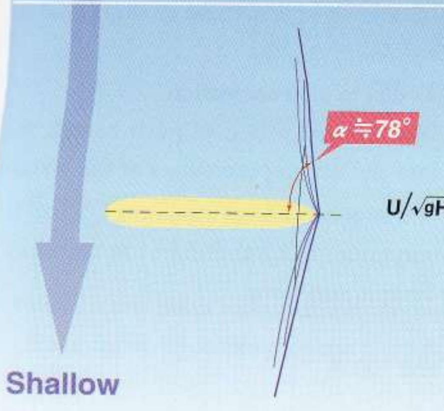
Recognizing the Signs of Squat

A ship's officer on watch will notice the following tendencies in the ship's behavior when the ship comes into shallow water:

1. Hull resistance is increased and the ship begins to slow down as it becomes affected by squat.
2. As shown in **Fig.2-7**, the diverging wave pattern appears to widen as the Froude Depth Number (F_{nh}) is increased.
3. The close proximity of the propeller to the seabed tends to create greater hull vibration.

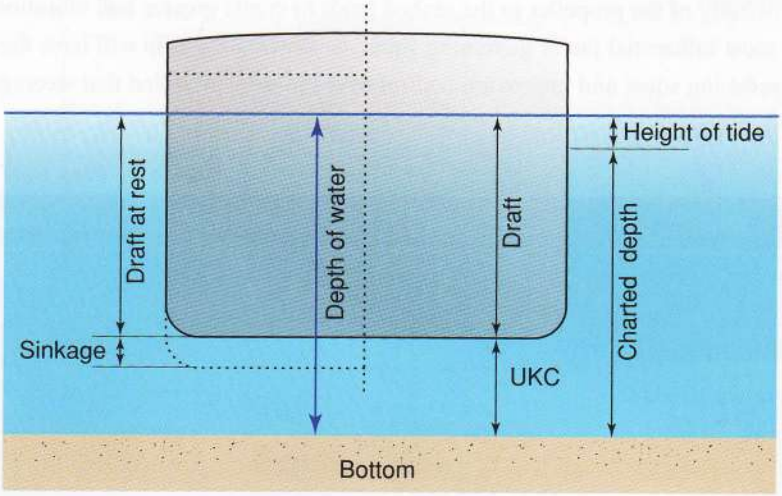
   Speed is the most influential factor governing squat, so slowing the ship will have the most immediate effect in reducing squat and improving control over the ship, provided that steerage way is maintained.

Fig.2-7 Water depth and wave pattern

Wave	F_{nh}	Sign of Squat	Remarks & Action to be taken
	$U/\sqrt{gH} = 0$	Nil	• No action to be taken
	$U/\sqrt{gH} = 0.7$	Slight	• Rather shallow water • Pay attention to UKC and speed. • Reduce speed if necessary.
	$U/\sqrt{gH} = 0.99$	Serious	• *Reduce speed to regain control of ship.* • Abnormal hull vibration is observed.

Required Under Keel Clearance

For safe navigation in shallow water, it is essential to keep sufficient clearance between the ship's bottom and the seabed depending on the conditions of the ship, the ship's maneuverability and the conditions of the sea area. This margin, known as "Under Keel Clearance (UKC)," is defined as shown in Fig.2-8.



Under Keel Clearance (UKC) = (Charted water depth) + (Height of tide)-(Ship draft at rest)

Fig2-8 Definition of under keel clearance (UKC)

The following factors should be taken into account when determining UKC:

1. Hull sinkage and change of trim

When navigating shallow water, the amount of bow sinkage should be kept in mind as ships tend to be trimmed by the head.

2. Sinkage of the fore and aft perpendiculars, and bottom bilges due to ship oscillation

When the encountered wave period synchronizes with a ship's natural period of pitch or roll, the amount of sinkage should be taken into consideration for fore and aft perpendiculars or the bottom bilges.

3. Accuracy of charted depth

The following is the international standard for permissible error in surveying:

- Permissible error of 0.3 m for water depth of 20 m or less
- Permissible error of 1.0 m for water depth between 20 m and 100 m

Therefore, the above errors in charted depths should be taken into consideration.

4. Meteorological and oceanographic conditions

- One hPa (one mili-bar) rise in atmospheric pressure depresses water level by approximately one centimeter
- When the ship comes into a sea area of seawater density ρ_2 from an area of seawater density ρ_1 the amount of the change in draft Δd is expressed by:

$$\Delta d = d_1 \cdot \frac{C_b}{C_w}\left(\frac{\rho_1}{\rho_2} - 1\right)$$

d_1: initial ship's draft at sea water density, ρ_1
C_b: ship's block coefficient
C_w: ship's water plane area coefficient

or

$$\Delta d = 1.025 \cdot (1/\rho_2 - 1/\rho_1)\ W/TPC$$

W: Displacement (T)
TPC: Tons per centimeter

Navigators should remember the following formula and value.
The formula gives approximate sinkage (cm) per 0.001 of change of density.

$$\Delta dp \fallingdotseq 0.001 \cdot W/TPC$$

Δdp : Sinkage per 0.001 change of density

In the case of VLCC,

$$\Delta dp \fallingdotseq 1.5\ \text{cm (full-load condition)}$$

Draft 20.01m at density 1.025 ≒ Draft 20.04 at density 1.023 ($\Delta d \fallingdotseq \Delta dp \times 2$)

- Surplus margins should be taken for the character of the sea bottom, which is considered to be 60 cm for rocky bottom, 30 cm for sand bottom.

5. Examples of regulation and criteria for standards

The European Marine Pilot Association (EMPA) has laid down the following criteria to be complied with regarding under keel clearance (UKC):

Condition	UKC
Open sea	≧ 20% draft
Outer harbor	≧ 15% draft
Inner harbor	≧ 10% draft

The IMO stipulates the following rule for a deep draft ship (having a draft of 15 meters) and a VLCC (a tanker of 150,000-DWT or more) passing Malacca and Singapore Straits:

- VLCCs and deep water vessels require an under keel clearance (UKC) of at least 3.5 meters at all times during the entire passage through the Straits of Malacca and Singapore.

$$UKC \geqq 3.5m$$

2.4 Effects of Narrow Channels

Bank effect

If a ship is proceeding along the centerline of a canal whose cross section is constant and symmetrical about its vertical center plane, then there is flow symmetry port and starboard and the ship is subjected to no yaw moment or side force.

However, when the ship is proceeding close to one side of the canal as shown in Fig.2-9, the increase in the velocity of flow between the hull and the near wall coupled with decreased velocity of flow between the hull and the far wall creates a force that draws the ship towards the near wall (suction force). Meanwhile, displaced water mass is accumulated between the bow of the ship and the near wall, generating a high water region. This high water region (i.e. high pressure region) creates a repulsive force towards the far wall at the bow, setting up a moment that tends to swing the bow towards the far wall (a bow out moment).

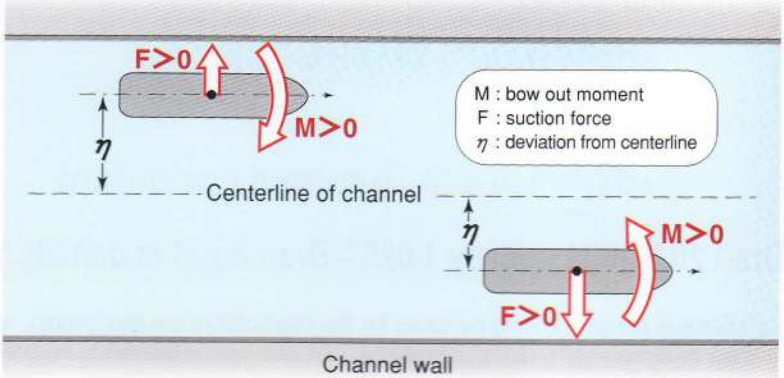


Fig.2-9 Bank effect

With a small amount of drift angle, the ship will run obliquely on the ship's path parallel to the centerline of the canal, maintaining the equilibrium of the side forces and moments created by the drift motion, bank effect and rudder deflection, as shown in Fig.2-10.

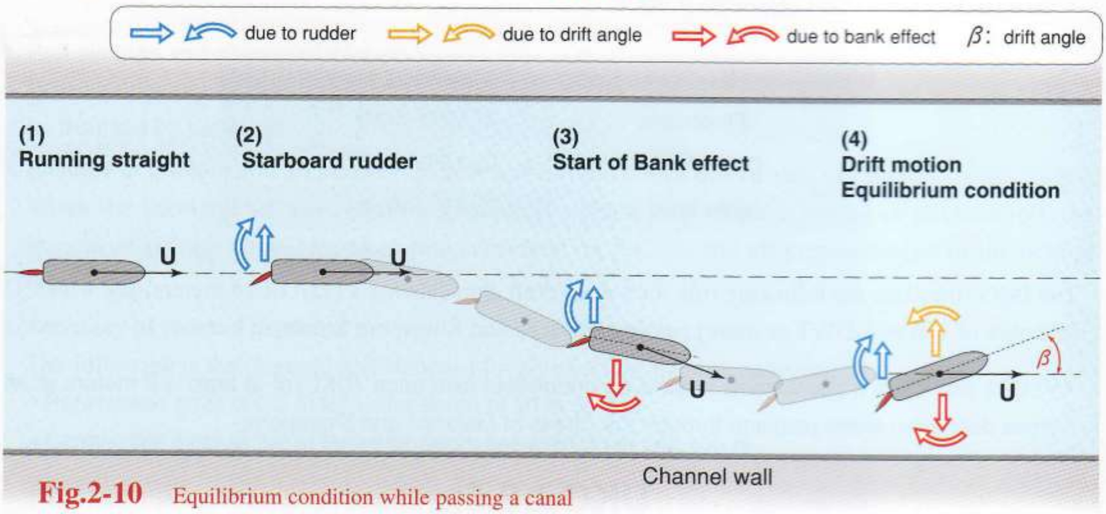


Fig.2-10 Equilibrium condition while passing a canal

Therefore, the check helm should be deflected towards the near wall to control the turning moment generated by the drift angle. However, a ship navigating a channel is in a situation of unstable equilibrium, and off-center course maintenance cannot be realized merely by deflecting constant rudder angles and holding it fixed. For this purpose, when a difference is detected for the anticipated equilibrium condition, the rudder should be deflected to correct the difference. By continuing such steering, the ship's path may be kept parallel to the centerline of the canal. The mean deflection of the rudder may be regarded as the check helm. **Fig.2-11** shows experimental results of required check helm to maintain off-centerline course under equilibrium conditions with changes in water depth. The abscissa shows the ratio of distance off-centerline to ship breadth. In all cases, equilibrium drift angle was relatively small. It is said that, with a maximum rudder angle of $\pm 35°$, a reserved rudder angle of 20 degrees or so is required for the safe ship handling in confined waters. Accordingly, the allowable check helm is limited to $\pm 15°$ for a ship with a maximum designed rudder angle of $\pm 35°$. For this reason, it is dangerous for a ship to proceed through a path excessively remote from the centerline of the canal.

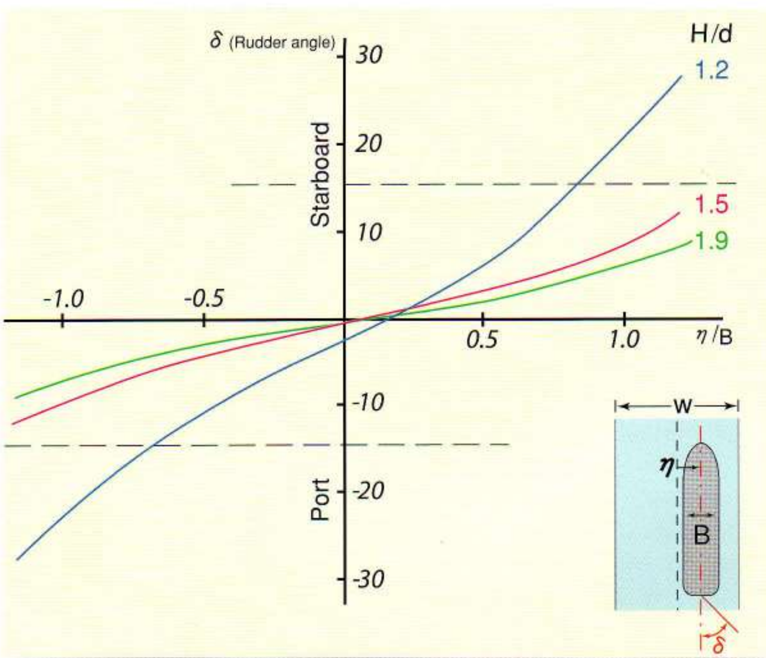


Fig.2-11 Required check helm to maintain off-centerline course

When navigating shallow water with an inclined seabed athwart the ship's beam, and for the same reason as proceeding close to one side of a channel, a suction force is created that draws the ship towards the shallower side, and a bow-out moment swings the bow towards the deeper side.

It is reported that the effect of seabed inclination on course keeping is surprisingly great, and that a significant amount of rudder deflection is required to maintain course.

There exist not a few harbor-approach channels with seabed inclinations, where care should be taken during transit.

Interaction Between Two Ships

Close passage of two ships and the resulting hydrodynamic interactions between the two are operationally important for situations such as overtaking or meeting in a restricted channel, maneuvering to avoid collision, and passing a ship moored adjacent to a narrow channel. Interaction in the case of meeting (ships moving in opposite directions head on or nearly so) rarely causes problems as the ships usually pass each other relatively quickly and there is insufficient time for the pressure systems to change in any significant way. Most critical situations arise when one ship is overtaking the other and the period of close proximity is relatively long. According to the results of model tests, touching and collision accidents are caused by the superposition of the following factors:

1. Both ships are making high speed and the speed difference between the ships is small.
2. Both ships are in an overtaking situation and have sufficient time to interact; this differs from a meeting situation.
3. Both ships are running parallel with close passage.
4. Both ships are navigating shallow waters or restricted waters that are susceptible to interaction.

1 Interactions between two similar-sized ships in an overtaking situation

Fig.2-12 shows a diagram of forces and moments with the relative position of the two ships when ship **B** is overtaking ship **A** in a narrow channel.
The following two regions may cause a dangerous situation:

- When the bow of overtaking ship **B** overlaps 1/4 to 1/3 of its length with the stern of ship **A**, dangerous force moments towards the other ship are created. (When abreast, the ships are drawn together by bodily suction amidships while bow-out moments and repulsive moments arise in both ships.)
- As ship B moves further ahead of A, ship A abruptly changes the direction of moment from "bow-out" to "bow-in", and, with a drawing force to ship B, the vessls are at risk of touching.

To prevent the danger induced by ship interactions, it is necessary to reduce speed (less than 10 knots), and to keep a sufficient lateral separation distance of at least one ship length in the parallel run.

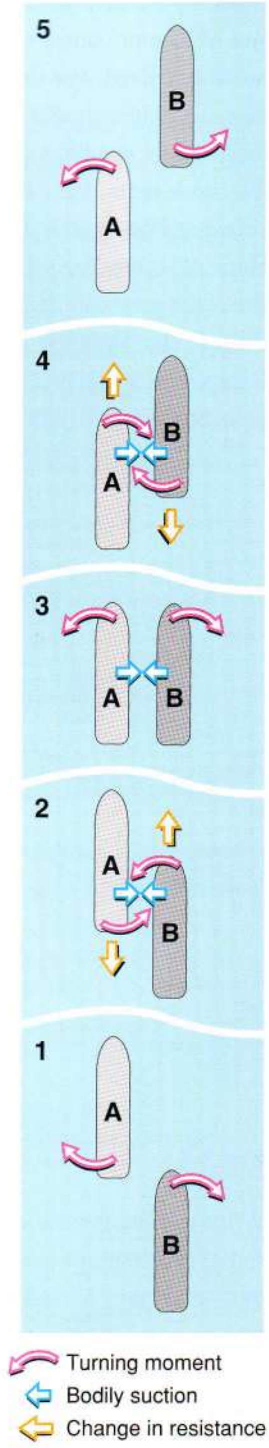


Fig2-12 Interactions between two ships of similar size

2 Interaction between a tug (or a small craft) and a large ship

When the tug is overtaking the large ship to change station from the stern to the bow, the tug is affected by interaction considerably more than the large ship. The tug is moving in water flow that is dominated by the streamlines of the pressure field surrounding the large ship.

Fig.2-13 shows the illustration of the forces and moments working on the tug when the tug is changing station from the stern to the bow.

From the figures, the following is known:

- **The tug approaching the stern of the large ship will experience suction force and bow-in (towards the large ship) moment.**
  The rudder is to be deflected outwards. (Fig.2-13, ❶ and ❷)
- **When the tug is approaching abreast of the large ship, the tug will experience suction force and bow-out moment, and the rudder is to be deflected inwards. However, the suction force and bow-out (against the large ship) moment are relatively weak. (Fig.2-13, ❸)**
- **When the tug is approaching the bow of the large ship, the tug will encounter increasing pressure and an increase of engine output is required to overcome the resistance barrier. Due to the greatly increased suction force and bow-out moment, enhanced inward rudder deflection is required. (Fig.2-13, ❹)**
- **At the moment the tug moves ahead of the large ship, suction force changes rapidly into repulsive force and bow-out moment into bow-in moment. To cope with the bow-in moment, the rudder is to be deflected outward. In case of untimely switching of rudder deflection, the tug's bow will be turned to the bow of the large ship, which may result in collision. (Fig.2-13, ❺)**

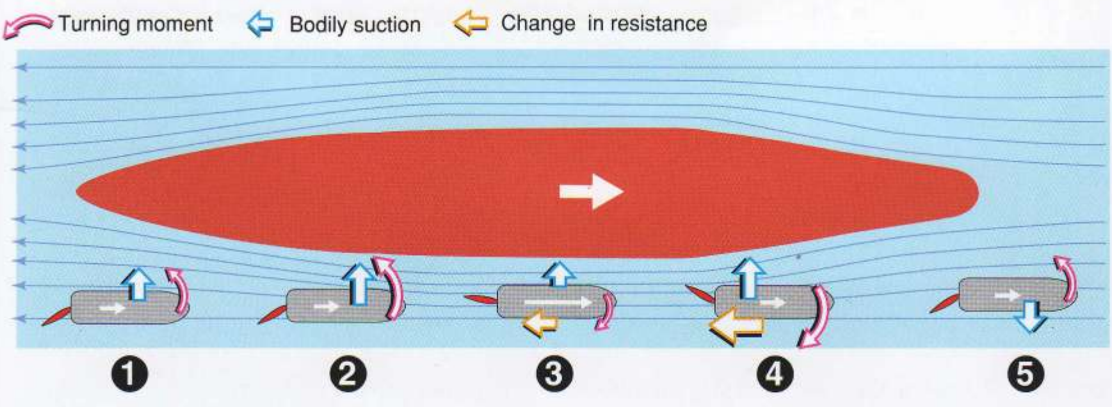


Fig2-13 Interaction between a tug and a large ship

3 Interaction between moored and passing ships

As shown in **Fig.2-14**, the characteristic features of the interactions on the moored ship are summarized as follows:

- The longitudinal force has two peaks in opposite direction - the first forward, the second afterward.
- The lateral force is characterized by initial repulsion, followed by attraction between the ships and repulsion again at the end of the passage.
- The yawing moment goes through four phases - bow repulsion, bow attraction, bow repulsion and bow attraction.

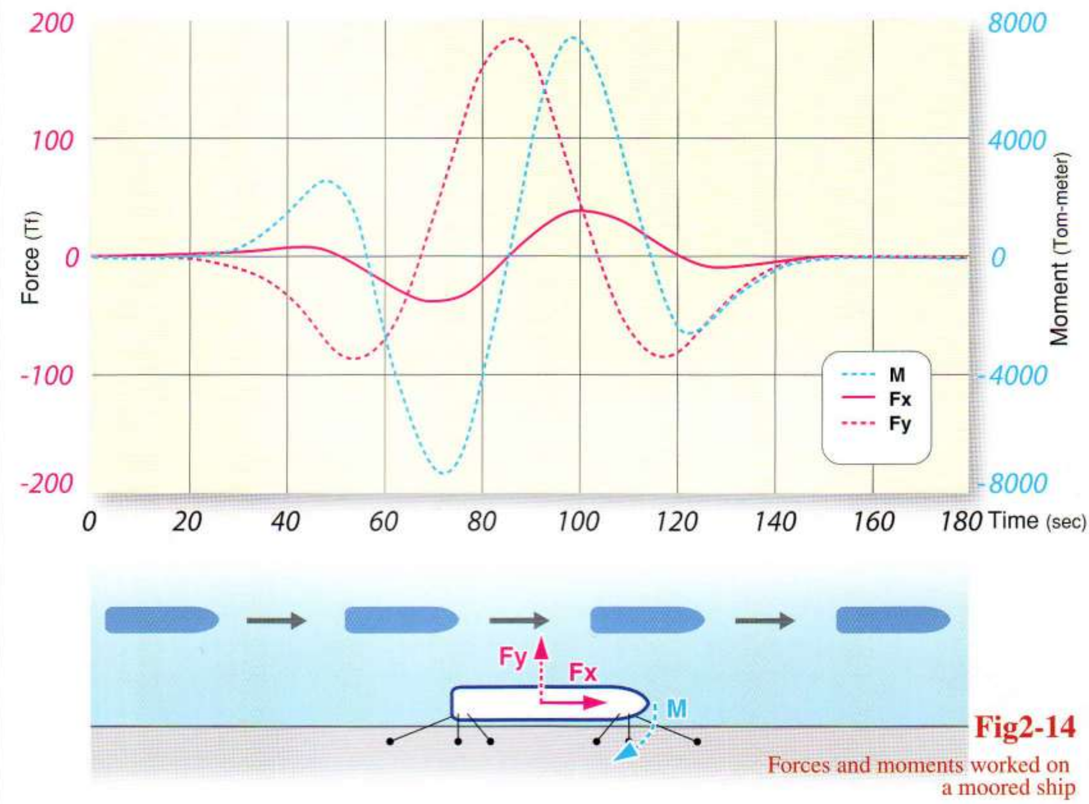


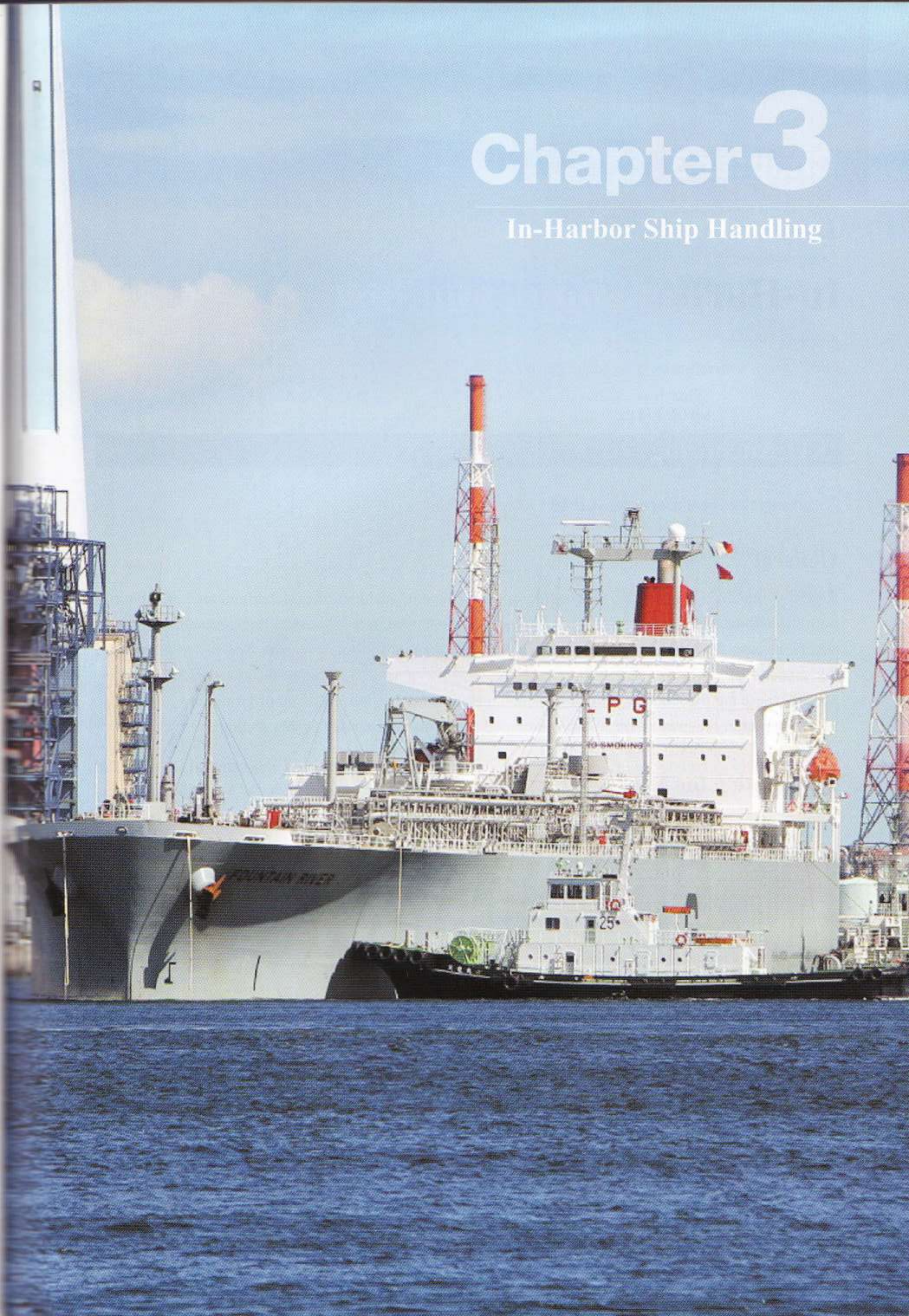
Fig2-14
Forces and moments worked on a moored ship

The forces and yaw moment on the moored ship are directly proportional to the size and square of the speed of the passing ship, and inversely proportional to the water depth and lateral separation distance. Besides the hydrodynamic interaction between two ships, the motion of the moored ship is influenced by the wave generated by the passing ship. Particularly, the effect is conspicuous in surge motion, and involves the danger of rending mooring rope and of damage to the ship's side due to contact with the wharf. As described above, the effect grows stronger as the surrounding water depth becomes shallower, the ship passes at a faster speed and with a smaller lateral separation distance.

Therefore, particularly in shallow waters, the passing ship should keep the lateral separation distance as broad as possible, and keep its speed as slow as possible while maintaining steerage way.

Chapter 3

In-Harbor Ship Handling



Chapter 3

In-Harbor Ship Handling

3.1 Anchoring

General

Recently, there has been an increase in the following type of accident: the anchor and anchor cable run out to the bitter end when the anchor is let go from the hawse in a deep water anchorage; the accident occurs because the weight of the anchor and cable and the momentum developed by the free-fall exceed the capacity of the brake. Furthermore, accidents involving vessels lying at anchor continue to occur. Most of these are the result of dragging anchor, and concern drifting, collision or grounding.
Anchoring safely to prevent the above-mentioned accidents is discussed in this section.

Preparation for Anchoring

When anchoring, prior investigation of the following conditions for anchorage is required:

1. Direction and strength of wind and current
2. Depth of water
3. Type of seabed (Select a type of seabed with good anchor holding characteristics)
4. Location of lee-shore, shoals, or hazards such as submarine cables and other obstacles
5. Maneuvering room for approach
6. Swinging room after anchoring
7. Conditions affecting visibility, weather and currents

Routing and speed reduction plans on the way to the anchorage are to be made, and the anchoring method and approximate lengths of cable to be paid out should be decided in advance.
The following are types of anchoring method, as shown in **Fig.3-1**.

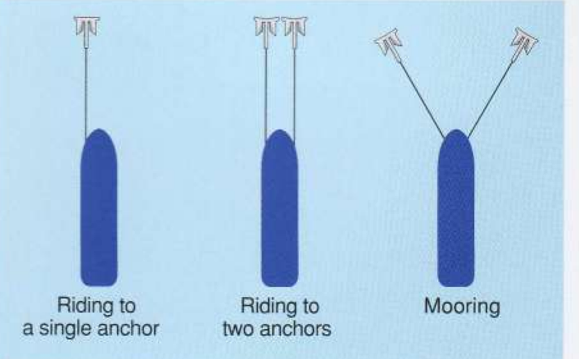
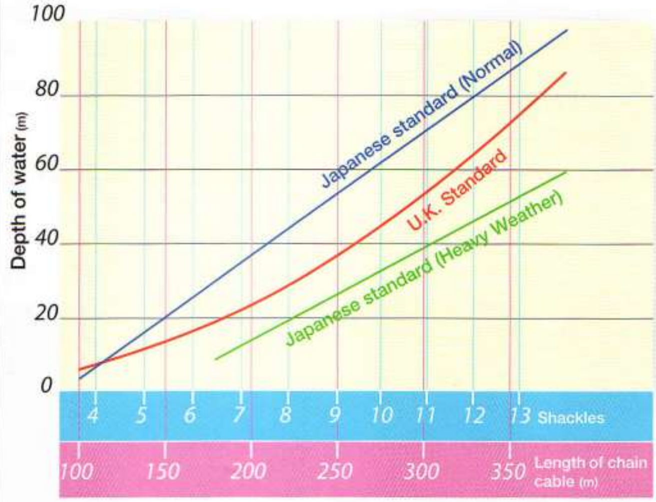


Fig.3-1 Anchoring methods

The riding to a single anchor is the most common method, but the other two acceptable methods -- mooring or riding to two anchors -- should be used when weather and current conditions demand. Once the method has been chosen, the next decision involves whether to anchor to starboard or port. Finally, preparations are made for letting go anchor. When riding to a single anchor, the following empirical standards are given for the required lengths of cable to be paid out:



❶ Japanese standard:

- Normal anchoring
  $Lc = 3 \times H + 90$ (m)
- Heavy weather anchoring
  $Lc = 4 \times H + 145$ (m)

❷ U.K. standard (Admiralty Manual of Seamanship, London):

$Lc = 27.5 \times 1.5\sqrt{H}$ or $Ns = 1.5\sqrt{H}$

Lc : length of cable to be paid out (m)
H : water depth (m)
Ns : shackles of cable to be paid out

Fig.3-2
Length of cable to be paid out
(U.K & Japanese standard)

Preparations for letting go anchor.

After the trial run of the windlass, the following procedures are required for making the anchor ready for letting go: (see **Fig.3-3**)

- Engage the cable holder and the pin for firmly securing lever.
- Remove the anchor lashings.
- Remove the chain stopper upon confirming it is free from any load, a condition that requires the stopper to be secured at rest by the securing pin.
- Release the brake and walk back (out) the cable. ("Walk-back" means letting out cable using a geared windlass.)
- Walk back the anchor to the "cock-bill" condition or into the water depending on state of anchorage. When walking back the anchor into the water, ship speed should be reduced to a range considered safe for lowering the anchor into the water.

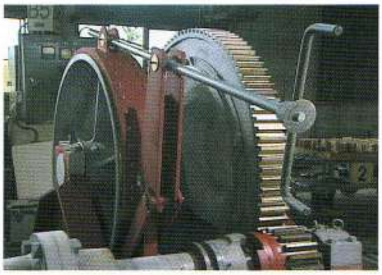


Fig. 3-3 Windlass

- Set the brake firmly, disengage the cable holder and set the pin for the securing lever to the disengage position. The windlass is ready for letting go anchor by free-fall, when the anchor is held solely by the windlass' braking force.
- The opposite anchor should be readied and set on standby in preparation for an emergency.
- If the ship is loaded with inflammable liquid or gas, a water-flushing system for the hawse should be prepared. The water will be used to prevent sparks caused by anchoring operations.
- In addition to anchoring preparations on the forecastle, personnel on the navigation bridge are required to make preparations for use of the echo-sounder and the speed meter for the purpose of measuring water depth and ship's headway, respectively.

Anchor and Anchor Cable

The specifications of anchor and anchor cable to be equipped are determined with the Equipment Number of the ship stipulated in the Regulations for Equipment of Ships.
Each classification society lays down its own requirements in compliance with the above standard.

Anchor capability

It is desirable that an anchor exhibits overall capability covering the following properties:

1. The anchor flukes bite into the seabed without fail after the anchor is let go.
2. The anchor possesses sufficient holding power (resistance) to cope with the force dragging the anchor.
3. The anchor maintains postural stability without turning over when it is pulled through the seabed.

Types of anchor

The major anchors commonly used in merchant ships and naval vessels are shown in Fig.3-4.
In merchant ships, the AC14 type anchor appears to be the most widely used, because of its high holding power and postural stability.

Fig.3-4 Major anchors

JIS anchor AC14 anchor Danforth

Holding power of anchor

The holding power of the anchor is normally expressed as a factor of its own weight.

$$H_p = \lambda_a \cdot W_a \quad \text{or} \quad \lambda_a = \frac{H_p}{W_a}$$

H_p : holding power of anchor (ton)
W_a : weight of the anchor (ton)
λ_a : coefficient of the holding power

For example, the AC14 anchor will hold more than 10 times its own weight if the seabed is good; in poor seabed of soft, silty mud, the holding power will drop to about 3 times anchor weight.

However, the holding power of the JIS type anchor is, at best, half that of an AC14 anchor of equal weight under normal seabed conditions.

Fig.3-5 shows the AC14 anchor under pulling test.

The figure shows that the anchor bites well into the seabed and maintains stable posture without turning over.

On the other hand, Fig.3-6 indicates that the JIS anchor tends to turn over when dragged, and subsequently breaks out with flukes up.

Fig.3-5 AC14 anchor biting into the bottom

Fig.3-6 JIS anchor turned over

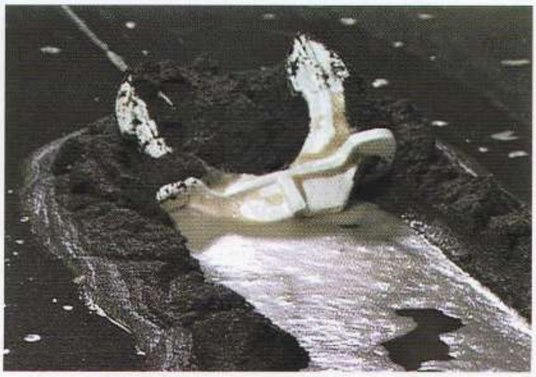
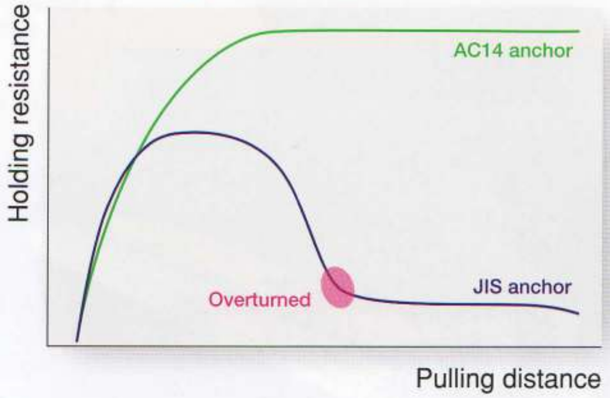


Fig.3-7 illustrates the characteristic holding power curves of the AC14 and JIS anchors. The AC14 anchor exhibits high and stable holding power, whereas the holding power of the JIS anchor declines drastically after it turns over and loses the ability to grip the seabed.

Fig.3-7 Holding power characteristics curve



Besides the holding power of the anchor itself, the contribution of the anchor cable cannot be ignored. Moreover, the anchor cable plays the important role of absorbing some of the energy acting on the anchor by changing the shape of its catenary.

Fig.3-8 shows the anchoring system when riding to a single anchor.

Total mooring power **P** is the sum of the holding power of the anchor ($H_p = \lambda_a \cdot W_a$) and the frictional resistance of the cable laid over the seabed ($\lambda_c \cdot W_c \cdot \ell$): that is,

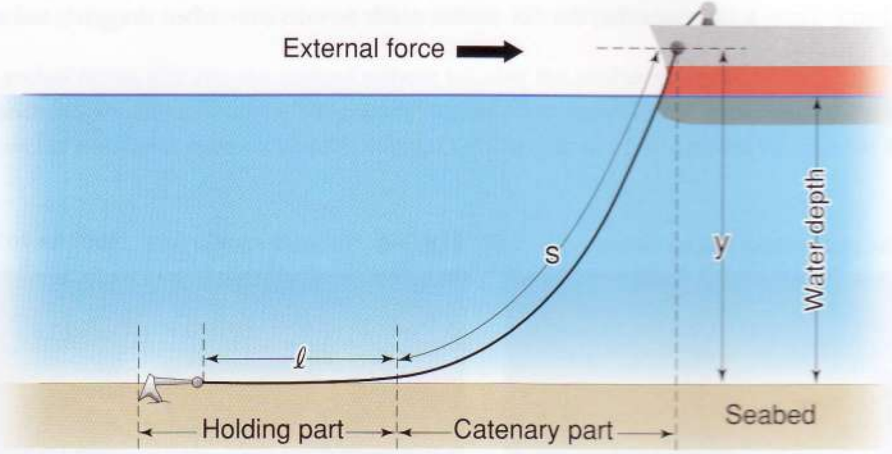


Fig3-8 Anchoring system

$$P = \lambda_a \cdot W_a + \lambda_c \cdot W_c \cdot \ell$$

P : mooring power (holding power of anchor and cable) (ton)

λ_a: coefficient of holding power

W_a: anchor weight (ton)

λ_c: coefficient of cable resistance per unit length (λ_c=0.75)

W_c: cable weight per unit length (ton/m)

ℓ : holding length of cable (m)

Anchoring Operations

Approach to an anchor berth

Anchoring method varies according to water depth, current and wind conditions at the anchorage.
Riding to a single anchor by dropping anchor (letting go the anchor under sternway) is normally used because of its handling simplicity when letting go or weighing anchor. The ship proceeds in accordance with the speed reduction plan, and the engine is stopped before arriving at the anchor berth, advancing solely by inertia. The engine is put astern just before the intended location so that the ship may come to a stop in the anchor berth. The anchor is let go and the cable is paid out under sternway.
Personnel on the navigation bridge record the ship's heading when the anchor is let go, and plot the position of the bridge (anchor position) on the chart.

Anchoring in water of 20 meters or less depth

When anchoring in water of 20 meters or less depth, the anchor may be let go freely by releasing the brake from the cock-bill position, and an amount of cable approximately equal to twice the depth of water should first be allowed to run out freely to enable the anchor to embed itself. Thereafter, the windlass brake should be applied so that the cable is kept growing at an angle of about 30 degrees to the vertical. The brake should not be applied forcefully. A free-falling anchoring can cause parting of the cable and damage to the windlass.
In large ships, sternway after letting go the anchor should be adjusted within 0.5 to 1.0 knot to prevent an excessive strain on the cable. When the intended shackles of the cable are paid out, sufficient brake should be applied to cause the flukes of the anchor bite into the seabed.
When the cable tautens and then slackens, it is a sign that the ship is brought up. At the same time, the ship begins to turn towards the weather.

Anchoring in water of 20 to 50 meters depth

When anchoring in water of 20 to 50 meters depth, the free-fall anchoring from the cock-bill position may cause the cable to attain a dangerous speed as it runs out, the result being a parting of the entire cable.
There is also risk that the anchor may fracture on striking the bottom at high speed.
To prevent such hazards, walk back the anchor into the water until it reaches about 5 meters above the bottom, then let go the anchor.
Afterwards, the proper brake should be applied to control cable running out speed, and sternway of the ship should be maintained within the permissible range. (**Fig.3-9**)

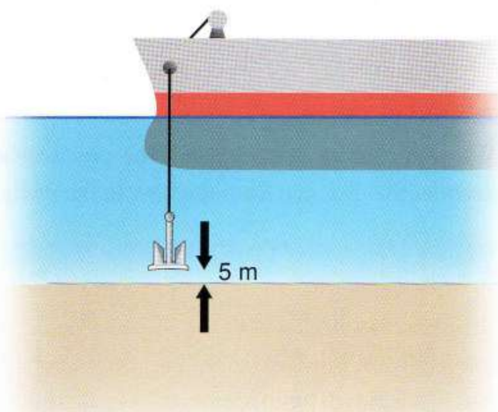


Fig3-9
Anchoring in water of 20 to 50 meters depth

Anchoring in water of 50 meters or greater depth (Deep anchoring)

When anchoring in water of 50 meters or greater depth, the anchor and the amount of cable intended for use are paid out by the walk-back method.

In large ships, sternway over the ground should not exceed 0.5 knot after the anchor has been embedded in the bottom.

This is because if the ship's sternway is greater than the walk out speed of the cable, parting the cable or damage to the windlass may occur due to excessive strain on the cable. (Fig.3-10)

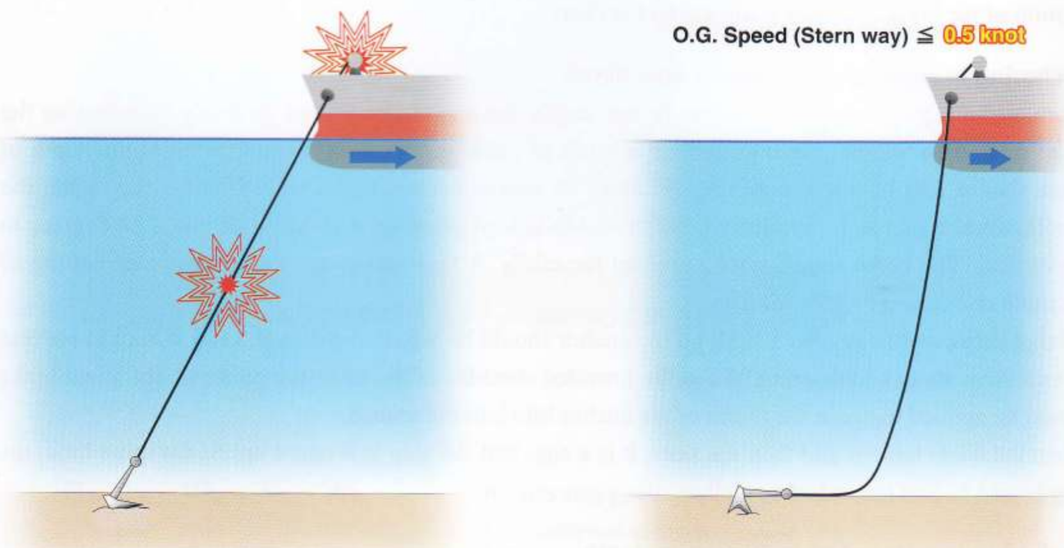


Fig3-10 Anchoring in water of 50 meters or greater depth (Deep anchoring)

Anchor position

When anchoring is completed, the precise anchor position should be plotted on the chart taking into account the distance from the bow to the navigation bridge and the amount of cable paid out.

Permissible water depth for anchoring

Permissible water depth for anchoring is not determined by the total length of equipped cable, but by the capacity of the windlass.

Generally, a windlass has a lift capacity of 3 to 4 shackles with an anchor. Accordingly, permissible water depth will be in the range between 82 to 110 meters.

The rated capacity of a windlass must be sufficient to hoist two shackles of cable at an average rate of 9 meters/min, with the anchor and 3 shackles of cable suspended in water without touching the bottom. (The rough calculation at this rated capacity is that 3 minutes is needed to hoist one shackle of cable.)

Anchoring Under Wind and Current Effects

In an anchorage where the effects of wind and/or current are strong, there is risk of dragging anchor due to excessive strain on the cable.
There also is risk of holding failure of the anchor, as the cable is often laid out meanderingly along the bottom, which hinders the anchor's ability to embed and hold.
When approaching the anchorage, well-chosen landmarks, beam references and the ship's speed meter are to be used to reckon the ship's movement, as the precise speed over the ground is difficult to confirm.

Approaching with head-to-wind/stream

When riding to a single anchor, the approach is made head-to-wind or head-to-stream, and then the anchor is let go.
To allow the anchor to embed and hold, a length of cable more than twice the depth of the water should be allowed at first to run out freely, after which a sufficient length of cable should be paid out under brake to prevent the anchor from being dragged.

Approaching with wind or current on the beam

When approaching with wind or current on the beam, sufficient speed is required to maintain the vessel's predetermined track because leeway or current set increases drastically as the ship's speed decreases. The ship should stem the wind or current just before letting go the anchor, at which time preparation for making bold alteration of course is necessary since the vessel rapidly loses way.
The weather anchor should be let go with the ship stopped, and as the ship drifts downstream the cable should be paid out gradually (if necessary, the astern engine may be used) in such a way as to keep the ship head-to-wind or head-to-stream.

Approaching with wind or current on the stern

Anchoring with wind or current on the stern should be avoided because control of headway is difficult and the cable may be subjected to an excessive strain.
If there is no other alternative, then make the approach with headway as slow as possible, and let go the turning side anchor just before the location of the anchorage.

Swing Motions and Dragging Anchor

A ship at anchor will swing around the anchored position in the wind, drawing a figure-eight, as shown in Fig.3-11.

Subsequent to head-to-wind position at the extreme end of the windward (Fig.3-11 ❶,❺), the ship begins to be swept away backward. When the ship's fore-and-aft line is in line with the cable direction or a little after (Fig.3-11 ❷,❻), maximum tension is exerted on the cable.
Dragging anchor will occur when the anchor loses its grip on the bottom and starts sliding over the bottom, a result of impulse force exceeding the anchor's holding power.

To control swing motion, the following measures are taken:

1. Deepen ship's draft by ballasting to reduce wind-affected area
2. Adjust ship's trim by-the-head while keeping the propeller under water
3. Use a swing-check anchor with another anchor, lowering it to one-and-half depths of water on its cable

For PCCs or LNG carriers with large wind-affected areas, risk of dragging anchor is said to be high at the following wind speeds:
15 m/s when lying at a single anchor, 20 m/s when a swing-check anchor is dropped, and 25 m/s even when the ship is lying at two anchors.

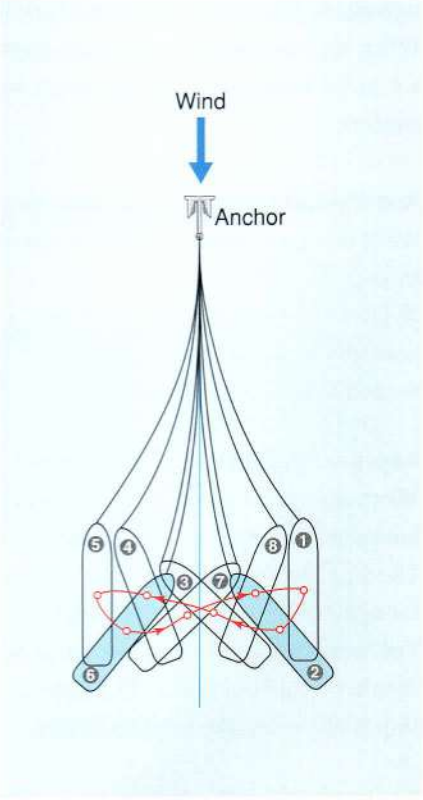


Fig.3-11 Swing motion in wind

Anchor Watch

Personnel on anchor watch should pay strict attention to sudden changes of weather, signs of dragging anchor, signs of cable fouling and dangerous behavior of other ships in the vicinity, and the master should immediately be informed when anything unusual is observed.
When the master detects signs of dragging anchor, the following counter measures are taken (depending on the situation):

- Letting go the swing-check anchor
- Paying out an extra length of the cable
- Keeping the ship's head to the wind and easing cable tension using the main engine and rudder, or bow thruster.

Other measures, such as shifting anchorage or drifting offshore also should be considered.
Methods of detecting anchor dragging are as follows:

- Checking the ship's position by radar or other instruments
- Checking the course recorder
- Checking the ship's swing behavior
- Checking tightening sequences of the cable
- Checking the indicator of the Doppler log

The following phenomena can be regarded as early signs of the anchor being dragged:

- the course recorder indicates a distorted curve instead of a regular sine curve
- the periodical swing motion of the hull is stopped, and the ship is gradually swept down with wind on one side of the hull (Fig.3-12)
- the Doppler log indicates the ship is moving in a certain direction at a rate of one knot or more over the ground
- the cable remains taut at all times
- abnormal vibration is felt on the hull
- the relative positions of other ships in the vicinity change markedly

As stated above, the most important thing is early detection of dragging anchor when lying at anchor in a gale.

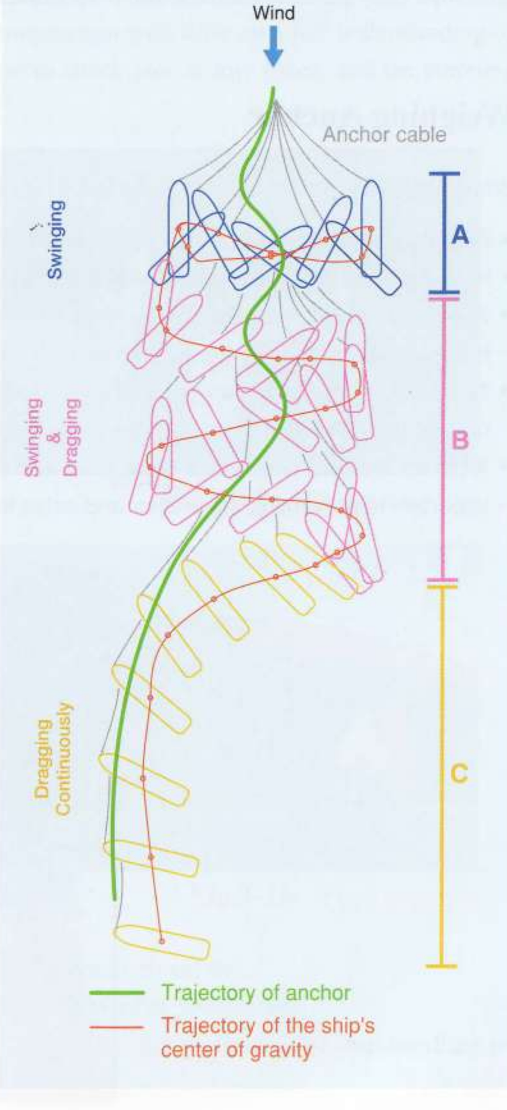


Fig.3-12 Dragging anchor

Sighting anchor

In a river or an estuary, the bottom is usually covered with a thick layer of silt or soft mud, and sometimes it may be difficult to weigh anchor after it has been buried deep in mud for an extended period. When a ship is obliged to lay at anchor in such an anchorage for a long period, the anchor should be hove up and let go again everyday or couple of days to prevent it from getting stuck.

Slipping anchor

In an emergency, the ship may be obliged to slip the cable or cables and proceed to sea.
When slipping a cable, the end should be buoyed to enable it and the anchor to be recovered, and the wire rope buoy pendant used should be of sufficient strength to recover the cable.

Weighing Anchor

Preparations for weighing anchor are the same procedures for anchoring.

- Preparation of pumping is required for washing the anchor and cable.
- Heaving in the cable is commenced by the master's order.
- When the cable is taut due to wind and current, or when an excessive strain is exerted on the cable, main engine or bow thruster is used to ease tension on the cable.
- The brake is applied when the anchor is finally hove up into the hawse pipe, and the cable holder is disengaged. The stopper is set after confirming it is no longer bearing the anchor's load.
- After the forecastle-station is dismissed, anchor lashings should be secured firmly as these are very important in preventing the anchor and cable from running out to the bitter end in stormy seas.

3.2 Berthing

General

In harbors and ports where maneuvering areas are confined and shallow, there are many navigational restrictions. Therefore, ship operators are required to maneuver their vessels in accordance with prevailing environmental conditions. Additionally, when entering and leaving port also involves berthing and unberthing operations, ship handling is not easy. This difficulty is due to the problem of directional control and course-keeping, a direct result of poor steerability at low speed and the influence of wind and current. Under such circumstances, ship operators are required to use assistance in ship handling, assistance such as the use of tugs when necessary, in conjunction with their own full understanding of ship maneuverability, including use of rudder deflection to check yaw at low speed, and the stopping power of various reverse engine settings.

Assistance by Tugs

1. Types of tug

Tugs are classified by propulsion type as follows:

- Voith-Schneider Propeller (VSP type)
- Controllable Pitch Propeller (CPP type)
- Azimuthing Drive Propeller (Z type)

Fig.3-13 VSP type propulsion

Fig.3-14 CPP type propulsion

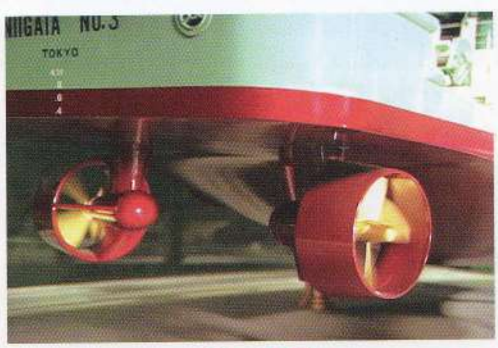


Fig.3-15 Z type propulsion

In Japan, the Azimuthing Drive Propeller Type (Z type) is the predominant tug.
Such tugs are equipped with two steerable propulsion units that revolve 360 degrees.
By controlling both the direction and revolutions of the propellers, tug assistance for ship handling is available in all directions and with varying thrust.

2. Towing force of a tug

When a tug is built, its towing force is measured by a pulling test as shown in Fig.3-16, where the tug's strength of pull on the bollard is determined. The value for bollard pull (towing force) varies with the type of main engine and propulsion system. The bollard pull of a Z type tug is said to be approximately 1.5 tons ahead and 1.4 tons astern per 100 BHP of the tug.
The bollard pull of a VSP type tug is said to be approximately 1.0 ton ahead and 0.7 ton astern per 100 BHP of the tug.

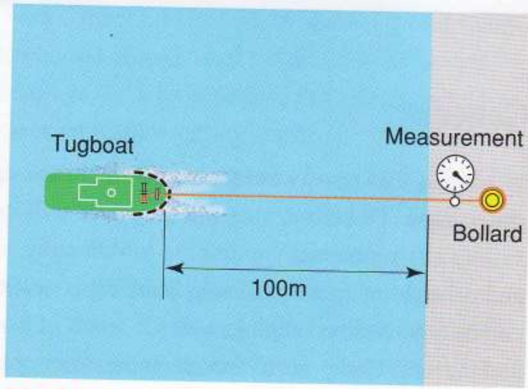


Fig.3-16 Measurement of towing force (bollard pull)

However, the towing force of a tug will decrease when:

- the ship being assisted is making headway
- the tug's discharge current impacts against the ship's underwater hull
- the tug and the ship are being oscillated by seas and swells

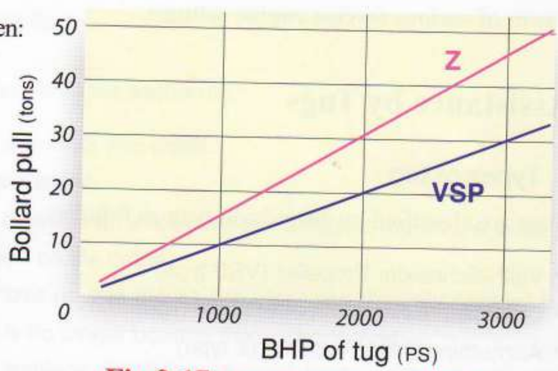
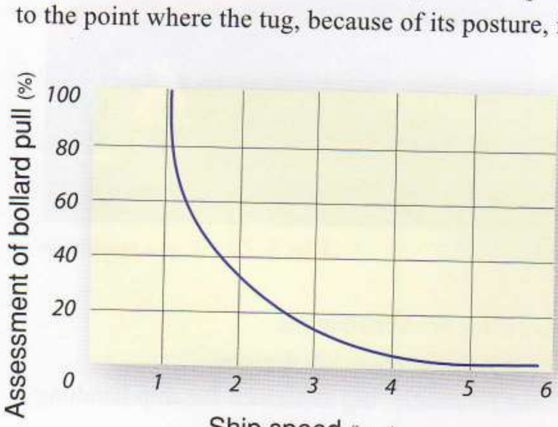


Fig.3-17 Bollard pull versus BHP of tugs

Particularly, when the ship assisted is making headway, the increase in the tug's power consumption for lateral motion means that effective towing force is reduced sharply as ship speed increases (See Fig.3-18). As the ship gains headway and its speed increases, it will increasingly drag the tug, even to the point where the tug, because of its posture, is in danger of heeling over.



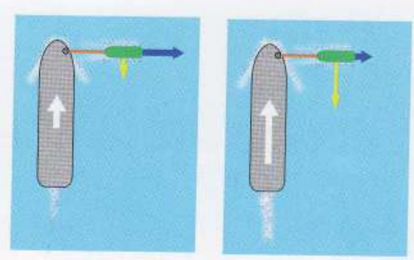


Fig.3-18
Towing force reduction with a ship getting underway
(one-knot headway = 100)

3. Use of tugs

The use of tugs is decided in accordance with ship handling requirements, such as controlling a towed ship's speed, lateral motion and yaw-rate.

(1) Lateral motion control

In pulling-out operations, the tug's paid-out rope length is reckoned ranging from 2.0 to 2.5 times the tug's length (L). (Fig.3-19)

As the towed ship's size increases, the length of rope increases.

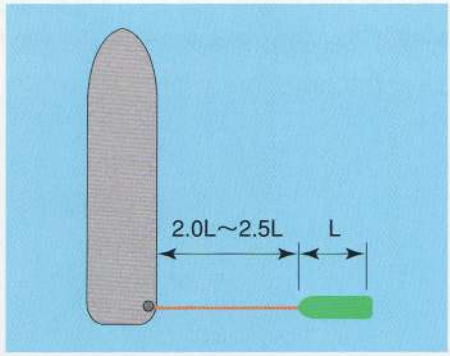


Fig.3-19 Standard length of towing line

Fig.3-20 shows the arrangement for assistance in lateral motion control by one tug.
It is common to use this arrangement in combination with a bow thruster or with an anchor.
Fig.3-21 shows the arrangement for assistance in lateral motion control by two tugs.

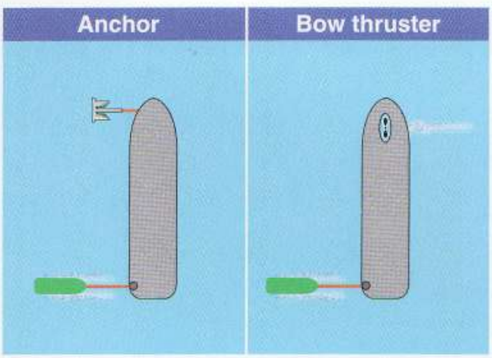


Fig.3-20 Assistance in lateral motion control by one tug

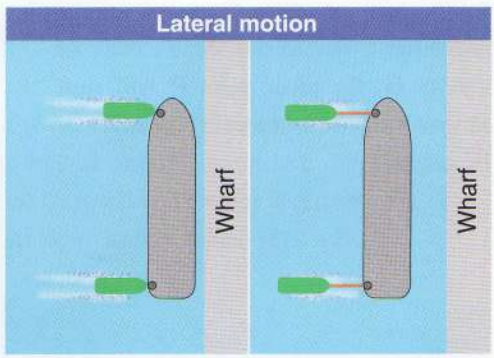


Fig.3-21 Assistance in lateral motion control by two tugs

(2) Pivoting motion control

Fig.3-22 shows the arrangement for assistance in pivoting motion control.

Regarding tug operations, either the pushing or pulling method is used.

The pulling method is needed for broad sea room; this method suffers from a decrease in towing force due to the impact of discharge current, but allows flexible use of tug.

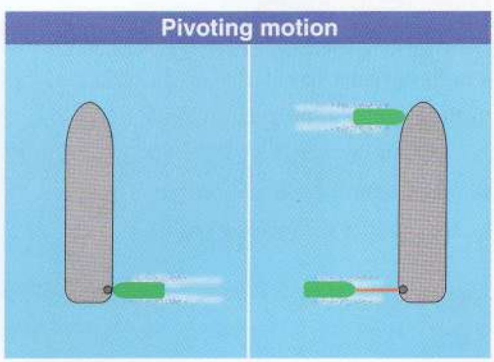


Fig.3-22 Assistance in pivoting motion control by one or two tugs

When a tug tows or pushes the stern of a ship, the ship's pivot point will be aft of the bow, about one-third the ship length. (Fig.3-23, Fig.3-24) When the bow is towed or pushed, the pivot point will be forward of the stern about one-third the ship length.

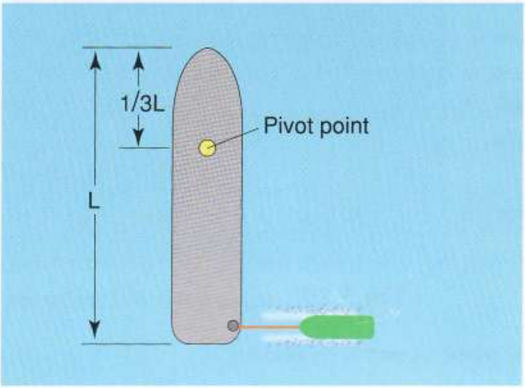


Fig.3-23
Point of action of tug and pivot point of ship

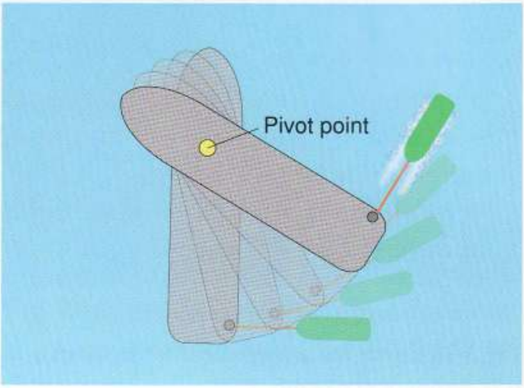


Fig.3-24
Ship under pivoting motion

As the point of action **C** exerted by the tug shifts closer to the ship's center of gravity **G**, the pivot point **P** will shift farther from the center of gravity **G**. (Fig.3-25)

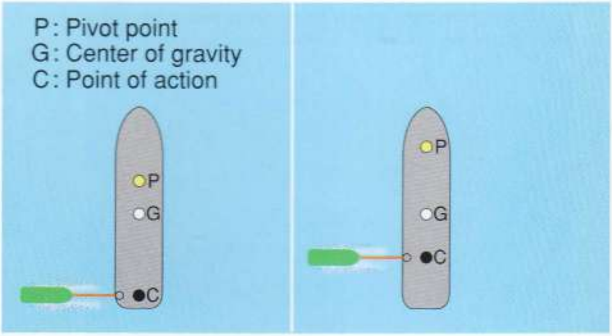


Fig.3-25
Change of pivot point with change in point of action

Consequently, turning in a short round requires a circular maneuvering area with a radius greater than GP + 1/2 L, with the turning center at the pivot point **P**.
As shown in Fig.3-26, the farther the point of action from the center of gravity, the smaller the turning radius.

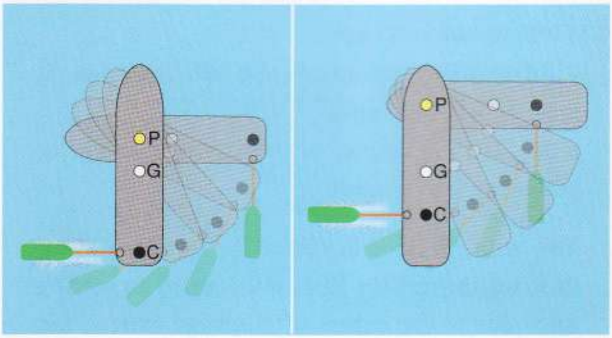


Fig.3-26
Comparison of turning radius with change in point of action

Fig.3-27 shows the trajectories of a ship under one-knot headway making a 90-degree turn with the assistance of a tug pushing abeam either the bow or the stern of the ship.
As shown in the figure, it is known that pushing abeam of the ship causes a relatively large kick-out.
At the same time, however, it enables the ship to turn in a smaller maneuvering area than if the ship were pushed abeam the bow.

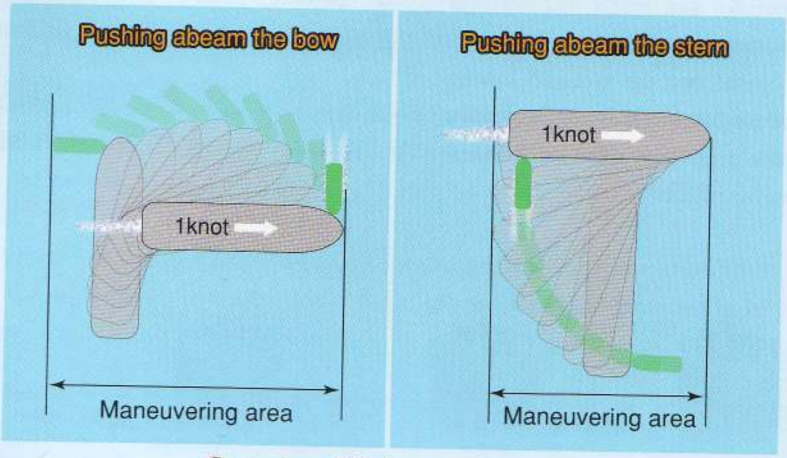


Fig.3-27
Comparison of 90-degree turning trajectories when bow or stern being pushed

When a tug assists the pivoting of a ship in conditions of strong wind and current, towing the bow in the direction of the wind and current requires a broad maneuvering area due to the ship's increased range of motion. On the other hand, towing the stern against the wind and current is effective for pivoting in a smaller area. The ship will be in motion close to turning in a short round. (Fig.3-28)

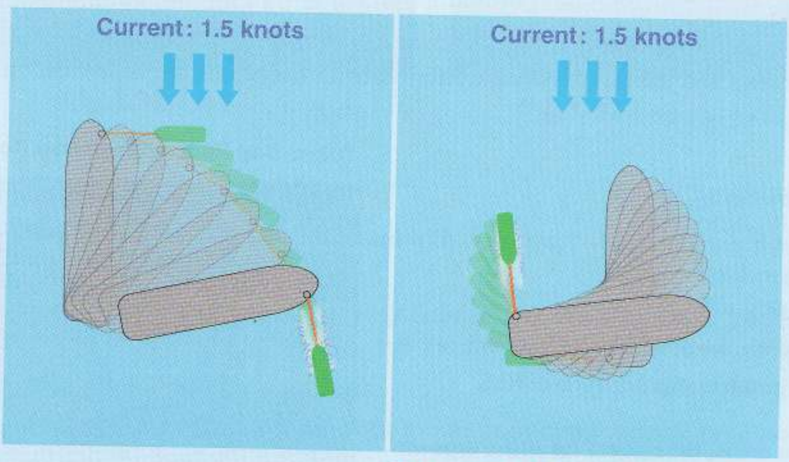


Fig.3-28
Tug assistance in pivoting motion under wind and current

Therefore, close attention should be paid to ship handling in maneuvering areas with strong winds and currents.

(3) Required towing force in berthing operations

Fig.3-29 shows the required towing force on berthing operation relative to ship size, parametrizing water depth (H) to draft (d) ratios, (H/d). In the figure, the required towing force is shown vertically, and vessel displacement tonnage horizontally.

It should be noted that the required towing force increases as displacement tonnage grows larger and water depth to draft ratio (H/d) becomes smaller.

Fig.3-29
Required tug towing force when berthing

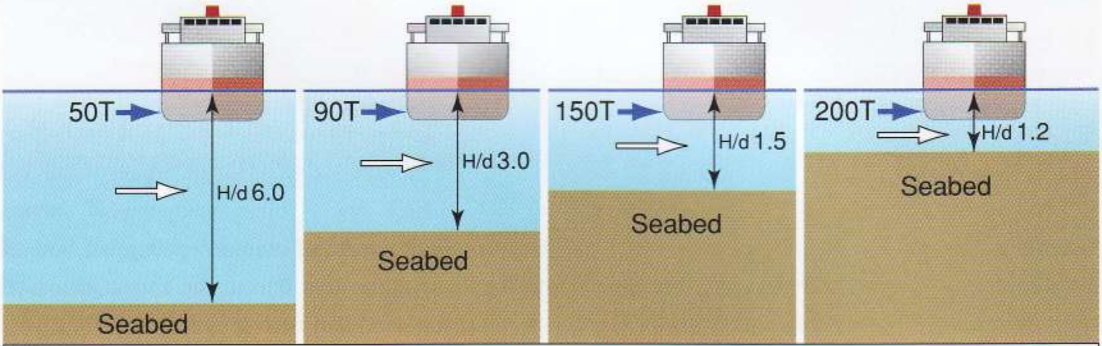


Fig.3-30 Effect of under keel clearance on current force

The number of tugs and the power necessary for berthing operations are dependent on the following conditions:

- condition of the berth
- ship size
- ship handling method
- weather conditions
- most importantly, wind velocity and current set, as well as water depth to ship's draft ratio (H/d).

In some harbor areas, the criteria for using tugs are laid down as shown in **Table 3-1**.

Tokyo Bay Pilot Association (for reference)

	>100,000		>60,000		>40,000	
	Enter	Leave	Enter	Leave	Enter	Leave
Bulker	5	3	4	3-2	3	2
LNG	4	3	3	2	–	–
VLCC	5	3	4	3	–	–

Table 3-1 Number of tugs required when entering or leaving

(4) Safe handling of towropes

Slipping off or parting of towropes will result in serious accidents.

In some cases, ship bitts to which towropes are made fast lack sufficient strength; it is necessary to check the safe working load of bitts.

To prevent damage to a towrope, it should be made fast to the inner bitts as far as conditions permit, as shown in **Fig.3-31**.

Synthetic fiber rope has high resistance to chafing over flat surfaces, but poor resistance against sharp edges and sideslips.

Due to malfunctions and rusty, rough surfaces of rollers and fairleads, chafing can cause ropes to part.

For this reason, it is essential to maintain ship-mooring equipment in good condition.

For example, the rusty surfaces of fairleads must be scraped and smoothed, shafts must be re-adjusted, and rollers greased.

If ropes are bent or stretched over sharp angles or corners, or if they come into contact with the ship's hand-rails, chafing against sharp edges or corners may cause the rope to part, as shown in **Fig.3-32.**

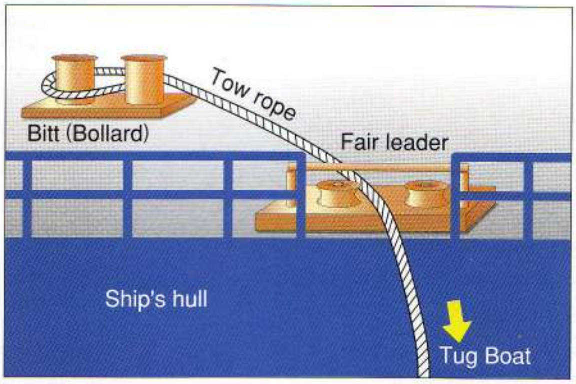


Fig.3-31 Taking tow rope to bitts

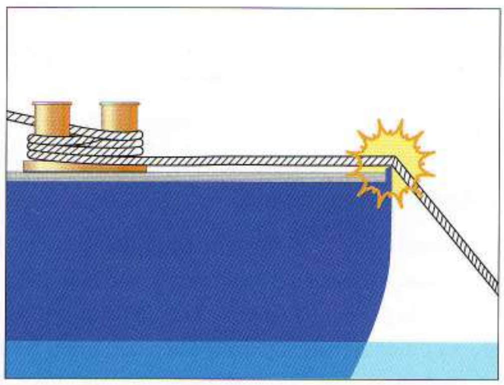


Fig.3-32 Rope in contact with sharp edge

For operational safety, a heaving line should be used with the correct type of monkey fist.

Never substitute a shackle for a monkey fist.

It is an unfortunate fact that towropes or mooring lines in use will sometimes part for unforeseen reasons.

Parted lines can easily cause injuries and fatalities.

Therefore, keep personnel from working or standing by on the extension lines of tensioned ropes.

Berthing and Mooring

Berthing alongside a wharf

1. Speed of approach

In the handling of berthing ships, it is very important to control the ship's approach speed, as well as directional control. As a ship approaches its objective location, its headway should gradually be reduced, and hull inertia should be stopped at the predetermined point. On the assumption that the ship can employ breaking power through the use of Dead Slow Astern engine, guidelines for speed reduction schemes for LNG carriers, PCCs and container ships are shown in Fig.3-33. The same guidelines for VLCCs are also shown in Fig.3-34.

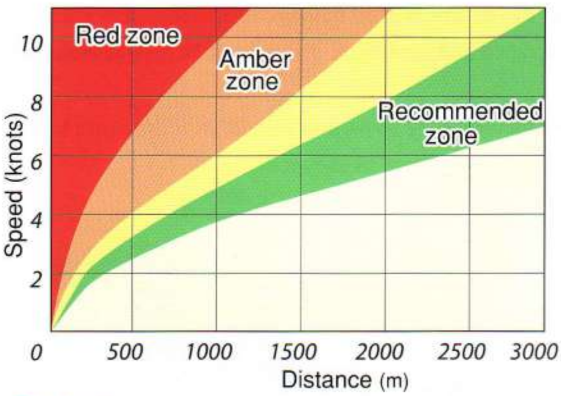


Fig.3-33 Speed reduction schemes for LNGs, PCCs, and Container ships

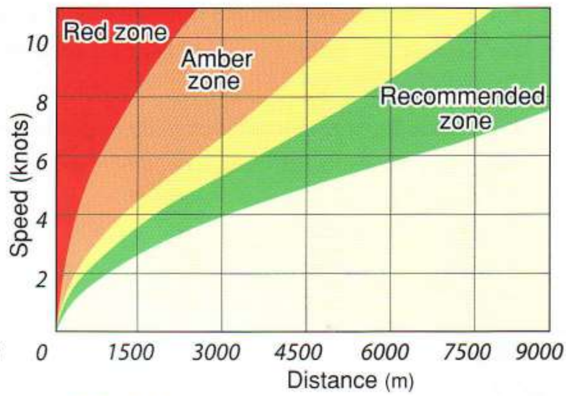


Fig.3-34 Speed reduction schemes for VLCCs

2. Approaching a wharf

To prevent damage to the wharf and fenders, a large-size ship should reduce its headway to zero somewhere at a distance of one ship length or ship breadth from the wharf, and then move laterally, berthing with the ship's heading kept parallel to the wharf. Wharfs and shore-based mooring facilities are usually designed assuming a berthing velocity of 15 cm/sec. Actual berthing velocities are much lower, however, and should not exceed 10 cm/sec for ordinary-size ships, and 5 cm/sec for large-size ships. Fenders absorb the berthing energy of the ship. Their purpose is to prevent damage to hull and wharf. When berthing with a ship's heading nearly parallel to the wharf, the energy of the ship against the mooring facilities will increase in proportion to displacement tonnage and the square of the ship's approach velocity, which can be written as:

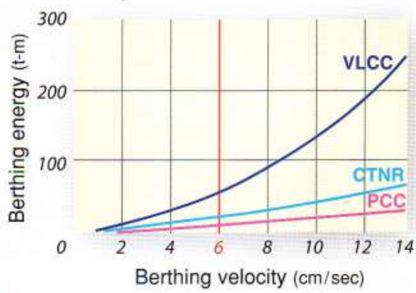


Fig.3-35 Berthing energy versus berthing velocity

$$E=\frac{1}{2}\cdot\frac{W}{g}\cdot V^2\cdot C$$

E : Berthing energy (ton · m)
W: Displacement tonnage (ton)
V : Berthing velocity (m/sec)
g : 9.8m/sec² C : Coefficient
Berthing speed < 8~10cm/sec (generally)

The value of coefficient C changes considerably with the type of ship, water depth and other factors. Fig.3-35 shows the calculated results of berthing energy on each ship type, where it is known that the berthing energy of a VLCC increases sharply when the berthing velocity exceeds 6 cm/sec.

3. Positioning of ship on berthing operations

When a PCC with a short parallel body is berthing as shown in **Fig.3-36**, the ship's bow or stern has occasionally come in contact with corners of the wharf, car-stoppers or bitts.
This contact is due to a directional difference between fore-and-aft line of the ship and the face line of the wharf. The range of critical positioning, wherein a part of the hull is not in contact with the wharf, is determined by the wharf face line and the angular deviation of the ship's heading from that wharf line. (**Fig.3-37** right)

The left side of **Fig.3-37** shows the permissible amount of overhang **R** versus the angular deviation from the wharf line ***α*** on a PCC.
From the figure, the critical angular deviation corresponding to the amount of overhang can be found.
In the plotted case, when the permissible amount of overhang is 3 meters, the critical angular deviation of the stern is 2.3 degrees.

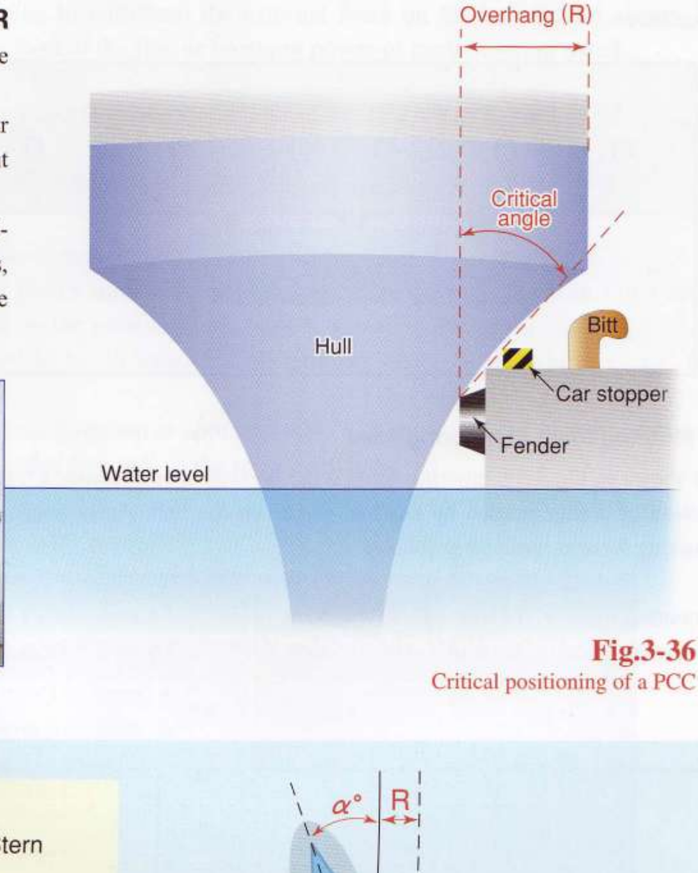


Fig.3-36
Critical positioning of a PCC

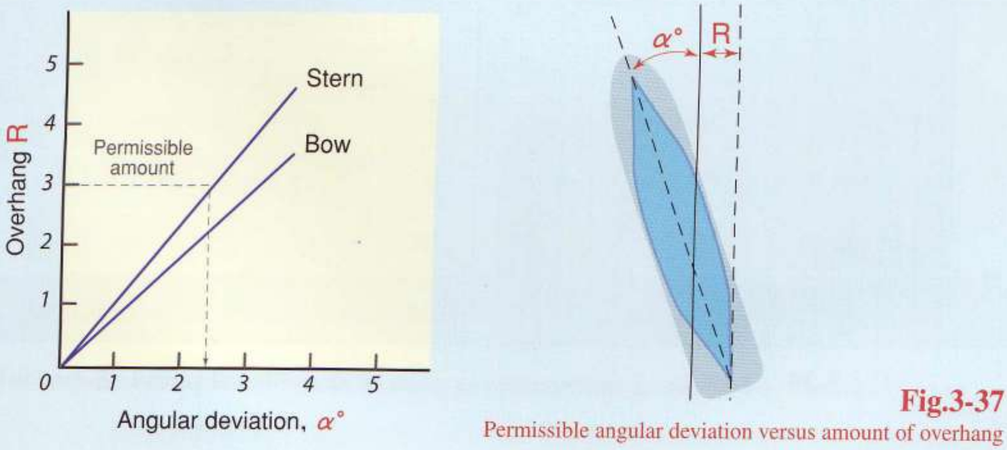


Fig.3-37
Permissible angular deviation versus amount of overhang

Mooring

1. Mooring arrangement

Mooring lines control a ship's motion and make the ship fast to a fixed position.
Fig.3-38 shows a fundamental mooring arrangement. Headlines and stern lines are used to control surge, sway and yaw. Spring lines control drift.
Moreover, since it is desirable that each line be extended as far as possible, it is necessary that attention be paid during berthing operations to insure these maximum lengths.
In a wharf where arrangement of longer mooring lines is not possible, additional lines should be deployed as necessary.

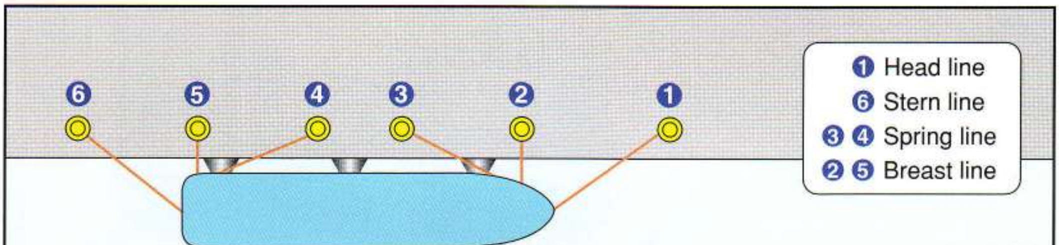


Fig.3-38 Basic mooring arrangement

2. Mooring force of mooring lines

As shown in Fig.3-39, mooring force is the horizontal component, $T \cdot \cos\theta$, of tension needed to withstand the motion of a ship exerted by external forces on the hull. Accordingly, as shown in Fig.3-40, the horizontal mooring force is resolved as follows:

- mooring force on the fore-and-aft direction Tx: $Tx = T \cdot \cos\theta \cdot \cos\phi$
- mooring force on the transverse direction Ty: $Ty = T \cdot \cos\theta \cdot \sin\phi$

θ : angle of elevation of the mooring line
ϕ : horizontal angle to the face line of wharf

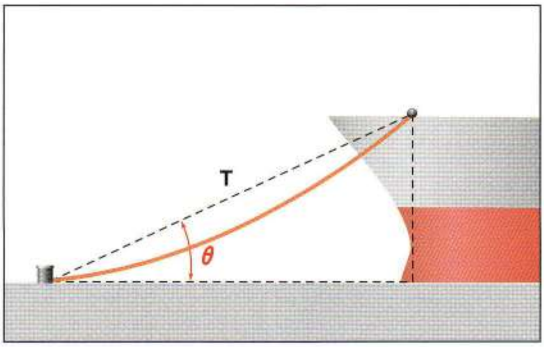


Fig.3-39 Definition of mooring force

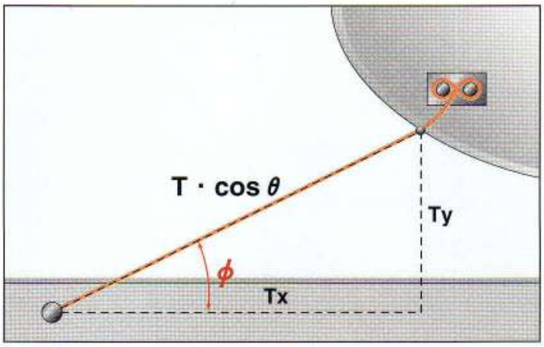


Fig.3-40 Horizontal mooring force vector

The sum of each mooring force, on the fore-and-aft and transverse direction, is the resultant mooring force.
Critical mooring force to cope with all external forces is determined by the condition that each component of external force should not exceed the corresponding component of the sum of each mooring force.
On the other hand, critical mooring force is determined in relation to the strength of mooring rope or the breaking power of the mooring winch.
That is, the load of each mooring line to withstand the external force on the hull should always be within the range of the safe working load of the line or breaking power of each mooring winch:

External force on hull ≦ 60 % of Minimum Breaking Load (MBL) of mooring line

or

External force on hull ≦ Breaking power of mooring winch

The smaller value of either of the above opposing forces becomes the critical mooring force.
Assuming a ship free from external forces such as wind and current, as moored shown in **Fig.3-38**, a calculated example of mooring force on the transverse direction is shown in **Table 3-2**.
The line pull of winches is assumed to be 25 tons, and all mooring lines, 14 lines in this case, are equally pre-tensioned.
The total mooring force on the traverse direction is approximately 128 tons, and the mooring force of each line is within the range of the settled line pull of the mooring winch.

Line	Number of lines	Angle		Mooring force per line	Total mooring force
		$\phi°$	$\theta°$		
❶ Head line	3	26	14	11	33
❷ Breast line	2	40	32	14	28
❸ Spring line	2	6	22	2	4
❹ Spring line	2	6	26	2	4
❺ Breast line	2	40	36	13	26
❻ Stern line	3	26	16	11	33
Total	14 lines				128 (ton)

Table 3-2 Calculated example of number of mooring lines and mooring force on transverse direction

3. Shift of a ship under wind effects

When a wind of 10 m/s is blowing off the wharf, the amount of shift of a PCC is simulated under various mooring conditions:

(1) The ship has been shifted laterally 1.6 meters under the mooring condition shown in Fig.3-38 with each mooring line of 70 mm ϕ arranged in pairs, 12 lines in total.
(2) When one additional line is deployed on each mooring point, except on the forward and aft spring lines, the ship has been shifted laterally 1.2 meters, the restraining effect of the additional lines being only 40 cm.
(3) When wire ropes of 40 mm ϕ are made fast to storm bitts as additional lines as shown in Fig.3-41, the ship has been shifted laterally only 5 cm, and the effectiveness of storm bitts mooring is clearly demonstrated.

In this case, each additional line should be as perpendicular as possible to the ship's fore-and-aft line, and the lines be extended as far as possible from the edge of the wharf.
However, when wind velocity exceeds 15 m/s, additional lines made of synthetic materials will lose their restraining power, and the ship will suffer a large lateral shift.

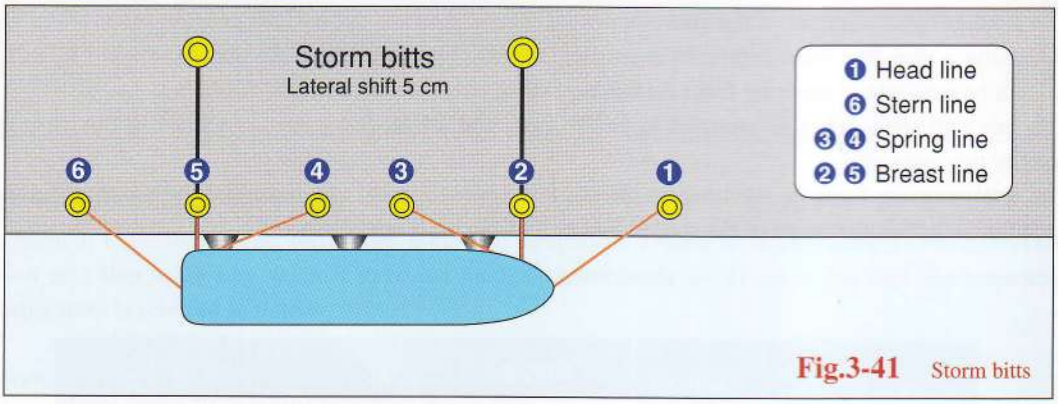


Fig.3-41 Storm bitts

Some Tanker terminals under strong wind and/or current equip storm wire and winch as shown in Fig 3-42.

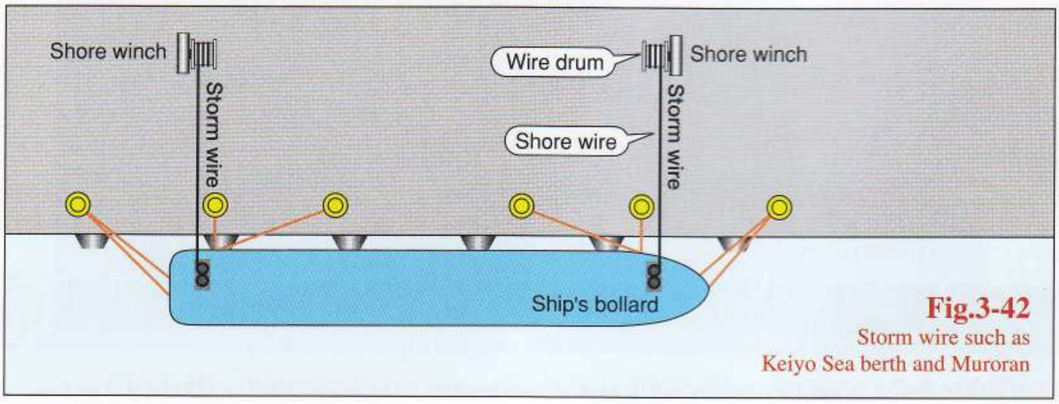


Fig.3-42 Storm wire such as Keiyo Sea berth and Muroran

4. Mooring lines

The numbers, types, lengths, diameters, and breaking loads of mooring lines with which a ship should be equipped are stipulated in the Equipment Number.
Commonly, ships are equipped with more mooring lines than the Equipment Number requires.
Synthetic fiber ropes are made of various materials, such as nylon, polyester and polypropylene.
High performance fiber ropes are now sometimes used for mooring lines. The fiber materials used in these ropes are much stronger and also stiffer than conventional rope-making fibers.
Because they are much stiffer, ropes made of this new class of fibers are called high-modulus fiber ropes. These high-modulus fiber ropes are almost as strong as wire ropes of the same size, and they are also almost as stiff. While the properties of synthetic fiber rope make it highly resistant to chafing over flat surfaces, it has poor resistance to chafing over sharp edges and sideslips.
It also deteriorates under exposure to ultra-violet rays.
Because the extent of deterioration in strength of mooring lines varies with cycles and duration of use, it is necessary to check the condition of mooring lines daily. Wire ropes (or high-modulus fiber ropes) are used to moor tankers and LNG carriers in order to avoid damage to loading arms; synthetic fiber ropes are used to moor ships of other types.
Deploying additional lines for mixed mooring, the combination of full-length synthetic ropes and wires should be avoided.

5. Operational precaution of mooring

Mixed mooring (Fig.3-43)

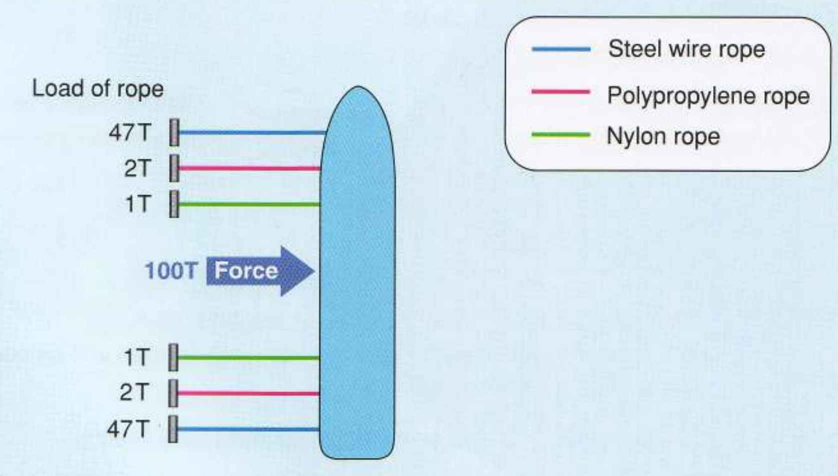


Fig.3-43 Effect of mooring material

**Hence, Two or more lines leading in the same direction should always be of the same material.
Never mix wire and synthetic fiber ropes leading in the same direction.**

Mixed mooring (Fig.3-44)

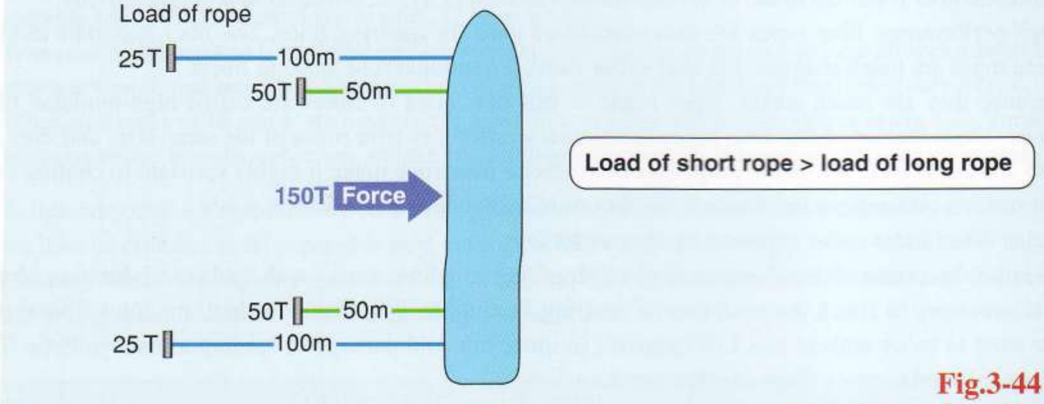


Fig.3-44
Effect of length of moorings
(same size/same materials)

Therefore two or more lines leading in the same direction should, as far as possible, be of the same length.

Key numbers for mooring lines

11m: Length of tail rope (Fig.3-45)

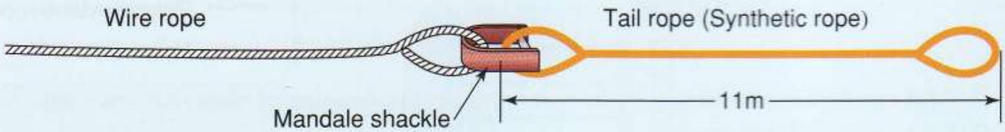


Fig.3-45 Length of tail rope

125%: MBL of Tail rope ÷ MBL of Mooring wire > 125%
(MBL means MBL of each material before making eyes and splices.)
MBL: Minimum Breaking Load

60%: Brake capacity of Winch ÷ MBL of Mooring lines ≒ 60%

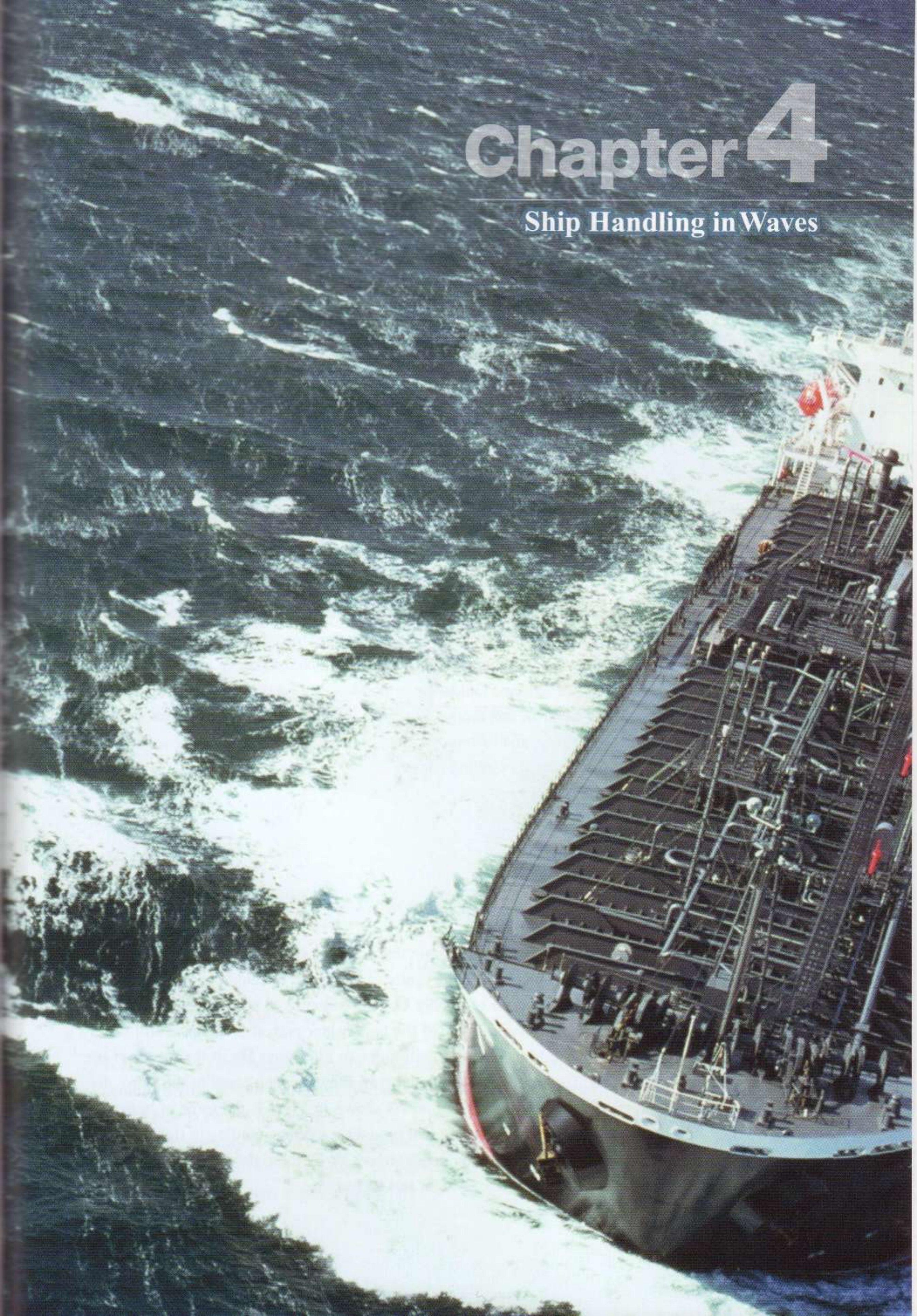
18 months: Tail rope should be renewed every 18 months.
Otherwise every tail rope should be inspected and certified by manufacturer regularly.

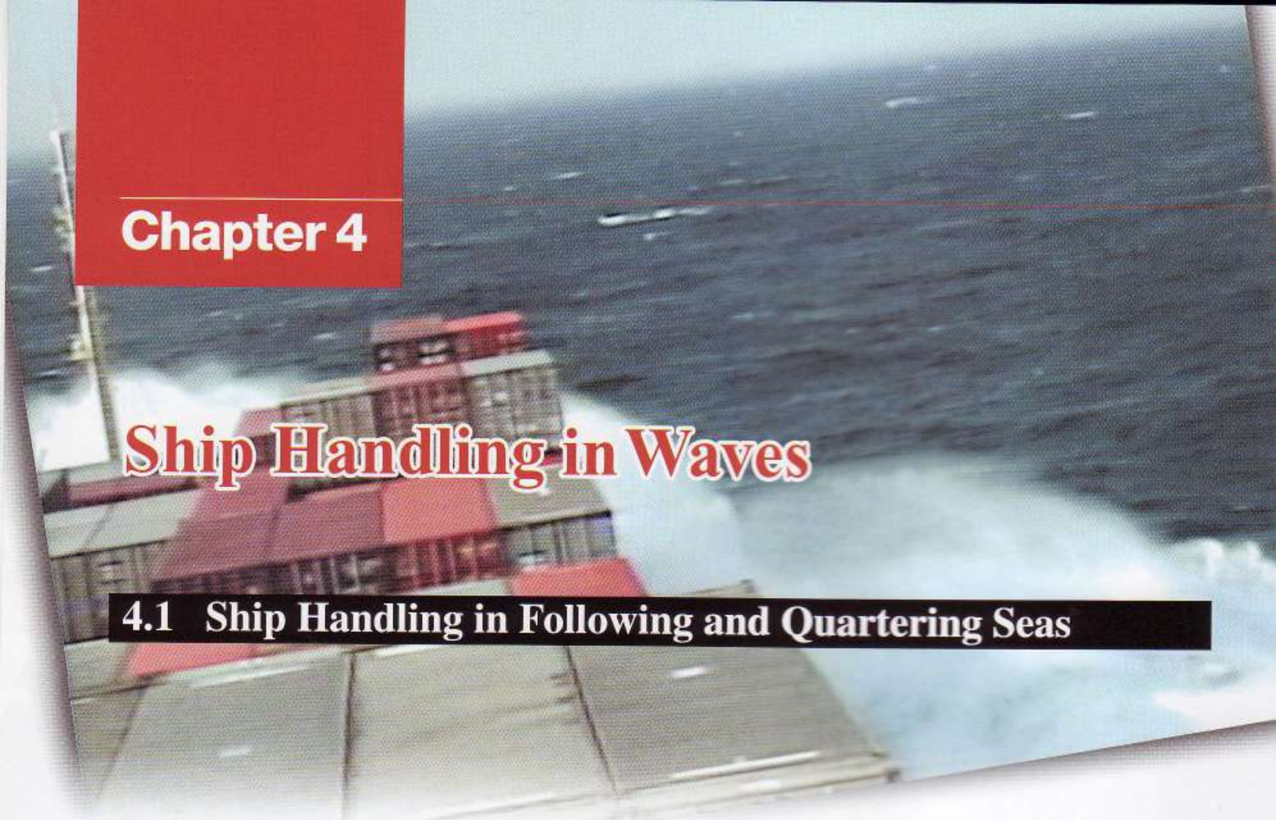
12 wires: Ras Tanurah port regulations require more than 12 wire moorings for mooring at the sea berth.

4-4-2: 4 head/stern lines-4 breast lines-2 spring lines

Chapter 4

Ship Handling in Waves





Chapter 4

Ship Handling in Waves

4.1 Ship Handling in Following and Quartering Seas

General

When navigating in severe following and quartering seas, a ship is likely to encounter various kinds of dangerous phenomena, which may lead to capsizing. We should, therefore, possess the fundamental skills for safe ship handling in following and quartering seas to avoid such danger.
With the same objective, the IMO has released Guidance to the Master for Avoiding Dangerous Situations in Following and Quartering Seas. In this section, we begin with a basic study of vessel stability and the fundamental properties of waves, and then move on to describe phenomena that pose a danger to ships and provide operational guidance for dealing with them.

Stability of Ships

Transverse Stability

1) Righting moment

A ship floating at rest is in a state of static equilibrium; that is, the gravitational forces acting on the center of gravity **G**, and the buoyancy acting on the center of buoyancy **B** being equal and acting in line with one another. The position of center of gravity **G** will remain fixed when the ship is heeled. The center of buoyancy **B** is the geometric center of the underwater part of the ship in still water. When the ship is heeled by some external force, it will move to a position B_1 in the center of the submerged volume of the ship. The forces of weight and buoyancy are each equal to the ship's displacement **W**, and act vertically in opposite directions. As shown in **Fig.4-1**, the force of buoyancy acting upwards through B_1 when the ship is heeled will produce a moment tending to right the ship, and this moment is calculated by multiplying the displacement **W** by the righting lever **GZ**, which is the horizontal distance between the forces of weight and buoyancy.

2) Transverse metacenter and transverse metacentric height

In most ships, for small angles of heel of up to about 10 degrees, the line of action of the force of buoyancy $\mathbf{B_1}$ will intersect the middle line of the ship at a fixed point **M** (Fig.4-1). The point **M** is called the transverse metacenter. The span between the metacenter **M** and the center of gravity **G**, **GM**, is called the metacentric height; it gives a measure of the initial stability of the ship, i.e. its stability at small angles of heel. The greater the metacentric height, (i.e. the lower the position of **G**), the greater the stability. In Fig.4-1, the angle θ is equal to the angle of heel, and the righting lever **GZ** is equal to $\mathbf{GM} \cdot \sin\theta$ (provided that θ is small and **GM** is positive [G is below M]). If the metacentric height is known, the righting moment can be found by multiplying the righting lever **GZ** by the ship's displacement **W**:

$$\textbf{Righting moment} = \mathbf{W \cdot GZ = W \cdot GM \cdot \sin\theta}$$

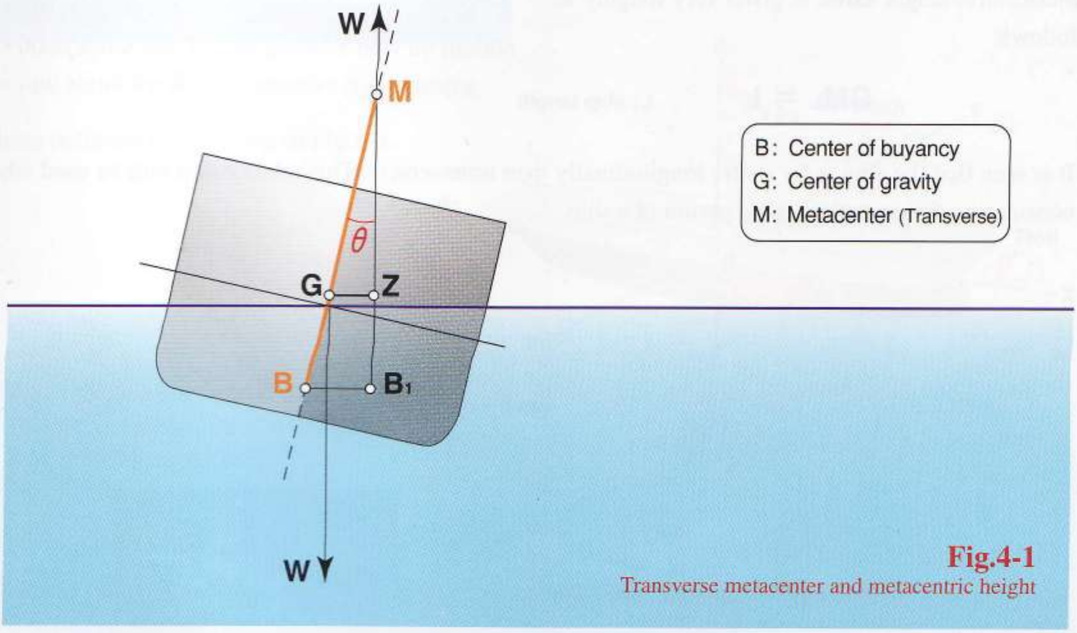


Fig.4-1
Transverse metacenter and metacentric height

The height of the transverse metacenter above the center of buoyancy **BM** is indicated by the following formula:

$$\mathbf{BM} = k\frac{B^2}{d} \qquad B\text{: breadth} \quad d\text{: draft} \quad k\text{: coefficient}$$

A ship with a large transverse metacentric height will roll with a short, rapid motion; such a ship is said to be stiff. A ship with a small transverse metacentric height will roll with a long, slow motion; such a ship is said to be tender.

Transverse stability is a very important factor when it comes to safe navigation in heavy seas; we refer to it often in this chapter.

Status	Transverse Metacenter	Rolling
Stiff	Large	Rapid
Tender	Short	Slow

Longitudinal Stability

The longitudinal metacenter **M_L** of a ship is found in a manner similar to that used to find the transverse metacenter.

Fig.4-2 shows a ship tipped forward by some external force; the longitudinal center of buoyancy **B** has moved forward to **B_1**. Thus a longitudinal righting moment **W·GZ** is produced; where **W** is the displacement of the ship and **GZ** is the length of the longitudinal righting lever. The longitudinal metacentric height **GM_L** is given very roughly as follows:

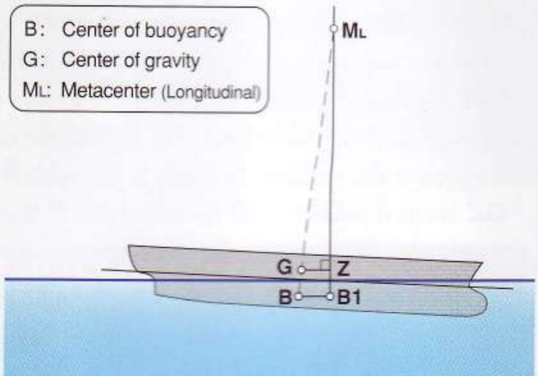
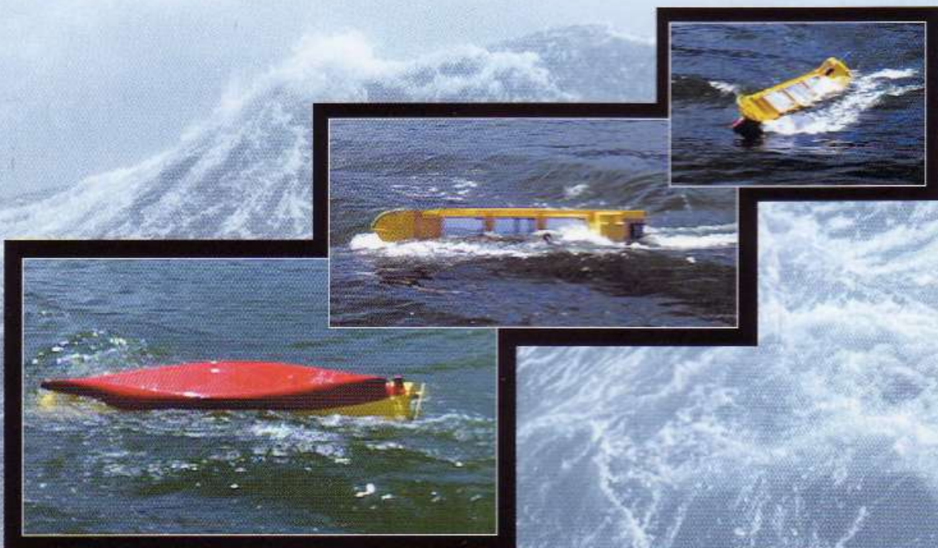


Fig.4-2 Longitudinal metacenter

$$GM_L \fallingdotseq L \qquad L\text{: ship length}$$

It is seen that the ship is far stiffer longitudinally than transversely. This relationship will be used when considering the natural pitching period of a ship.



Six Freedoms of Motion in a Seaway

The motions of a ship can be split into three mutually perpendicular translations of the center of gravity **G** and three rotations around **G**:

Three translations of the ship's center of gravity G in the direction of the X-, Y- and Z-axes:

- surge in the longitudinal **X**-direction, positive forward
- sway in the lateral **Y**-direction, positive to starboard side
- heave in the vertical **Z**-direction, positive downward

Three rotations about these axes:

- roll about the **X**-axis, positive right turning
- pitch about the **Y**-axis, positive bow up motion
- yaw about the **Z**-axis, positive right turning

These definitions are shown in **Fig.4-3**.

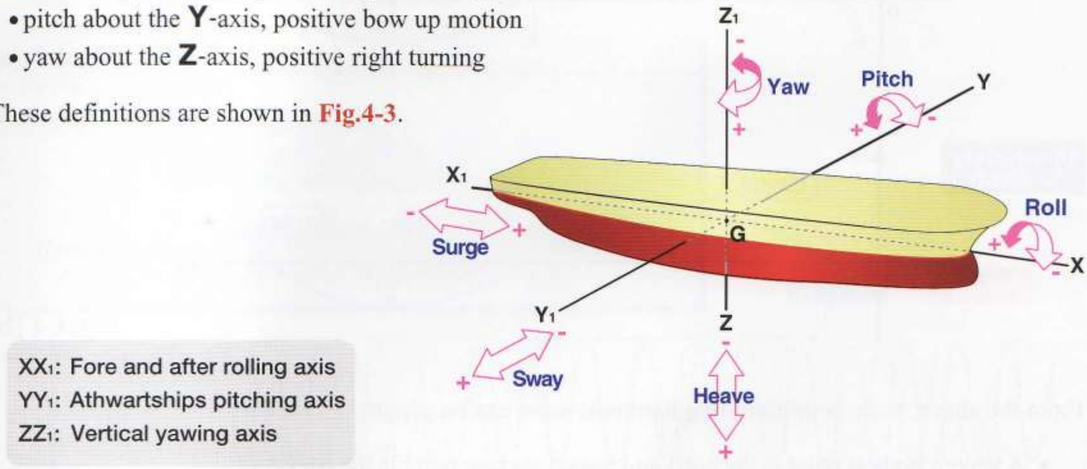
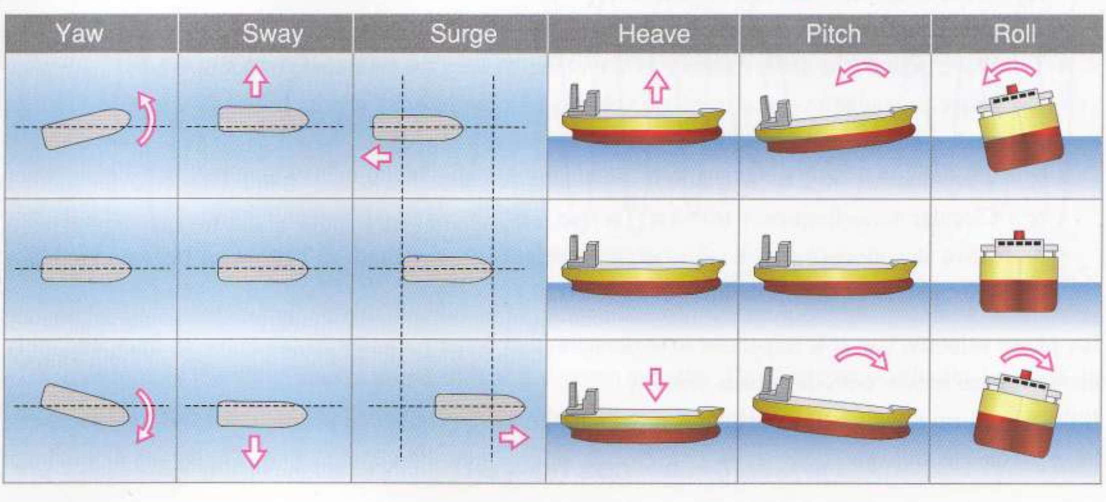


Fig.4-3 Six freedoms of motion



Basic Elements of Regular Waves

1) Defining a harmonic wave

Fig.4-4 (a) and Fig.4-4 (b) depict harmonic waves, ζ, from two different perspectives:

- Fig.4-4 (a) shows the wave profile (with wave amplitude, a, and wave length, λ) as a function of distance at a fixed instant in time.
- Fig.4-4 (b) shows time record of the wave profile (with wave amplitude, a, and wave frequency, ω) observed at one location.

H : Wave height
λ : Wavelength
Tw : Wave period
Cw : Wave propagation speed (Phase velocity)
a : Wave amplitude (H=2a)
Crest : Highest point of wave
Trough : Lowest point of wave
ζ : Shape of wave

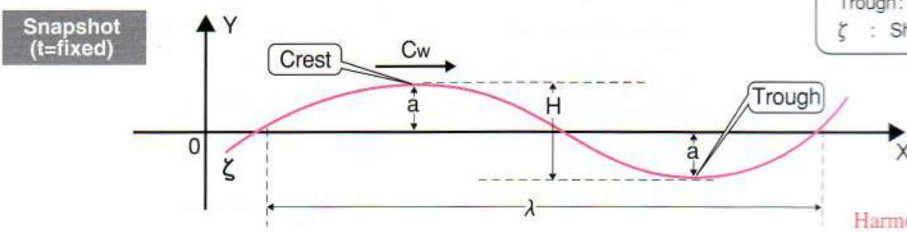


Fig.4-4 (a)
Harmonic wave definitions

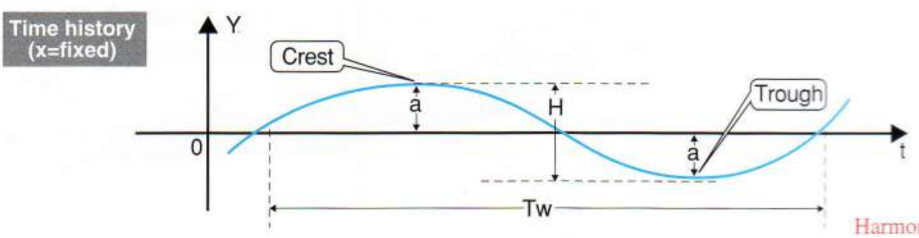


Fig.4-4 (b)
Harmonic wave definitions

From the above, basic definitions of a harmonic wave can be given:

- A wave's highest point is the crest and lowest surface point is the trough
- a : Wave amplitude (the distance from the still water level to the crest, or to the trough)
- H : Wave height (H=2a; twice amplitude)
- λ : Wavelength (horizontal distance between any two successive wave crests)
- Tw: Wave period (the same distance as wavelength along the time axis) (see Fig.4-4-b)
- Cw: Wave propagation speed or phase velocity (λ/Tw; velocity at which the wave profile undergoes a complete 360-degree cycle or phase change)
- k : Wave number ($k=2\pi/\lambda$ (rad./s))
- ω : Circular wave frequency ($\omega=2\pi/Tw$ (rad./s))
- δ : Wave steepness ($\delta=H/\lambda$; ratio of wave height to wavelength. When waves become too high, crests break at the upper limit of $H/\lambda=1/10$.)

For phase velocity, Cw, it is important to understand that water particles do not move at this speed; only the waveform moves with this phase velocity.

If the waveform moves in the positive X direction, the wave profile (the shape of the water surface) can be expressed as follows:

$$\zeta = a \cdot \cos(kx - \omega t)$$

2) Basic elements of regular deep waves

By applying the obtained relations to regular deep waves (longer deep-water gravity waves), simple and very practical relations between the wavelength (m) and phase velocity (m/s), or wave period (s) can be expressed as follows:

Wave velocity (C_W) (Phase velocity)	$C_W = 1.25\sqrt{\lambda}$ (m/s)
Wave period (T_W)	$T_W = 0.80\sqrt{\lambda}$ (s)
Wavelength (λ)	$\lambda = 1.56 \cdot T_W^2$ (m)

Miscellaneous items related to waves

1) Group velocity and wave energy

When superposing propagating waves with slightly different wavelengths, group waves (the envelope of the wave packet) are created as shown in **Fig.4-5**.

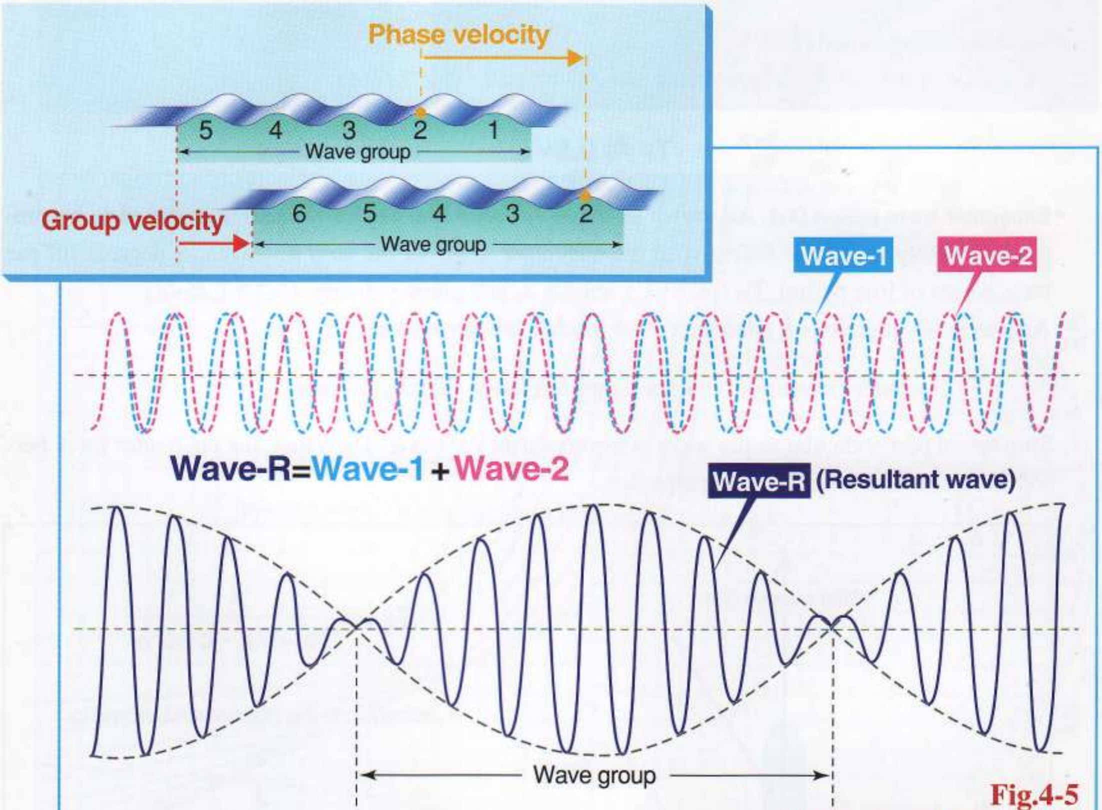


Fig.4-5
Wave groups and group velocity

The envelope of the wave packet propagates at the group velocity, Cg. The group velocity for deep water waves is expressed as: $Cg = \frac{1}{2} Cw$ Cw: phase velocity of the wave

The wave energy is also conveyed along a group velocity (the propagation of swell).

2) Significant wave height ($H_{1/3}$)

Significant wave height is defined as the average height of the highest one third (1/3) of all waves recorded over a particular time period. There is a fair correlation between significant wave height and visually estimated wave height. Significant wave height is used as a general measure of sea roughness.

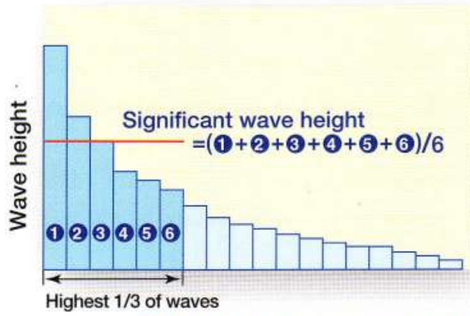


Fig.4-6 Significant wave height

3) Natural rolling/pitching periods and encounter wave period

- **Natural rolling period (T_R).**

Natural rolling period is to be measured when the ship is in calm seas. The value is roughly estimated by the following equation:

$$T_R \fallingdotseq \frac{0.8B}{\sqrt{GM}}$$

B: ship's breadth
GM: ship's metacentric height

- **Natural pitching period (T_P).**

The value of natural piching period is roughly estimated by the following equation:

$$T_P \fallingdotseq 0.5\sqrt{L}$$

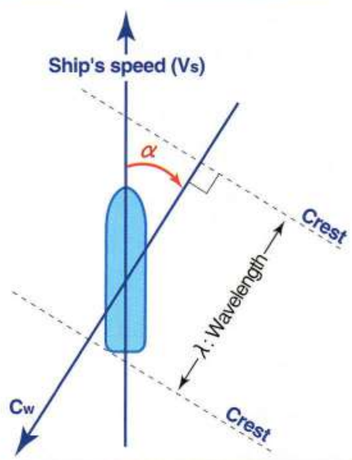
L: ship length (m)

- **Encounter wave period (T_E).** As shown in Fig.4-7, a ship making Vs (m/sec) is assumed to be running obliquely in regular waves with the encounter angle of the ship to waves, α degrees off the bow, waves of true period, T_W ($=0.8\sqrt{\lambda}$), length, λ, and phase velocity, C_W ($= 1.25\sqrt{\lambda}$).

As previously mentioned, encounter wave period is expressed as:

Encounter wave period = wavelength/relative velocity to wave

Ship speed perpendicular to the wave is expressed as $Vs \cdot \cos\alpha$. Therefore, the encounter wave period is expressed by the following equation:



$$T_E = \frac{\lambda}{C_W + Vs \cdot \cos\alpha}$$

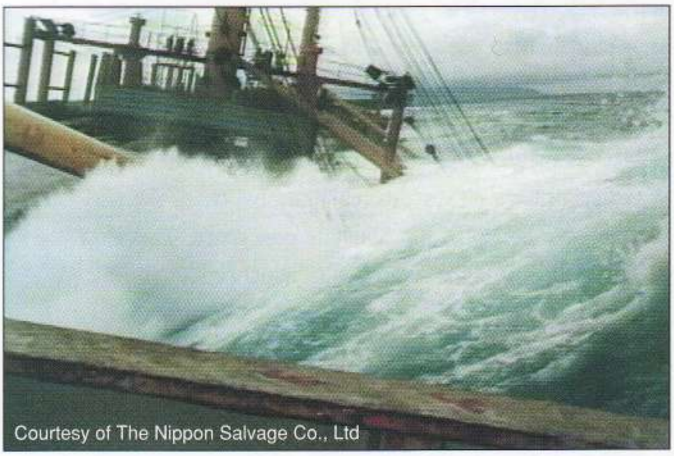
or, referring to the previous relationship,

$$T_E = \frac{\lambda}{1.25\sqrt{\lambda} + Vs \cdot \cos\alpha}$$

Fig.4-7 Encounter wave period (T_E)

Based on the above equation, a diagram is prepared as shown in **Fig.4-8**, and encounter wave period (T_E) is obtained using the encounter angle of the ship to wave (α), ship speed (V_s) and wave period (T_w).

A synchronous rolling motion will occur when the encounter wave period T_E is nearly equal to the natural rolling period of the ship, T_R, and this will cause large rolling motions. This phenomenon will be explained in the subsequent section.



Courtesy of The Nippon Salvage Co., Ltd

Example Vs : 14 Knots (Ship speed)
α : 30° (Encounter angle)
Tw : 11 sec (Wave period)
T_E : 8 sec (Encounter period)

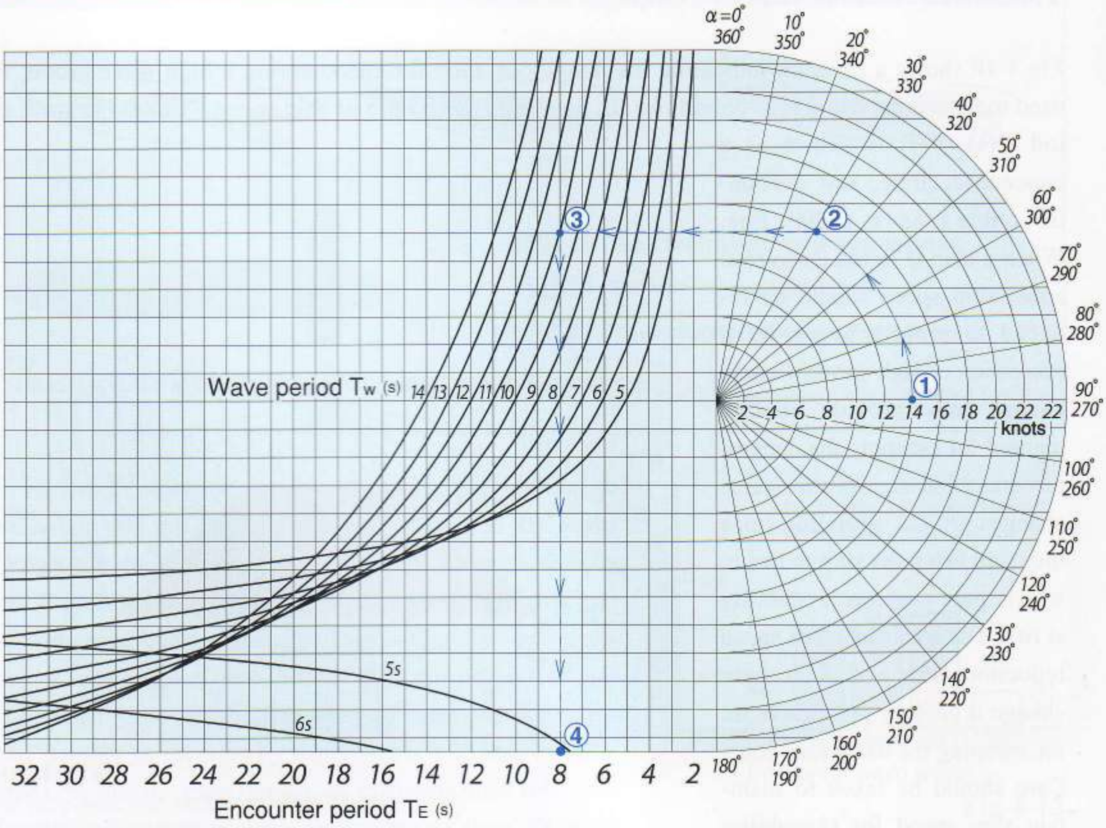


Fig.4-8 Determination of encounter wave period (T_E)

Dangerous Encounter with High Wave Group

The envelope of wave packet propagates at the group velocity, Cg, in deep water; $Cg=1/2 \cdot Cw$ (See page 075). When the above wave group velocity is nearly equal to the speed component of a ship to the wind direction, dangerous encounter with high wave group occurs; this is a phenomenon whereby the ship is attacked by a succession of high waves. As mentioned above, the maximum wave height of the successive waves can reach almost twice the observed wave height of the sea state concerned. This situation can result in the reduction of synchronous rolling motion, parametric rolling motion, or the occurrence of several dangerous phenomena, heightening the risk of capsize.

Fig.4-9 shows the definition of encounter angle χ, measured from the stern of a ship.

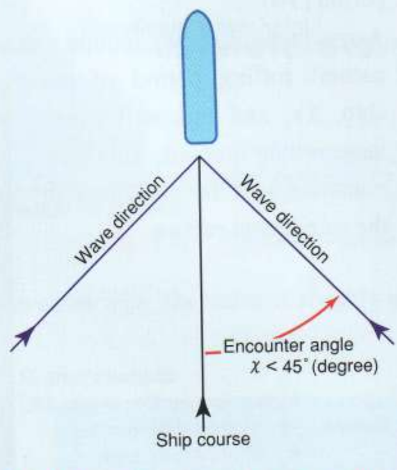


Fig.4-9 Definition of encounter angle, χ

Fig.4-10 shows a diagram indicating the dangerous zone for encountering a high wave group; it is used to determine dangerous conditions. In the figure, each ratio of ship speed V (knots) to wave period T (s), V/T, is shown as a concentric circle, and encounter angle χ as a radial line. When a ship is in the dangerous zone, ship speed should be reduced to prevent attack by a succession of high waves. Course change may provide another method for escaping the dangerous zone, but significant course changes are not advisable since they will bring the ship to beam, which puts transverse stability at risk. The combination of speed reduction with a slight course change is another possible tactic for escaping the dangerous zone. Care should be taken to maintain ship speed for steerability in wind and waves.

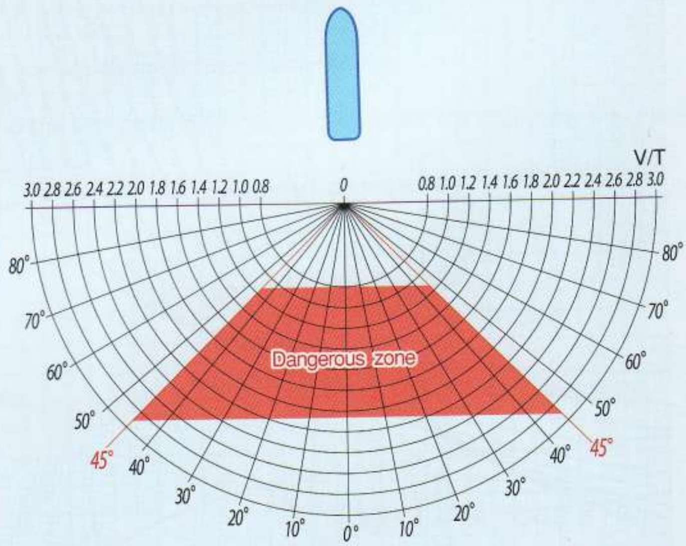


Fig.4-10
Diagram indicating dangerous zone of encountering to high wave group

Reduction of Intact Stability Caused by Riding on Wave Crest at Midship

When a ship is navigating in following and quartering seas, the effective beam of a ship-shaped hull can change considerably with changes in a ship's waterline profile, particularly when the ship has fine lines and a large flare (container ships and fishing vessels).

The metacentric radius, BM, and consequently, transverse stability will increase or decrease as a wave passes along the length of the hull. As shown in **Fig.4-11**, when a ship is riding on the wave crest, intact stability will be reduced considerably as the loss of waterplane area at the fore and aft ends reduces the ship's GM and transverse stability. On the other hand, when the wave trough is amidships, stability is increased as the extra waterplane area at the fore and aft ends increases the ship's GM and transverse stability.

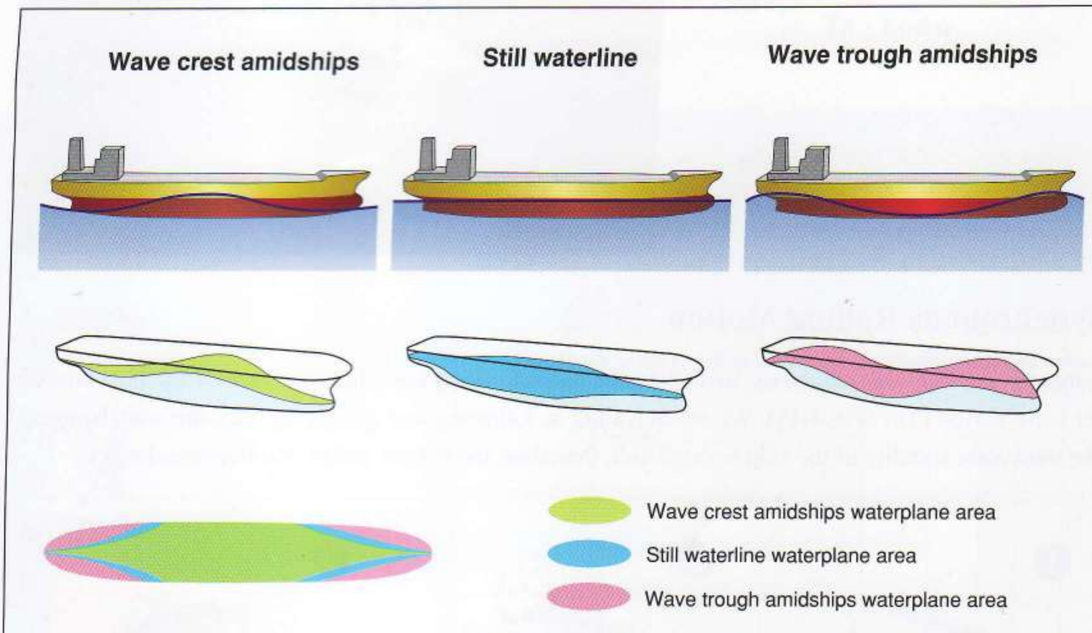


Fig.4-11 Change in ship's waterplane area with wave profile

The amount of stability reduction is nearly proportional to wave height and the ship may lose stability when the wavelength is one to two times ship length and wave height is large. This situation is especially dangerous in following and quartering seas, because the time spent riding the wave crest becomes longer (more time is spent in a state of reduced stability). **Fig.4-12** shows the frequency of capsizing due to reduced stability as revealed by experiments with ship models. Please note that the most dangerous capsizing zone relates to a direction of encounter wave angle ranging from 20 to 40 degrees from the stern.

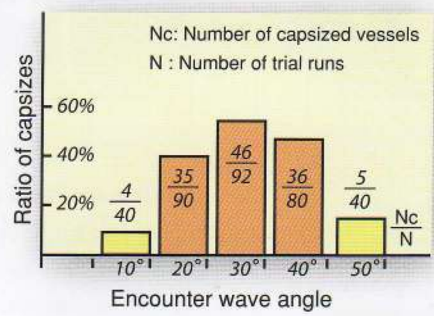
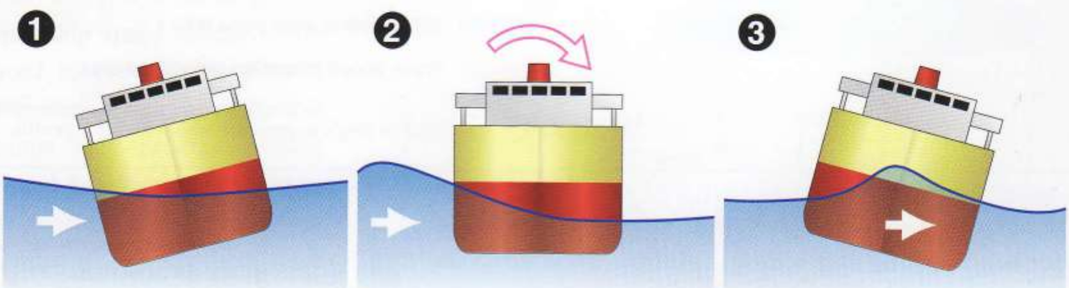


Fig.4-12
Number of capsized vessels to number of trial runs (model ship experiments)

Reduction of stability tends to be more significant when a ship is fine-lined with a large flare (container ships and fishing vessels) and less significant in full-hull ships (tankers and bulk carriers).
The faster the ship runs, the greater the risk of capsizing; reduction of stability is greatly increased because the ship is riding on a crest of a larger wavelength, i.e. larger wave height. To avoid the risk of capsizing due to reduced stability, ship speed should be reduced or course altered, or both, in order to change the encounter wave angle and period. When executing the above procedures, care should be taken not to induce other risks, such as beam seas that may place the deck under water or cause synchronous rolling motion.

Synchronous Rolling Motion

Large rolling motions may be excited when the natural rolling period (TR) coincides with the encounter wave period (TE) (Fig.4-13). When navigating in following and quartering seas, this may happen if the transverse stability of the ship is small and, therefore, the natural roll period becomes longer.



❶ Listing.
❷ Return roll is accelerated and reinforced by the next wave.
❸ The limits of ship's roll coincide with the wave crest (or trough).
- The rolling angle increases with each successive wave.
- This is known as "**synchronous rolling**". (Causing dangerous heavy rolling.)

Fig.4-13 Synchronous rolling

Fig.4-14 shows the zones of heavy rolling of ships with 8- and 24-second roll periods among waves of 60 to 180 meters in length. As seen in the figure, the zone of heavy rolling shifts from the beam to the quarter of the ship as the natural roll period becomes longer (i.e. the ship becomes tender.)

Course change or speed reduction is required to prevent synchronous rolling motion, i.e. avoiding synchronous roll, $T_R/T_E = 1$. The course or speed leading to synchronous roll can be obtained using the equation described on page 076 or by the diagram in **Fig.4-8** under the condition $T_R/T_E = 1$.

- Ship's relative course to wave (α) from the bow leading to synchronous rolling:

$$\cos\alpha = \frac{\lambda - T_R \cdot 1.25\sqrt{\lambda}}{T_R \cdot V_s}$$

- Ship speed (Vs m/s) leading to synchronous rolling motion:

$$V_s = \frac{\lambda - T_R \cdot 1.25\sqrt{\lambda}}{T_R \cdot \cos\alpha}$$

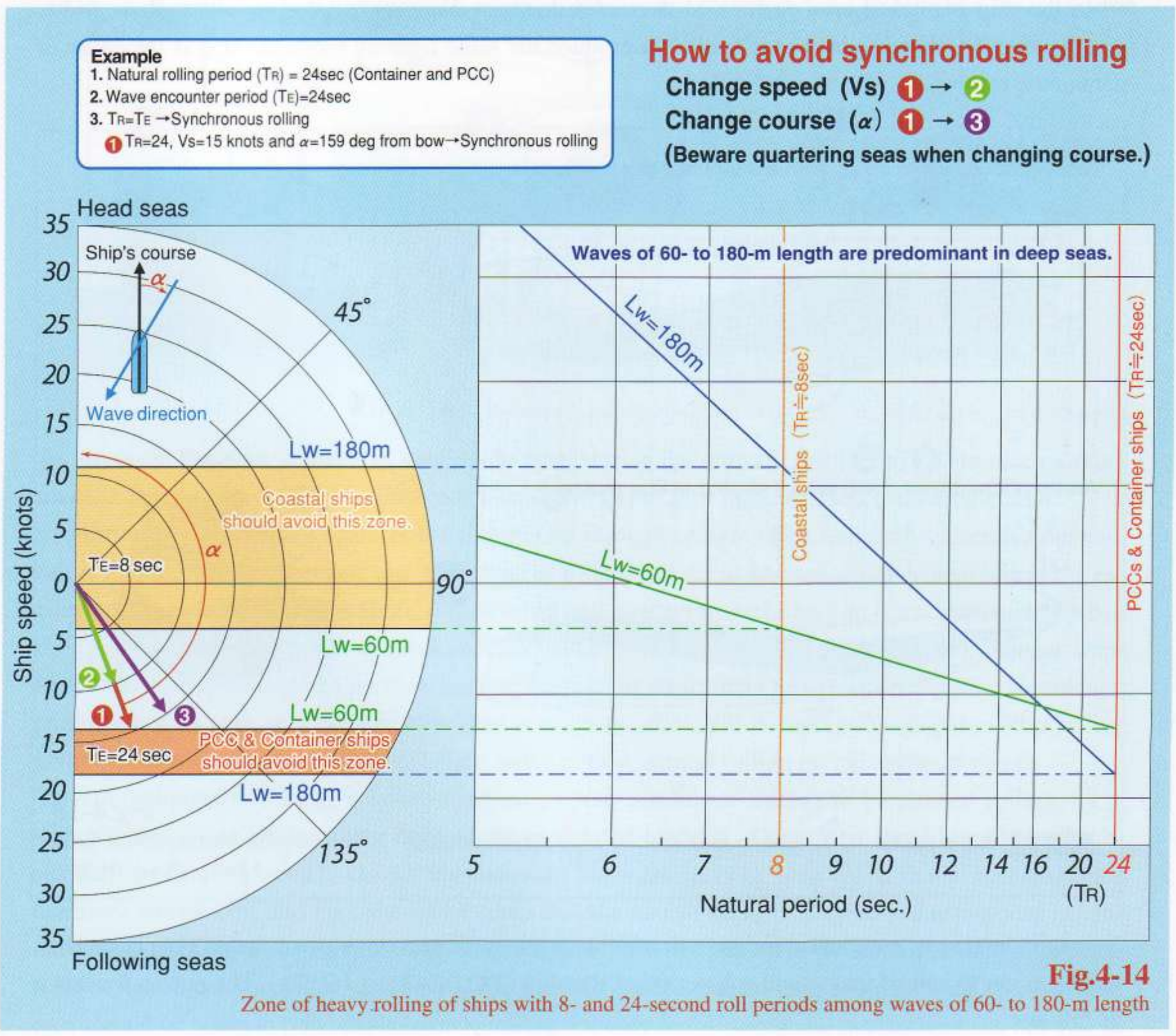


Fig.4-14

Zone of heavy rolling of ships with 8- and 24-second roll periods among waves of 60- to 180-m length

Parametric Rolling

Parametric rolling is an unstable phenomenon that rapidly generates large roll angles coupled with significant pitching. As explained on page 078 the transverse stability of a ship changes considerably with changes in its waterline profile. This can trigger roll if it occurs with a particular period.

Transverse stability is the product of the ship's weight (W) and righting lever (GZ) ($GZ = GM \cdot \sin\theta$); i.e. $W \cdot GM \cdot \sin\theta$. Changes in transverse stability vary with the periodic changes of righting lever GZ. This is the predominant cause of possible roll excitation, that is, parametric rolling.

Development of container ships requiring large deck cargo capacities and fast service speeds has raised the risk of parametric rolling. These ships have hull-forms with fine-lined, generously flared bows and a wide stern. Asymmetry between bow and stern hull lines tends to induce parametric motion.

As shown in **Fig.4-15**, when the ship is pitched stern down, GM increases due to the increase in effective water plane width, and the small angle of heel creates a large righting moment. On the other hand, when the ship is pitched bow down, GM decreases due to a decrease in effective water plane width, and the ship is obliged to heel over further to produce the same righting moment. This is the cause of parametric rolling.

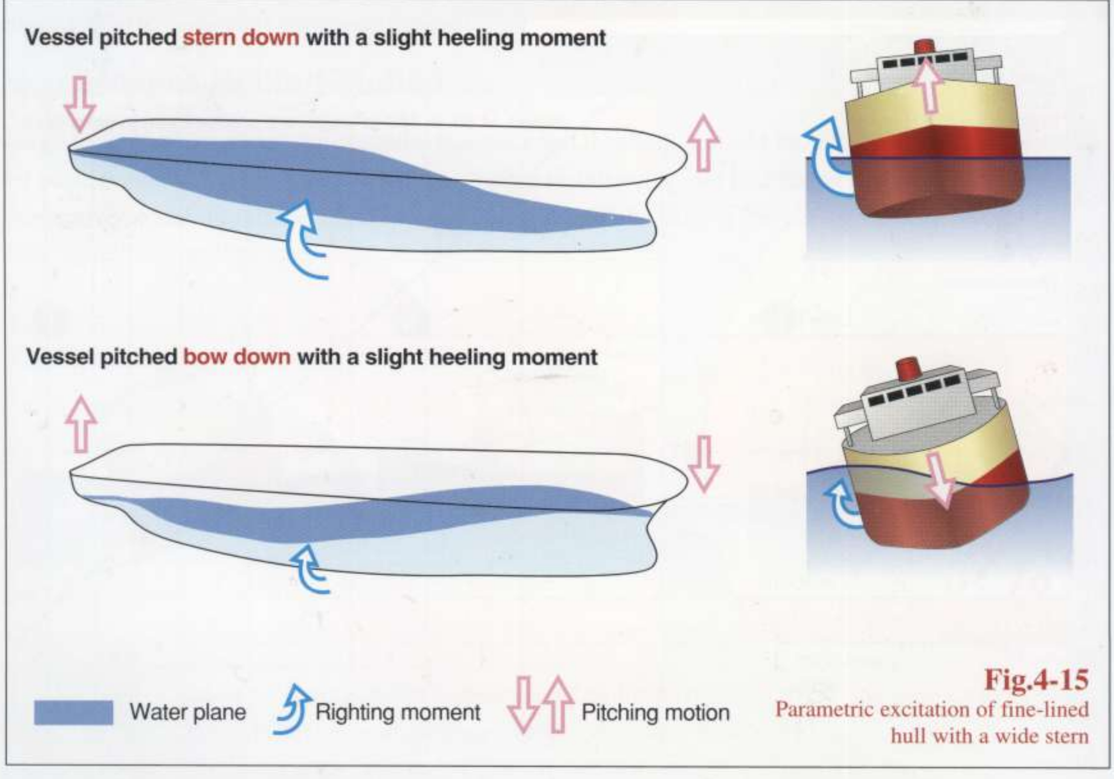


Fig.4-15
Parametric excitation of fine-lined hull with a wide stern

In longitudinal seas, parametric rolling will take place when the encounter wave period (T_E) is approximately equal to half of the natural roll period of the ship (T_R) (i.e. $T_E = 1/2 \cdot T_R$). The reason for this is as follows:

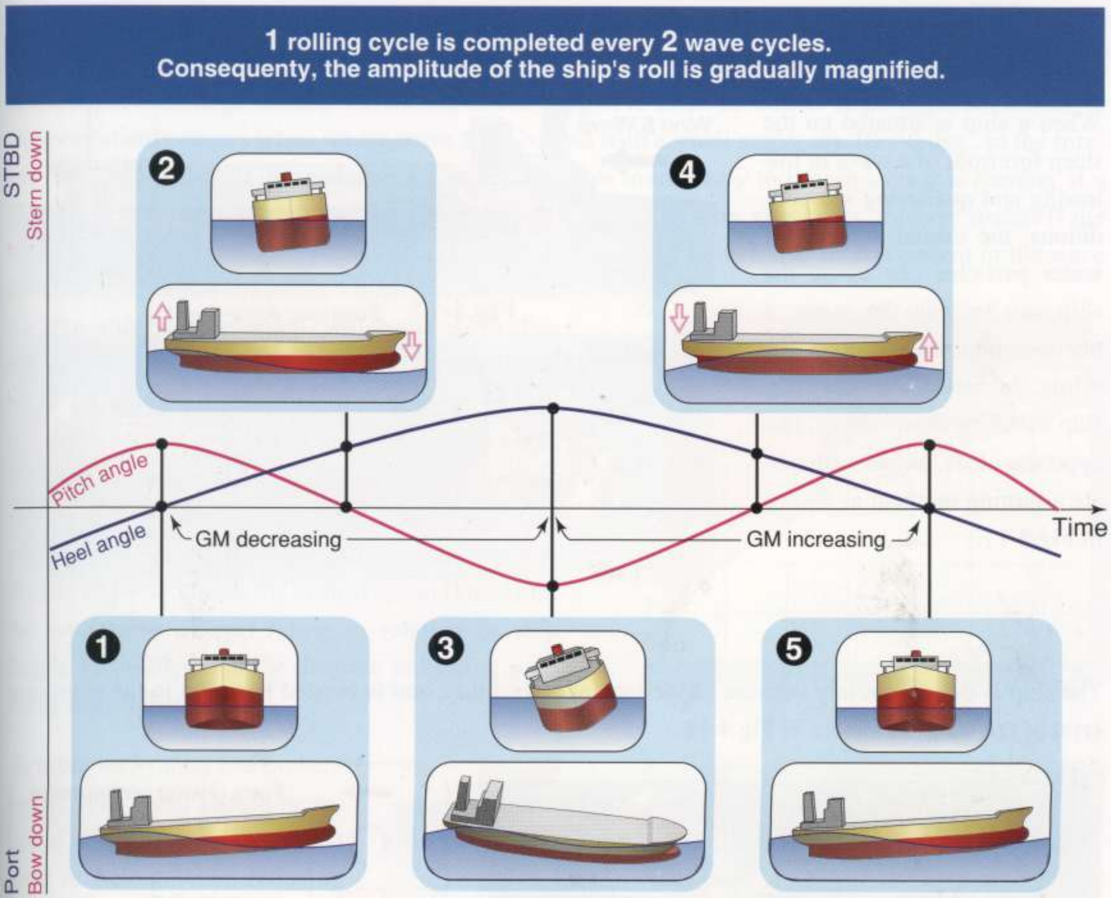


Fig.4-16 Parametric rolling condition (ship pitching at a period half its natural roll period)

As shown in **Fig.4-16**, transverse stability declines during the outward roll (❶ to ❷) to reach a minimum at the end of roll (❸) and then increases (❸ to ❹) to give the return roll extra momentum.
Stability starts to decrease again as the ship passes through upright (❺), and each successive outward roll is greater than the previous one. This type of rolling can occur in head and bow seas where the encounter wave period becomes short. In following and quartering seas, this can occur particularly when the initial metacentric height is small and the natural roll period is very long. (Large container ships tend to have long natural roll periods, ranging from 20 to 30 seconds.) Also, as exemplified by container ships, a ship with an extensive bow flare and a long, flat stern is susceptible to parametric rolling given the right combination of wave height, wave period, natural rolling period and ship speed.
To avoid parametric rolling, it is necessary to prevent conditions leading to parametric rolling, i.e. a ship pitching twice while rolling once under significant pitching. Ship speed should be reduced substantially or course altered to change the encounter wave period (T_E). Ship speed should be maintained to ensure steerability, and care should be taken that the course change or speed reduction does not induce other risks, such as synchronous rolling. Reports have been heard of parametric rolling in extreme head or near head seas when container ships and PCCs were subject to speed reduction. Accordingly, care should be taken to prevent parametric rolling not only in following and quartering seas, but also in head and bow seas.

Surf-riding and Broaching-to

When a ship is situated on the steep forefront of a wave in following and quartering sea conditions, the orbital velocity of water particles can cause the ship can to ride the wave, a phenomenon known as surf-riding. In such a situation (i.e. ship travelling down-slope), two opposing drift forces will create a turning moment as shown in Fig.4-17.

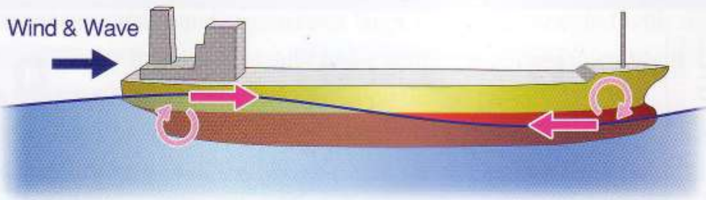
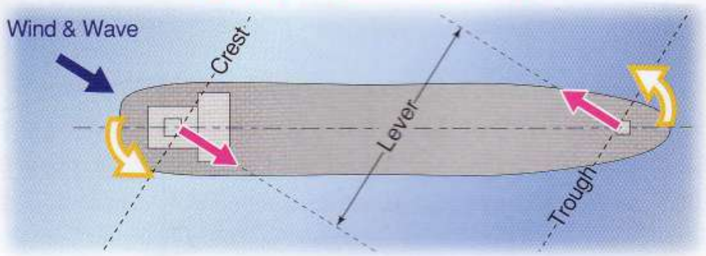


Fig.4-17 Travelling down-slope



The ship is turned forcibly because of the lack of steerability, and is twisted beam-on to the advancing crest of the wave, as shown in Fig.4-18.

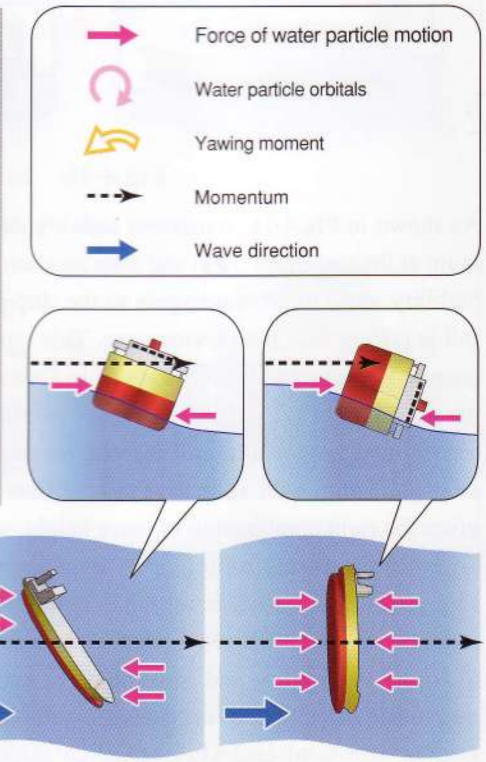


Fig.4-18 Illustration of broaching-to

This is known as broaching-to, and the ship is at risk of capsizing due to the sudden change of heading and unexpectedly large heeling. Broaching-to can happen to small as well as large ships. Broaching-to more commonly occurs when waves arrive from behind with a small angle, say 10~30 deg., to the fore-and-aft axis of the ship. In moderate sea states, a ship is more likely to broach-to if it is running at a high speed and is slowly overtaken by the waves. Broaching-to may also occur at lower speeds if the waves are very steep. As mentioned above, when ship speed is so high that its component in the wave direction approaches the phase velocity of the wave, the ship will be accelerated, will begin surf-riding and then broach-to. The critical speed for the occurrence of surf-riding is considered to be $1.8\sqrt{L}$ (knots), where **L** is ship length. It should be noted that there is a marginal zone ($1.4\sqrt{L}$~$1.8\sqrt{L}$) below critical speed where a large surge may occur. This event is almost equivalent to surf-riding in terms of danger. **Fig.4-19** shows the critical speed (knots) for the occurrence of surf-riding in relation to ship length. **Fig.4-20** shows the diagram indicating surf-riding dangerous zones.

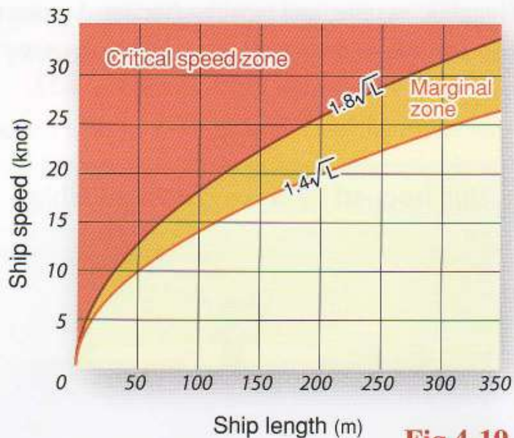


Fig.4-19
Critical speed for surf-riding and ship length

To avoid surf-riding and broaching-to, ship speed should be reduced to the marginal speed zone or below. After reducing speed, if the ship is in the marginal zone and a large surge is felt, speed should be reduced further. Surf-riding can occur when a ship is running in shallow waters, even when the ship is making a relatively low speed. This is because the phase velocity of waves is slower in shallow waters, and the critical speed may be attainable at a relatively low ship speed.

It is important that seafarers operating high-speed pleasure boats and fishing vessels in shallow waters bear this phenomenon in mind.

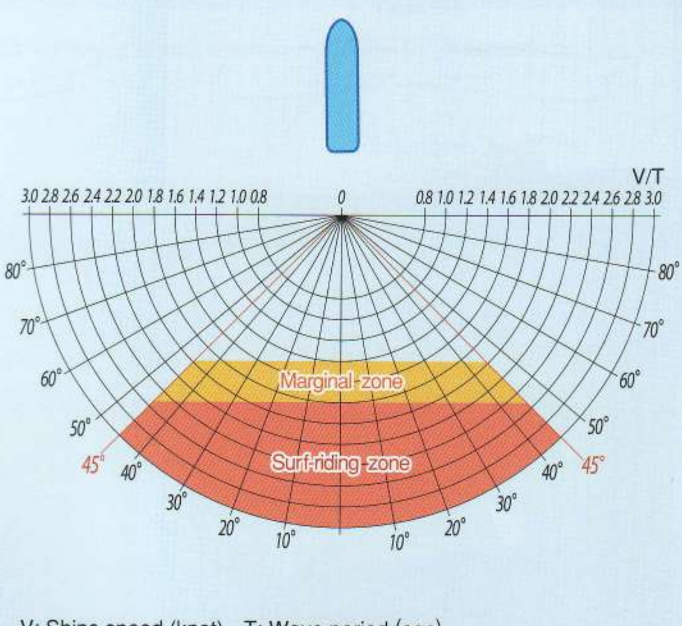


Fig.4-20
Diagram indicating dangerous zone due to surf-riding

4.2 Ship Handling in Head and Bow Seas

Ship Motion in Head and Bow Seas

A ship among waves is repeatedly subjected to heaving, pitching and rolling as shown in Fig.4-3. Hogging, sagging and twisting (torsional moment) can also be generated depending on the ship's relative position to the waves; i.e. whether the waves crest or trough amidships, or the ship is among oblique waves as shown in Fig.4-21 and Fig.4-22.

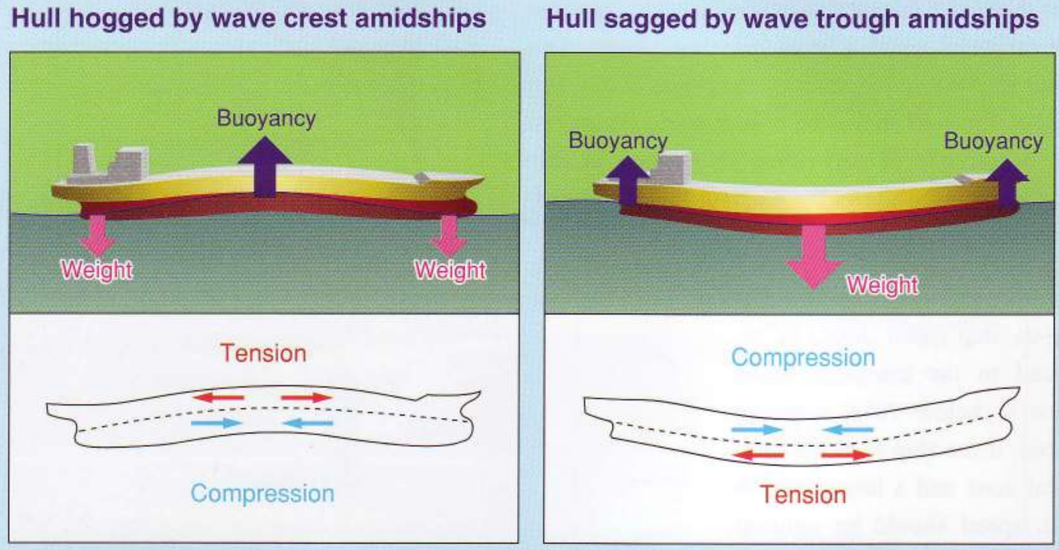


Fig.4-21 Hogging and sagging

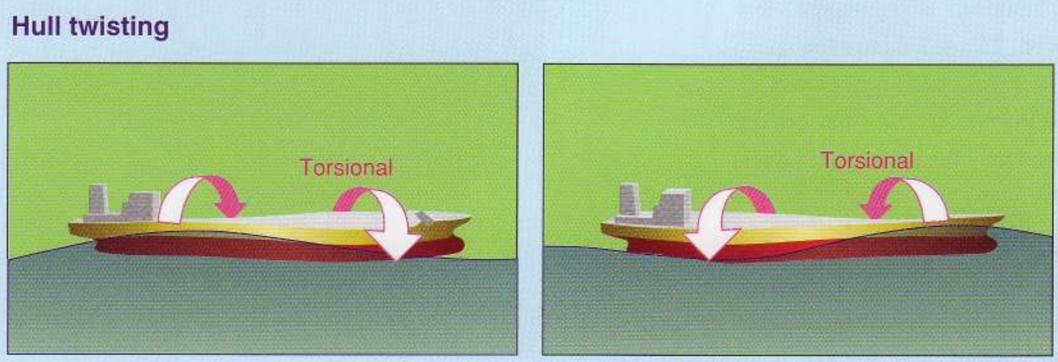


Fig.4-22 Twisting (torsional moment)

Compounding the above, *ship speed is reduced due to added resistance from wind and waves.*
This phenomenon is especially likely in head and bow seas.
A ship's pitching response to any wave is determined by the wave's encounter length relative to the *ship's length, as well as the period of encounter:*

- The ship's pitching motion is less significant when wavelength is shorter than ship length because the influence wave is small. Pitching is restrained; the bottom of the bow does not emerge from the water, and the bow does not dip severely enough to take green water. (**Fig.4-23**)
- When wavelength is longer than ship length, the ship pitches and heaves easily following the fore and aft wave profile. (**Fig.4-24**)
- When wavelength is equal to ship length pitching motion is at its most intense. Heaving of the ship on a crest and plunging of the bow into the next wave will accelerate. Fluctuations of water levels relative to waves at the bow and stern grow greater, leading to phenomena such as propeller racing, shipping water and slamming. (**Fig.4-25**)

Fig.4-23 Pitching motion when encounter wavelength is shorter than ship length

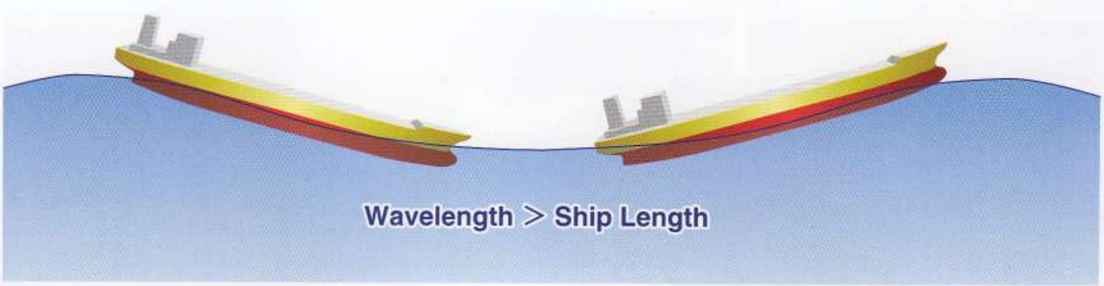


Fig.4-24 Pitching motion when encounter wavelength is longer than ship length

Fig.4-25 Pitching motion when encounter wavelength is equal to ship length

Fig.4-26 shows the calculated fluctuations of water level relative to waves at the bow.
From the figure, it is known that the fluctuating water level at the bow attains its greatest level when wavelength is equal to ship length; shipping of water can occur because the relative water level exceeds the bow freeboard; slamming can occur when the relative water level drops far enough below forward draft to expose the bottom plates at the bow.

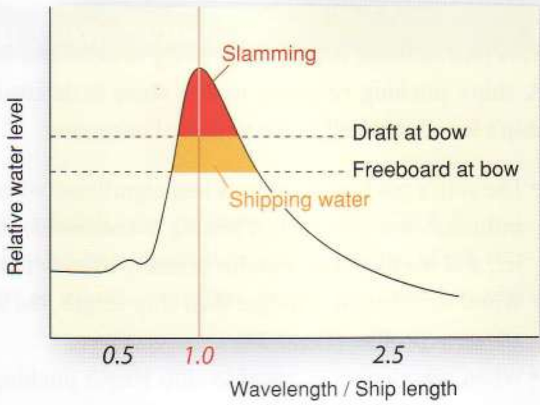


Fig.4-26 Fluctuations of relative water level at bow

Propeller Racing and Reduction of Ship Speed

Whenever a ship is pitching and heaving heavily at the bow, similar heaving motion is generated at the stern. As the relative motion between water level and the stern increases, the stern lifts out of the water and exposes part of the propeller, causing it to race. This great and abrupt reduction of propeller load results in a sudden increase in propeller revolutions, generating intense vibration. Known as propeller racing, this phenomenon can damage the propeller, the propeller shaft and the main engine. Accordingly, when a ship in ballast is navigating head and bow seas in still waters, aft draft should be deepened so that the ratio of propeller immersion to propeller diameter may be kept at 20 percent or more. (**Fig.4-27**)

Immersed depth of propellerr upper tip ratio

d / D ≧ 0.2 (20%)

Propeller immersion ratio

I / D ≧ 0.7 (70%)

I: propeller immersion D: propeller diameter

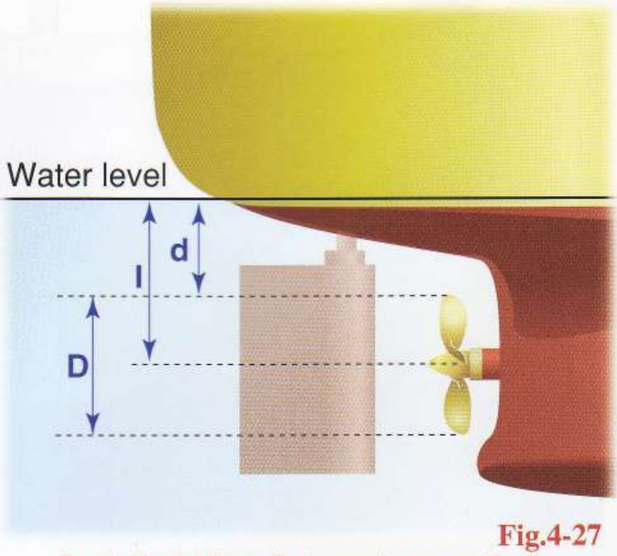


Fig.4-27
Required ratio of propeller immersion to propeller diameter

Please also note that nominal speed will be reduced due to added resistance, reduced propulsive efficiency and increased propeller load. **Fig.4-28** shows the nominal speed reduction in irregular waves when a 250-m-long container ship heads into a seaway. The figure makes it clear that the degree of nominal speed reduction increases significantly when wave height exceeds 6 meters.

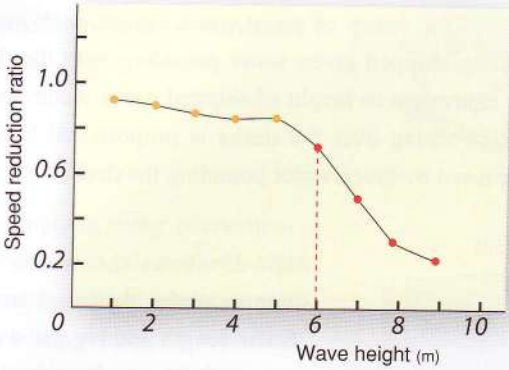
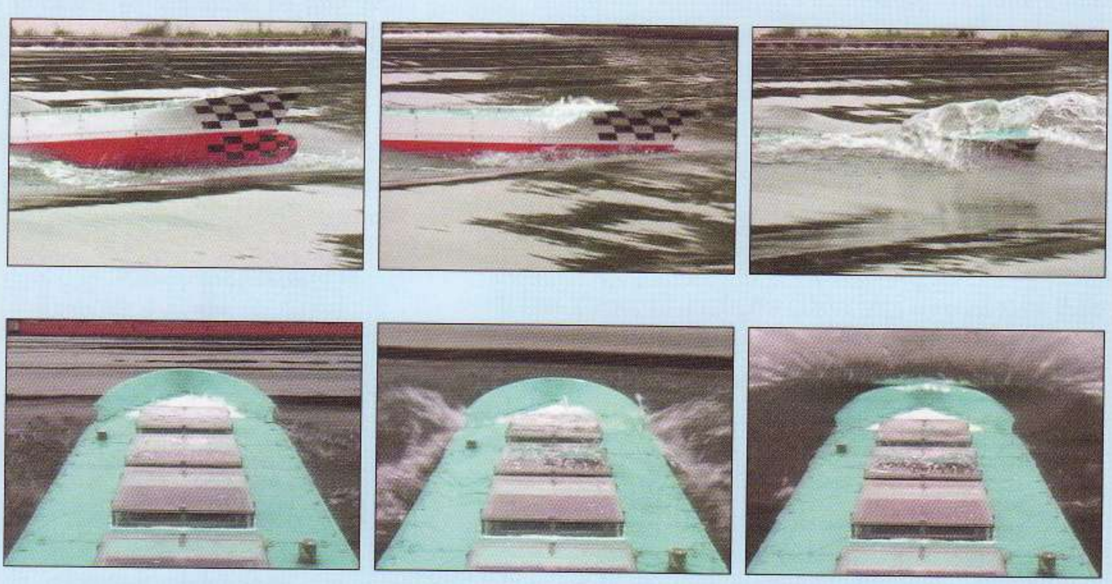


Fig.4-28
Nominal speed reduction in head seas
(full-loaded container ship)

When the main engine is subject to excessive torque brought about by added resistance to the hull, the result can be what is known as a torque rich condition, which can lead to engine trouble caused by overheating, or in abnormal consumption of fuel oil. In such an event, ship speed must be reduced.

Ship heading to high waves



Shipping Water Forward

Shipping water refers to green water sweeping down the upper decks beyond the forecastle bulwark. The impact force of green water can cause severe damage. Occasionally, deck machinery, deck cargo and hatch covers are damaged. Hatch cover damage may allow water to enter into the holds.

The impact force of shipping water has two effects: direct dynamic pressure created by the shipped green water; and impact force caused by the sweep of green water against deck machinery and other appliances. Dynamic pressure created by shipped green water pounding onto the deck can reach approximately twice the static pressure equivalent to height of shipped green water above deck. The dynamic stress of shipped green water sweeping over the decks is proportional to the square of ship speed; impact force is similar to that caused by green water pounding the deck.

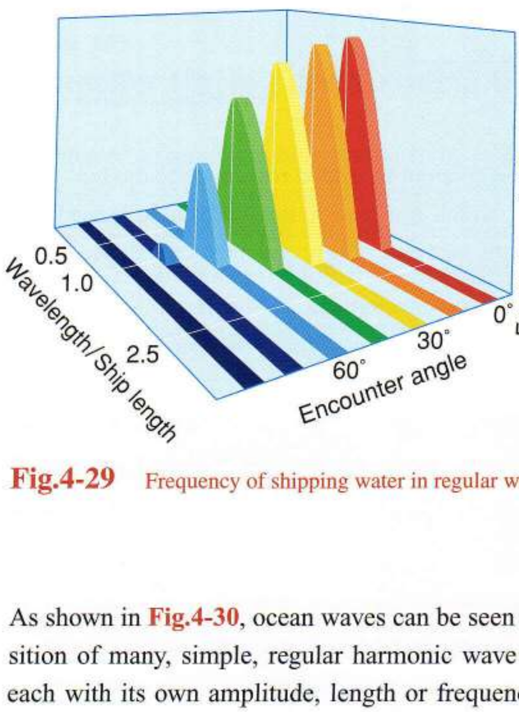


Fig.4-29 Frequency of shipping water in regular waves

Fig.4-29 shows the results of a tank test on shipping water. Assumed are an actual ship of 78.5-m length and regular waves of 3-m height (corresponding to Beaufort scale 3). The experiments were executed in combination with various ship speeds, wave encounter angles and ratios of wavelength to ship length.

From the figure, it is found that shipping water increases when ship length is equal to wavelength in head seas, and that the frequency of shipping water may be decreased by reducing speed and/or altering course.

As shown in **Fig.4-30**, ocean waves can be seen as a superposition of many, simple, regular harmonic wave components, each with its own amplitude, length or frequency and direction of propagation.

The interaction of these components can lead to irregularity. Needless to say, it is important to investigate shipping water phenomenon in irregular waves.

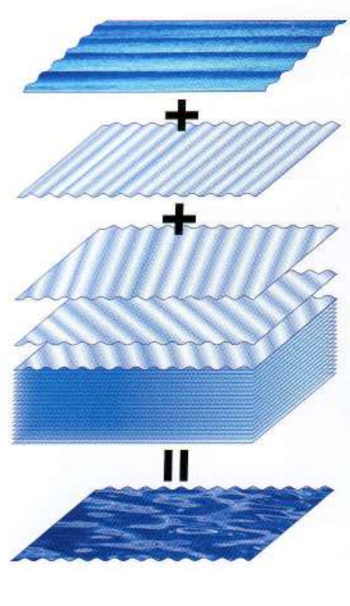


Fig.4-30
Concept of irregular wave

Fig.4-31 shows the result of shipping water tests. Assumed are a ship of 78.5-m length and irregular waves. From the figure, it can be seen that the frequency of shipping water increases proportionally with an increase in ship speed and decreases as the encounter wave angle (measured from the bow) increases.

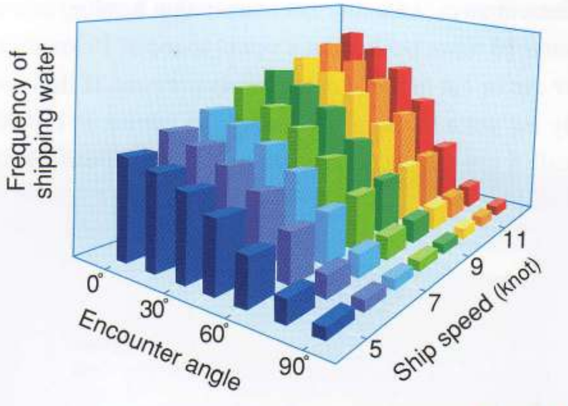


Fig.4-31
Frequency of shipping water in irregular waves

When considering shipping water phenomenon in head and bow seas, first check the Beaufort scale number, which relates to the height of corresponding waves, to calculate the frequency of shipping water, as shown in **Table 4-1.** (The Beaufort scale will be explained in Chapter 5.) Next, using probability theory, a critical operation diagram for the occurrence of shipping water can be obtained.

Beaufort scale	1~4	5	6	7	8	9	10	11	12
Wave height (m)	<1.0	2.0	3.0	4.0	5.5	7.0	9.0	11.5	14.0

Table 4-1 Beaufort scale and wave height

Fig.4-32 and **Fig.4-33** show critical operation diagrams for the occurrence of shipping water for a full-loaded container ship of 40,000 gross tons. Ship speeds are drawn in concentric circles and encounter wave angles in radial lines. Critical lines corresponding to the Beaufort scale (wave height) are shown as colored curves.

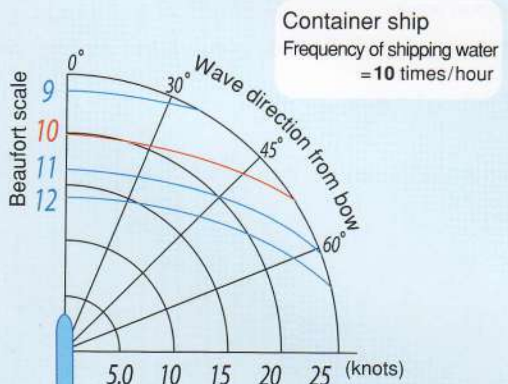


Fig.4-32
Critical operation diagram for the occurrence of shipping water on a container ship (10 times/hour)

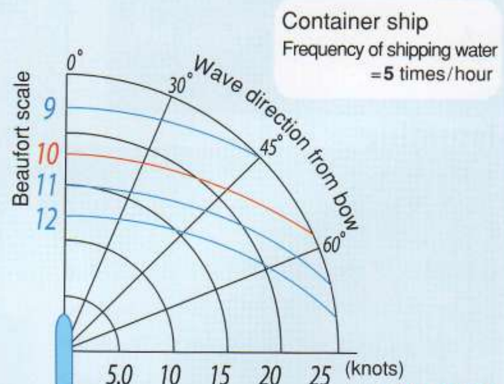


Fig.4-33
Critical operation diagram for the occurrence of shipping water on a container ship (5 times/hour)

These figures show that a container ship heading into a seaway with Beaufort scale 10 waves will ship water 10 times per hour at a vessel speed of 19 knots (**Fig.4-32**), and that the frequency of shipping water can be cut in half, i.e. to 5 times per hour, if ship speed is reduced to 17 knots. (**Fig.4-33**)
By the same token, a full-loaded ore carrier of 110,000 gross tons heading into a seaway of Beaufort scale 5 can reduce the frequency of shipping water by half, from 10 times per hour to 5 times per hour, if ship speed is reduced from 13.5 knots to 12.5 knots. (**Fig.4-34**, **Fig.4-35**)

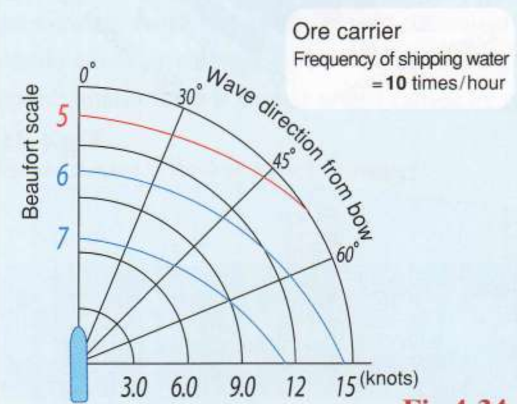


Fig.4-34
Critical operation diagram for the occurrence of shipping water on an ore carrier (10 times/hour)

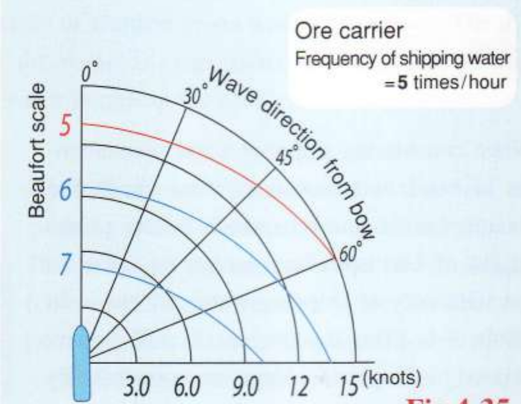


Fig.4-35
Critical operation diagram for the occurrence of shipping water on an ore carrier (5 times/hour)

The occurrence of shipping water as it relates to ship type and speed is summarized in **Table 4-2**. It is shown that a reduction of speed will considerably lessen shipping water.

	Coastal ship	Container	Ore carrier
Frequency of shipping water	Bf. 5	Bf. 10	Bf. 5
10 times/hour	12 knots	19 knots	13.5 knots
5 times/hour	11 knots	17 knots	12.5 knots

*Bf = Beaufort scale

Table 4-2
Ship types and speeds for the occurrence of shipping water

Slamming

When a ship proceeds at a relatively high speed in head seas, slamming may occur. Slamming may be classified into the following three types:

- **Bottom slamming** occurs when, due to heavy bow motion relative to waves, the forward part of a ship's bottom emerges from the water and then slams down heavily into the rising water of the next oncoming wave. (**Fig.4-36**)

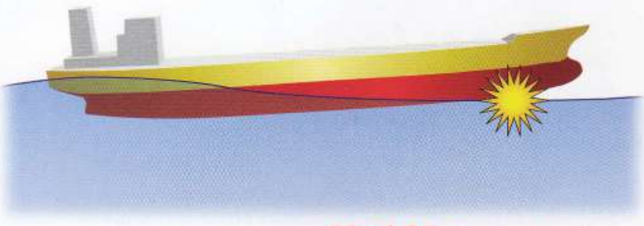


Fig.4-36 Bottom slamming

- **Bow flare slamming** occurs in a large flared ship when a high relative speed exists between water level and the flare. (**Fig.4-37**)

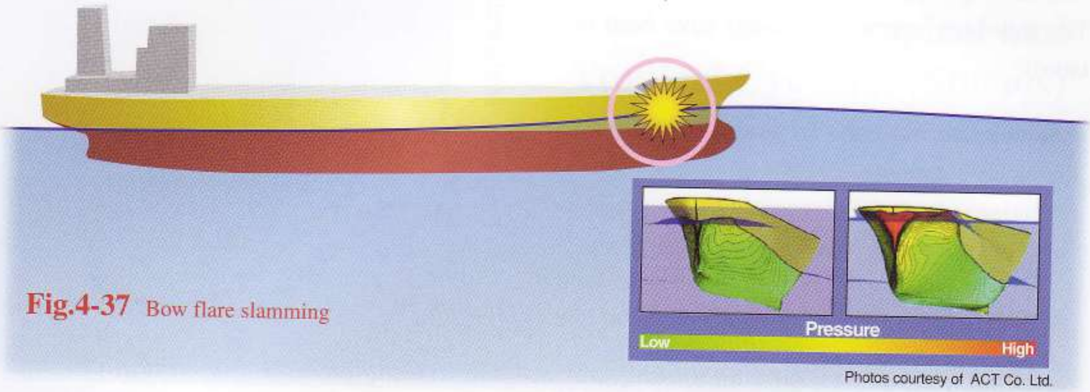


Fig.4-37 Bow flare slamming

Photos courtesy of ACT Co. Ltd.

- **Breaking wave impact** is caused by the build-up of breaking waves resulting from a superposition of bow waves and head seas. Large, fat ships are susceptible to this phenomenon. (**Fig.4-38**)

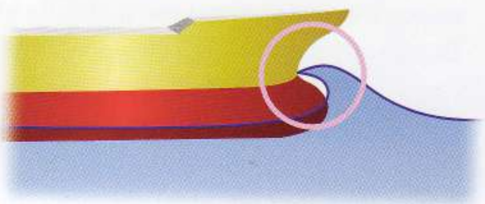


Fig.4-38 Breaking water (wave) impact

Heavy slamming will not only damage the ship's bow, forward bottom plating and bow flare, but the cargo as well. Immediately after slamming, high-frequency vibratory stresses, called whipping, will take place elsewhere in the hull, causing damage to the hull and various appliances.
Furthermore, as the frequency of slamming increases, cracks can develop in the hull structure and metal fatigue, caused by repeated stresses and strains, occasionally results in fatal hull collapse.

Whipping : High-frequency Vibratory stresses

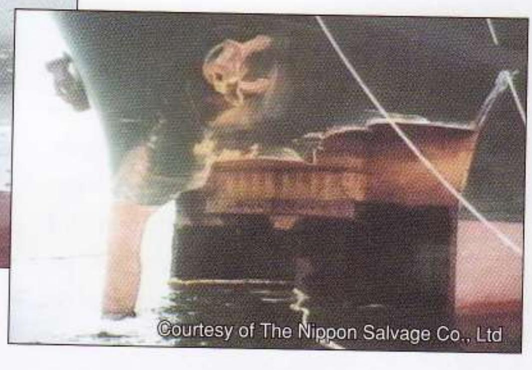


Fig.4-39 shows model experiments concerning a 78.5-m-long vessel experiencing slamming.
The following important findings have been obtained:

- Appropriate reduction of speed is effective in reducing slamming.
- Altering course to change encounter angle is also effective in reducing slamming.
- A ship in light condition with trim-by-the-stern is more susceptible to slamming compared to a ship in full-load condition.
- Slamming is likely when the ship is close to resonant pitching in head waves slightly longer than its own length.

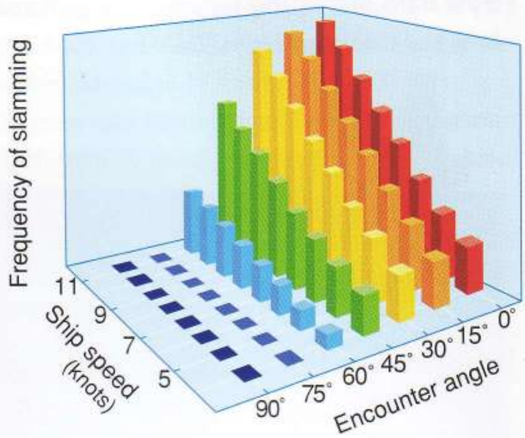


Fig.4-39
Frequency of slamming on a coastal ship in light condition

Care should be taken when reducing speed or changing course as these measures may have consequences with regard to parametric rolling, synchronous rolling or course control.

Fig.4-40 shows a critical operation diagram for slamming on a full-loaded container ship of 40,000 gross tons. The figure shows that a container ship heading into a seaway of Beaufort scale 10 (average wave height 9 meters) will suffer slamming 2 times per hour if the ship is making 13 knots. (When course is altered to 45 degrees starboard or port, the ship can make 19 knots.)
Occurrence of slamming relative to ship type and speed is examined in **Table 4-3**.

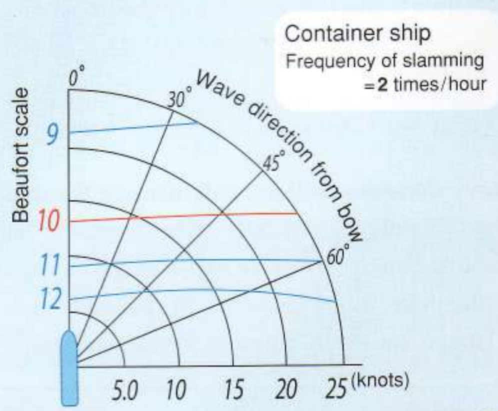


Fig.4-40
Critical operation diagram for the occurrence of slamming on a container ship (2 times/hour)

In this chapter, you have been shown many tables and diagrams for avoiding navigational risks in heavy seas and found these references to be simple and convenient measures. Moreover, reference data are now available for navigational risk phenomena as they relate to ship types and conditions. It is hoped that you are encouraged to achieve safe navigation in heavy seas by using these reference data.

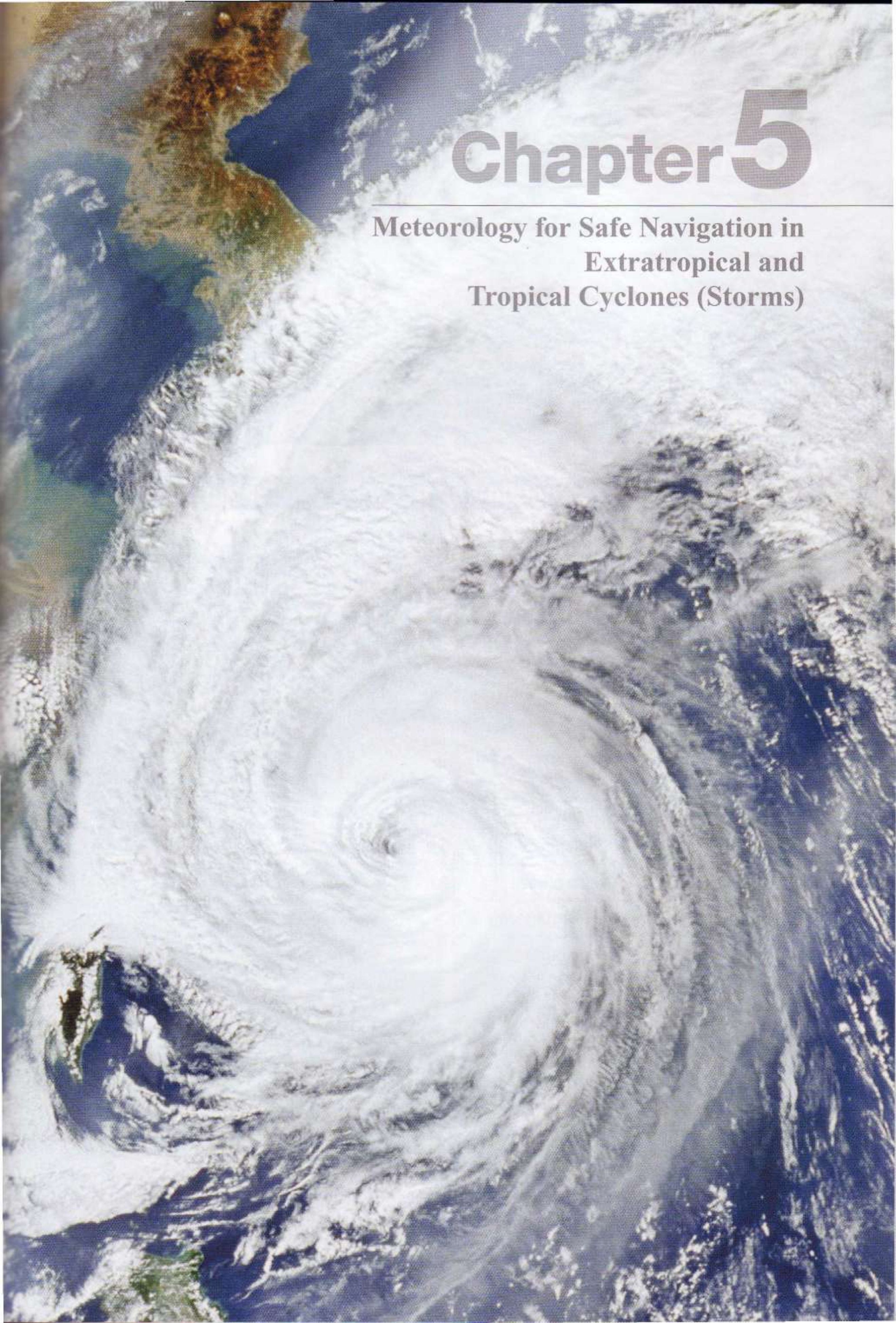
	Coastal ship	Container	Ore carrier
Frequency of slamming	Bf. 6	Bf. 10	Bf. 11
5 times/hour	5 knots	17 knots	8 knots
2 times/hour	4 knots	13 knots	5 knots

*Bf = Beaufort scale

Table 4-3
Ship types and speeds for the occurrence of slamming

Chapter 5

Meteorology for Safe Navigation in Extratropical and Tropical Cyclones (Storms)



Chapter 5

Meteorology for Safe Navigation in Extratropical and Tropical Cyclones (Storms)

5.1 Meteorological Phenomena in Waters Neighboring Japan

Beaufort Scale (Preliminary Guidance)

The Beaufort scale is an empirical measure describing wind intensity based mainly on observed sea conditions. It is used by countless weather stations and seafarers. A definition of the Beaufort scale is shown in **Table 5-1**, while **Fig.5-1** provides a visual impression of the sea states relative to the Beaufort scale.

Beaufort number	Wind speed (m/s)	Description	Probable mean wave height (m)	Sea condition
0	0~0.2	Calm	0	Calm (Glassy)
1	0.3~1.5	Light air	0.1	Ripple without crests
2	1.6~3.3	Light breeze	0.2	Small wavelets. Crests of glassy appearance
3	3.4~5.4	Gentle breeze	0.6	Large wavelets. Crests begins to break
4	5.5~7.9	Moderate breeze	1	Small waves, becoming longer
5	8.0~10.7	Fresh breeze	2	Moderate waves, taking a more pronounced long form
6	10.8~13.8	Strong breeze	3	Large waves with foam and spray
7	13.9~17.1	Near gale	4	Sea heaps up and foam begins to streak
8	17.2~20.7	Gale	5.5	Moderate high waves with breaking crests forming spindrift. Streaks of foam
9	20.8~24.4	Strong gale	7	High waves with dense foam. Wave crests start to roll over.
10	24.5~28.4	Storm	9	Very high waves with long overhanging crests
11	28.5~32.6	Violent storm	11.5	Exceptionally high waves: visibility affected
12	32.7over	Hurricane	14+	The air is filled with foam and spray: visibility seriously affected

Table 5-1 Beaufort wind scale

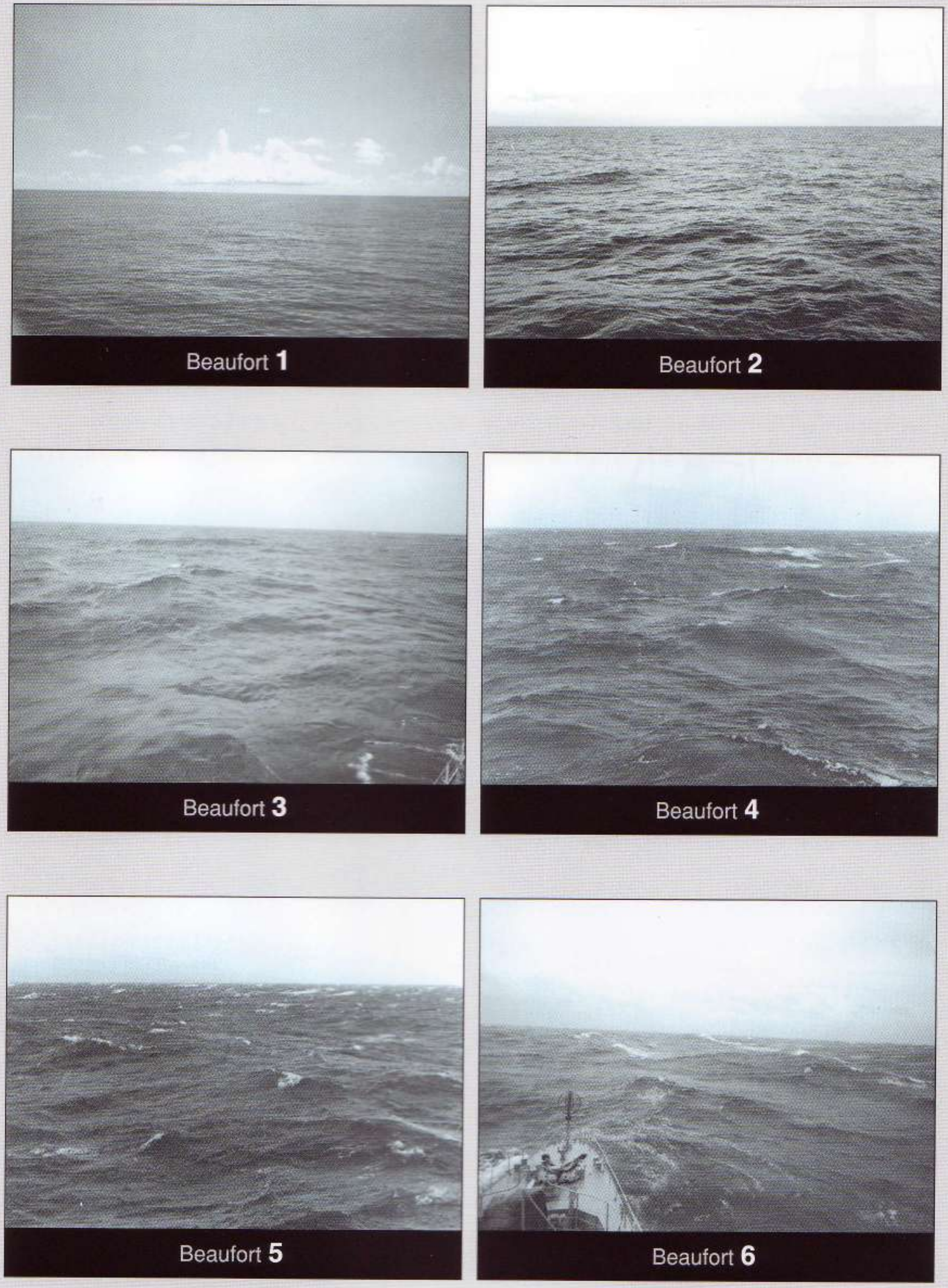


Fig.5-1 Sea state vs beaufort scale

Photos courtesy of Japan Meteorological Agency

Fig.5-1 Sea state vs beaufort scale

Photos courtesy of Japan Meteorological Agency

Formation and Development of Extratropical Cyclones and Typhoons

1. Formation and development of extratropical cyclones in waters neighboring Japan

The formation and development of extratropical cyclones are greatly affected by air masses in waters neighboring Japan. When an area of high atmospheric pressure remains over a continent or the ocean for an extended period of time, a large homogeneous air concentration may build up. This is called an air mass. There are two major air masses affecting meteorological conditions in waters neighboring Japan: one is the Siberian Air Mass, a cold air mass; and the other is the Ogasawara (North Pacific) Air Mass, a warm air mass. Depending on the season, the Okhotsk Air Mass and the Yangtze-River Air Mass will also influence meteorological conditions in waters neighboring Japan (**Fig.5-2**).

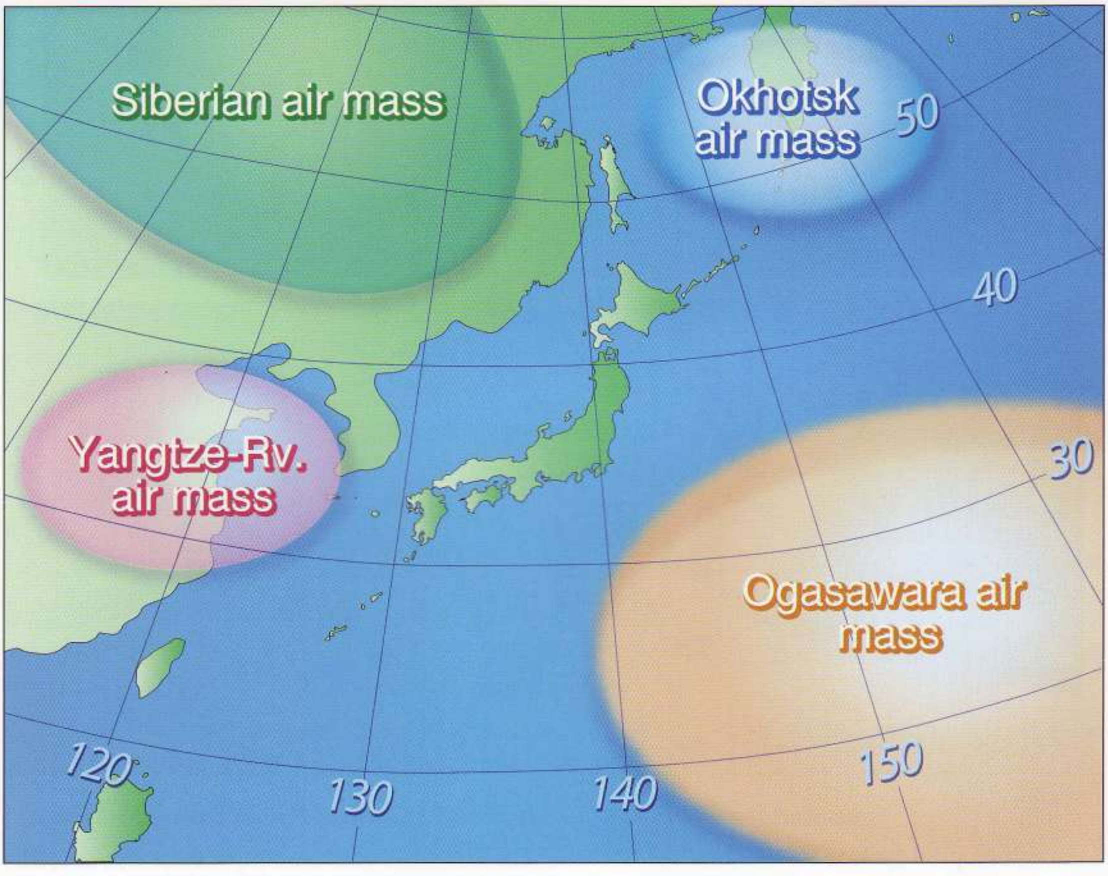


Fig.5-2 Air masses around Japan

The formation and development of extratropical cyclones are explained as follows: When two air masses with physically different characteristics come into contact with each other, fronts are formed in the boundary zone between the two air masses.

When the cold air mass is larger, it moves towards the warm air mass, the cold air moving the frontal boundary forward and raising the lighter warm air. A front formed in this manner is called a "cold front" (Fig.5-3).

CB: cumulonimbus

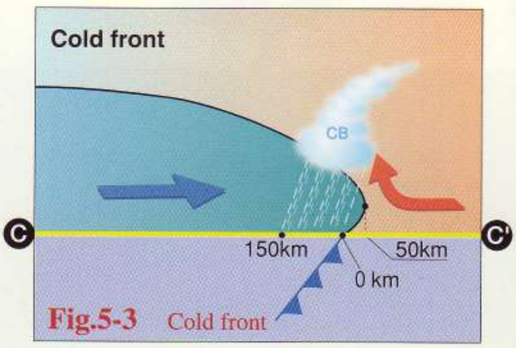


Fig.5-3 Cold front

When warm air predominates, the warm air moves towards the cold air mass and pushes the front forward with the lighter warm air creeping up the frontal boundary of the cold air mass. A front formed in this manner is called a "warm front" (Fig.5-4).

NS: nimbostratus

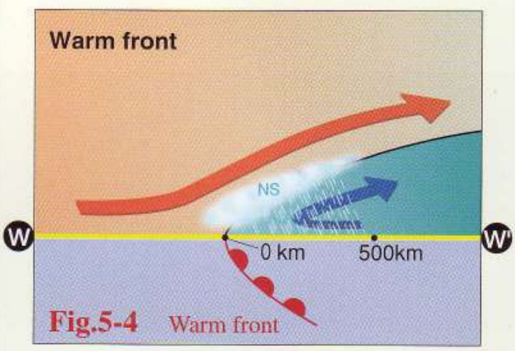


Fig.5-4 Warm front

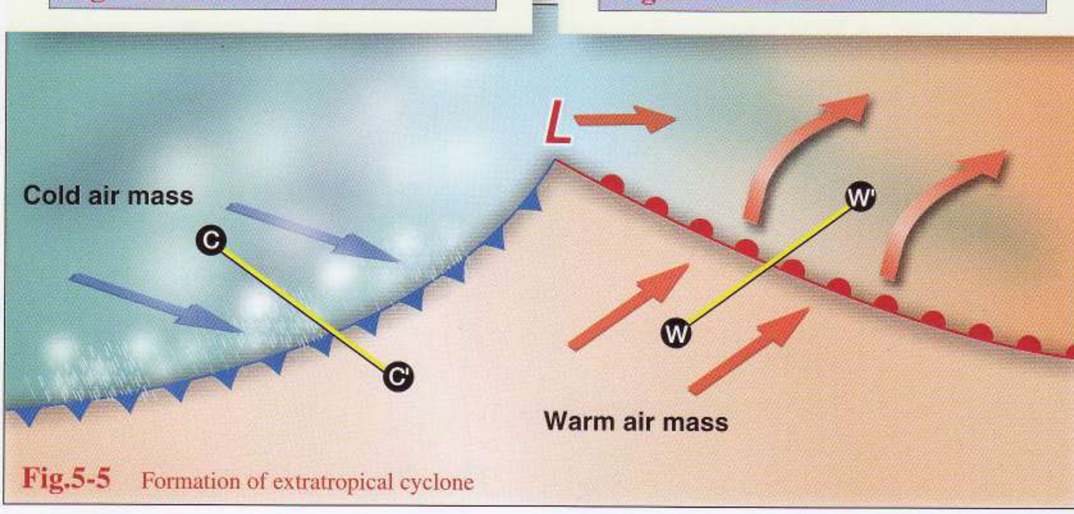


Fig.5-5 Formation of extratropical cyclone

An extratropical cyclone forms where these fronts meet. When a southern warm air mass moves northward and a northern cold air mass moves southward, an updraft is created by the contact between the two air masses (Fig.5-5).

As shown in Fig.5-6, this forms the counter-clockwise spiral flow of air that can develop into an extra-*tropical cyclone.*

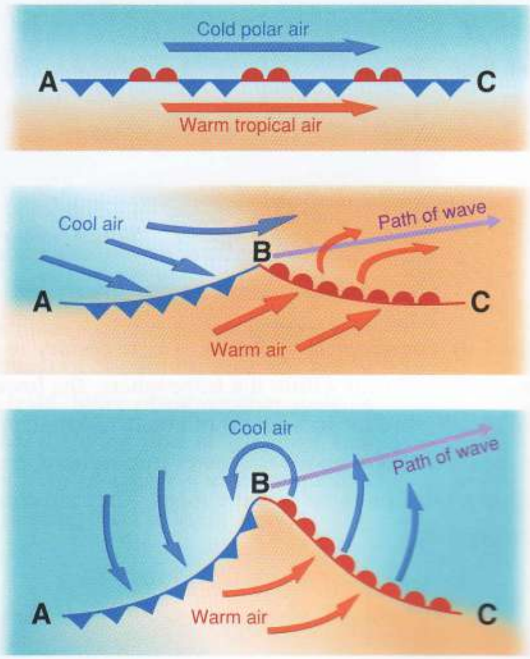


Fig.5-6
Formation of fronts in Northern hemisphere

The larger the difference in temperature between the two converging masses, the greater the potential strength of the extratropical cyclone. For this reason, strong extratropical cyclones are more frequent in winter than in summer.

Extratropical cyclones in the Northern hemisphere generally move northeastward at an approximate speed of 40 km/h or daily 10 degrees of longitude. Approximate maximum wind speed may be calculated using the following formula:

$$V\,(m/s) = 5\sqrt{1010-P}$$

V: maximum wind speed (m/s)
P: atmospheric minimum pressure (hPa)

Extratropical cyclones may be classified into the following two classes:

- Wind rain class: core atmospheric pressure is 1,000 hPa or less and maximum wind speed is 15 m/s or greater.
- Stormy wind and rain class: core atmospheric pressure is 980 hPa or less and maximum wind speed is 25 m/s or greater.

A developing extratropical cyclone is characterized by the following indications:

- core atmospheric pressure falls below 1,000 hPa
- rate of daily pressure decrease exceeds 10 hPa
- moving velocity exceeds 50 km/h

2. Surface and upper air weather charts

The well-known surface weather charts are used to find the location and strength of low and high pressure systems as well as warm, cold and stationary fronts. The highs and lows can be located with ***H*** and ***L*** symbols on the map. Isolines represent the isobars of surface atmospheric pressure (**Fig.5-7**).

H: High pressure ***L***: Low pressure

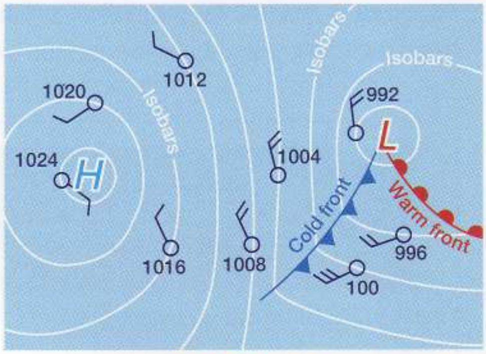


Fig.5-7 Surface weather chart

To understand meteorological phenomena caused by extratropical cyclones, it is necessary to grasp the three-dimensional structures of atmospheric air movement within the troposphere, the lowest region of the atmosphere, which extends from the planet's surface to a height of about 12 km. Upper air weather charts are produced for the portion of the atmosphere above the lower troposphere; pressure surface height, air temperature and wind speed are plotted on these isobaric maps. They are classified into the following levels of the atmosphere (See **Fig.5-8**):

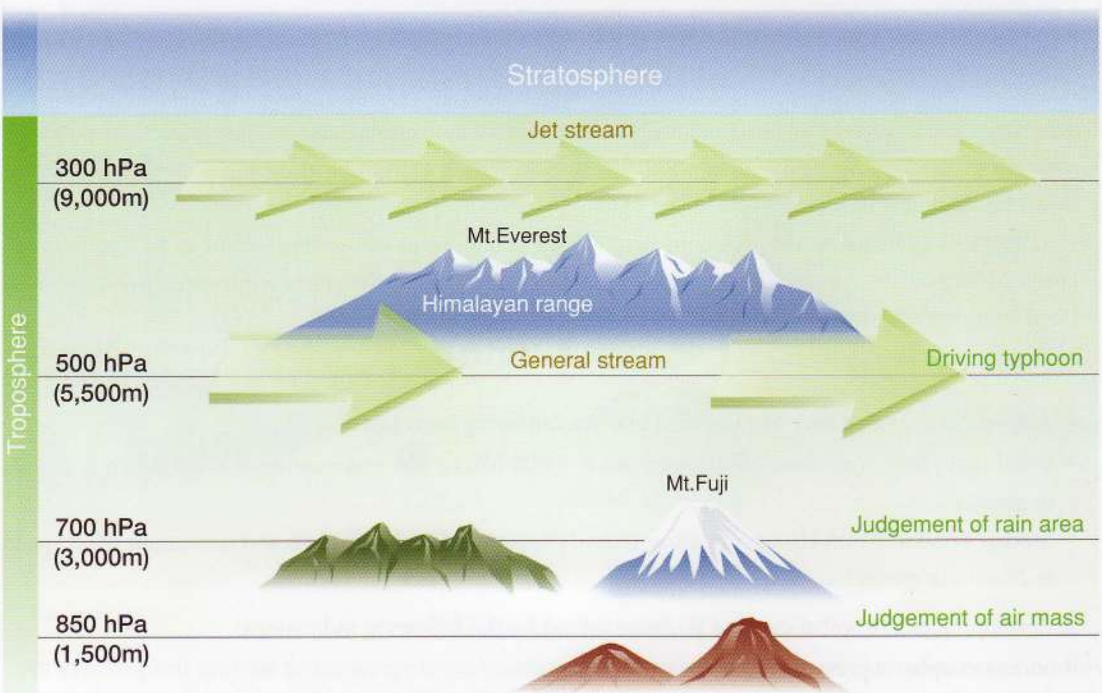


Fig.5-8 Upper air charts vs. altitudes

The charts represent height contours (lines connecting all points on the surface having the same altitude) as solid lines; and isotherms (lines connecting all points having the same temperature) as dotted lines (**Fig.5-9** and **Fig.5-10**).

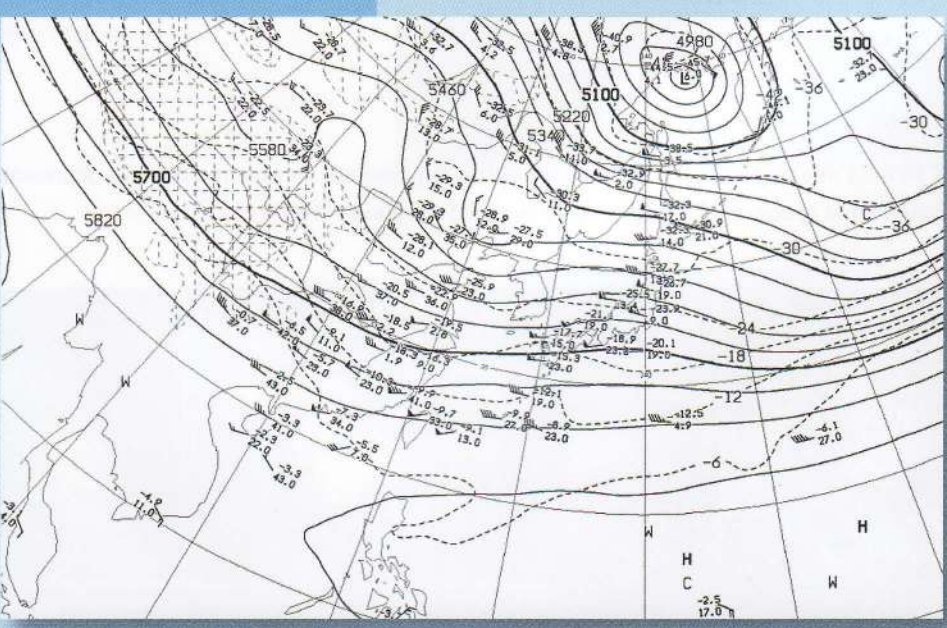
300 hPa charts may have "isotaches", which are lines connecting all points having equal wind speed. Ships mainly concern themselves with 500 hPa upper air charts representing weather conditions in the mid-troposphere; half the mass of the atmosphere lies below this level. Since many weather systems follow the wind flow at this level, this level is often considered to symbolize the steering level of these systems.

Fig.5-9 Upper air charts (500 hPa)

Solid line:
Isobaric surface / Height (m)
Dotted line:
Isotherms (500/700/850 hPa chart)
Isotaches (300 hPa)
W: Core of warm air
C: Core of cold air

Temperature -37.5
4.6
Dew point depression
(=Air temp − Dew point temp)

ANALYSIS 500 hPa: HEIGHT(M), TEMP(°C)



Courtesy of Japan Meteorological Agency

Fig.5-10 Upper air charts (500 hPa; isobaric surface and isotherms)

As shown in Fig.5-11, extratropical cyclones tend to develop in front of an upper-level trough.
When the upper-level trough deepens relative to the previous day, the low on the surface will strengthen.
Attention should also be given to the movement of upper-level isotherms, because the flow of cold air towards the south may cause extratropical cyclones to develop accompanied with gusting winds.
Particular care should be paid to the movements of isotherms on 500 hPa upper-air charts at -30˚C and -36˚C in winter, and at -24˚C in spring and autumn (Fig.5-12).
It is hoped that navigators will make optimum use of upper-air charts in combination with surface weather charts.

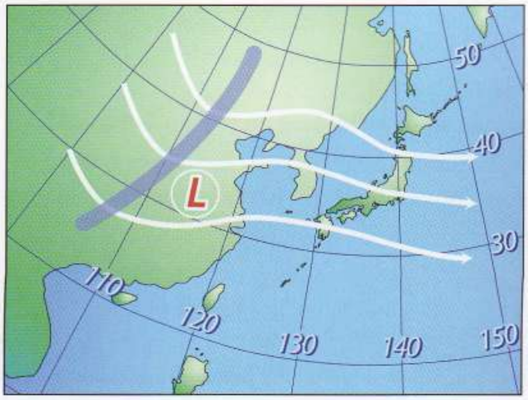


Fig.5-11 Upper-level trough air vs. low on surface

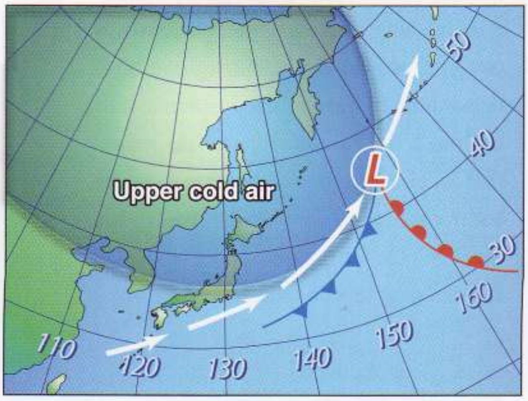


Fig.5-12 Development of extratropical cyclone and upper cold air influx

3. Typhoons

Lows formed in a tropical zone are called tropical depressions. In Japan, a tropical depression with a maximum wind speed of 17.2 m/s or more is called a typhoon (Fig.5-13).

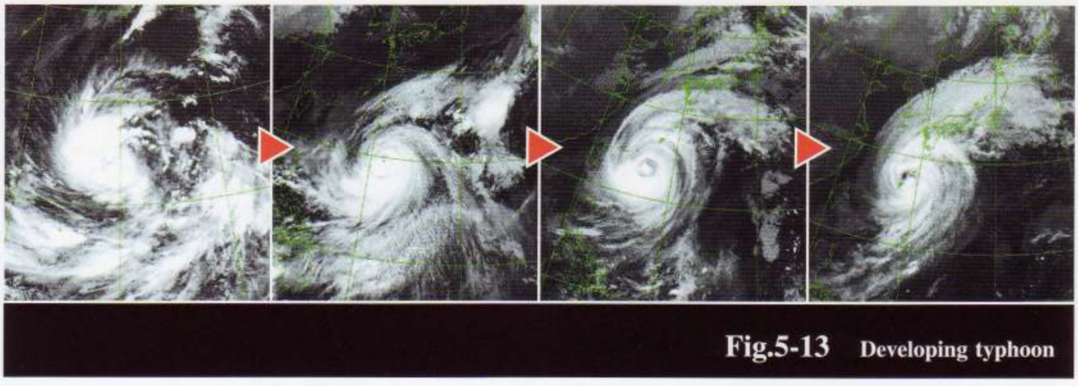


Fig.5-13 Developing typhoon

Photos courtesy of Japan Meteorological Agency

Fig.5-14 shows areas of typhoon formation. The most typhoons form in the eastern sea area off the Philippine Islands.

As shown in Fig.5-15, typhoons generally follow one of two paths: some move northwesterly after birth; while others veer to the right along the western fringe of the North Pacific Ocean High, then move northeasterly under the impact of the Westerlies. The path of the latter type is largely dependent on the strength of the Westerlies and the North Pacific Ocean High.

Most typhoons tend to advance toward the right, along 500 hPa upper-air chart contours 5,820 m to 5,860 m for the North Pacific Ocean High. Points of veer tend to correspond to the height ridges for the North Pacific High extending east to west on the same air chart (Fig.5-16).

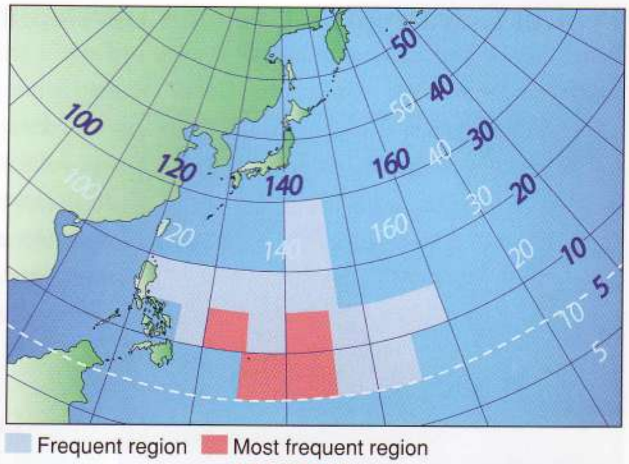


Fig.5-14 Areas of typhoon formation

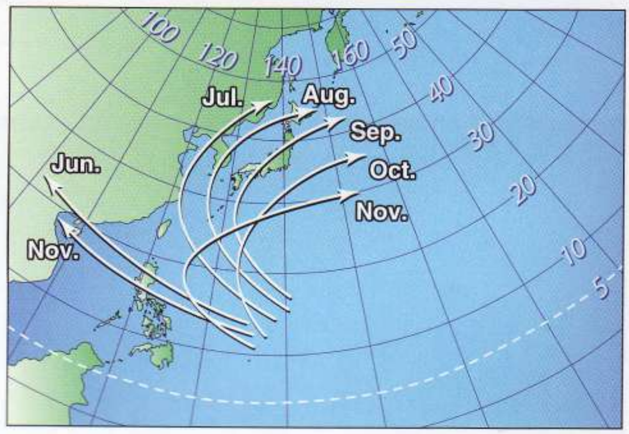


Fig.5-15 Paths of typhoons

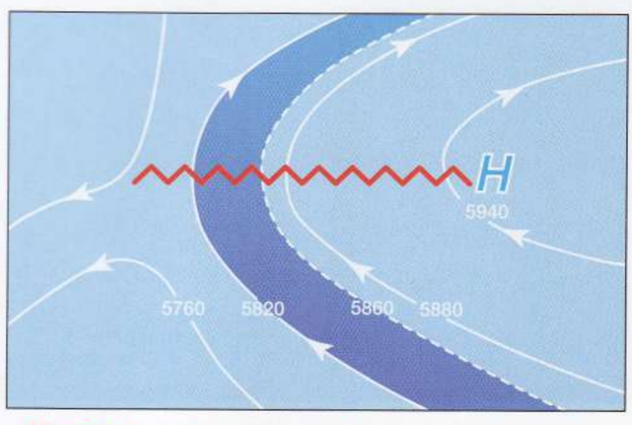
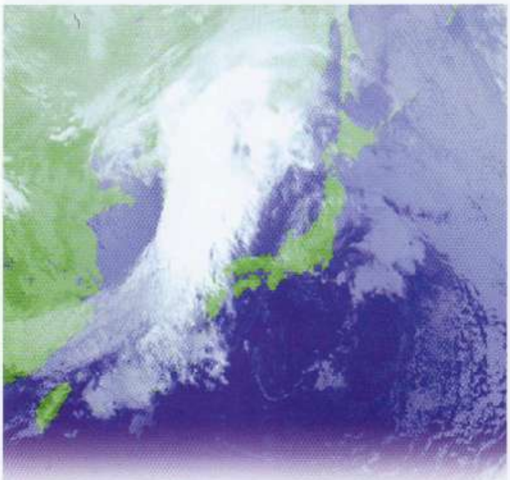


Fig.5-16 Advancing course and recurvature point of typhoon

Typical Extratropical Cyclones Developing in Waters Neighboring Japan



Courtesy of Japan Meteorological Agency

In waters neighboring Japan, many extratropical cyclones form from autumn to spring, and occasionally grow to typhoon-strength levels. As shown in **Fig.5-17**, they are categorized into the following three patterns based on origin and path:

- East China Sea Lows
- Japan Sea Lows
- Twin Lows

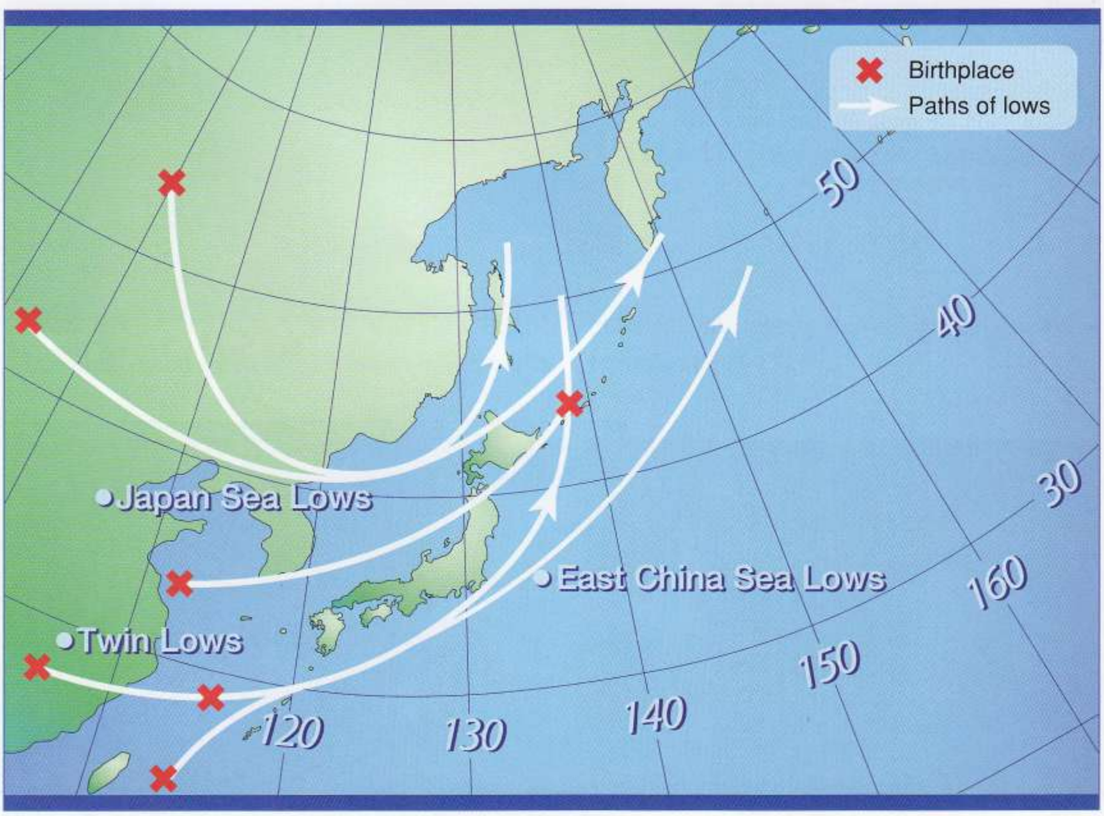


Fig.5-17 Paths of lows

East China Sea Lows

The East China Sea Lows originate in the East China Sea or near Taiwan when the rigid winter atmospheric pattern of high pressure in the west and low pressure in the east abates in the season from winter to early spring. Because a continental high extends to the southeast, a prominent trough is formed and frontal wave stimulated. Due to the above, the low develops rapidly and powerfully while proceeding along the southern coast of the Japanese archipelago. Particularly, the lows swell significantly accompanied by very heavy seas as they proceed northeastward along the southern coast of Japan at a speed ranging 50 km/h to 80 km/h. Fig.5-18 shows the development sequence of an East China Sea Low. The development of the low is enormous.

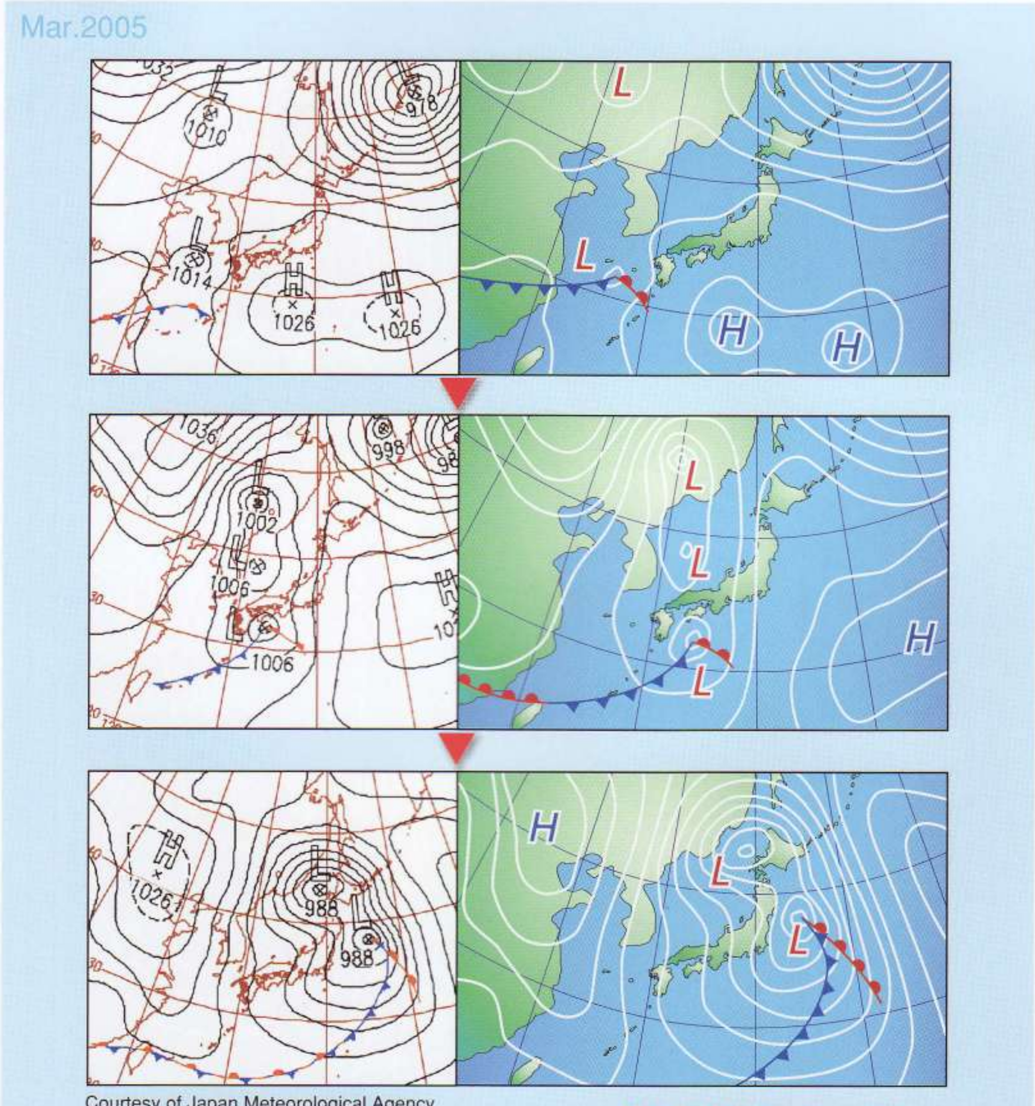
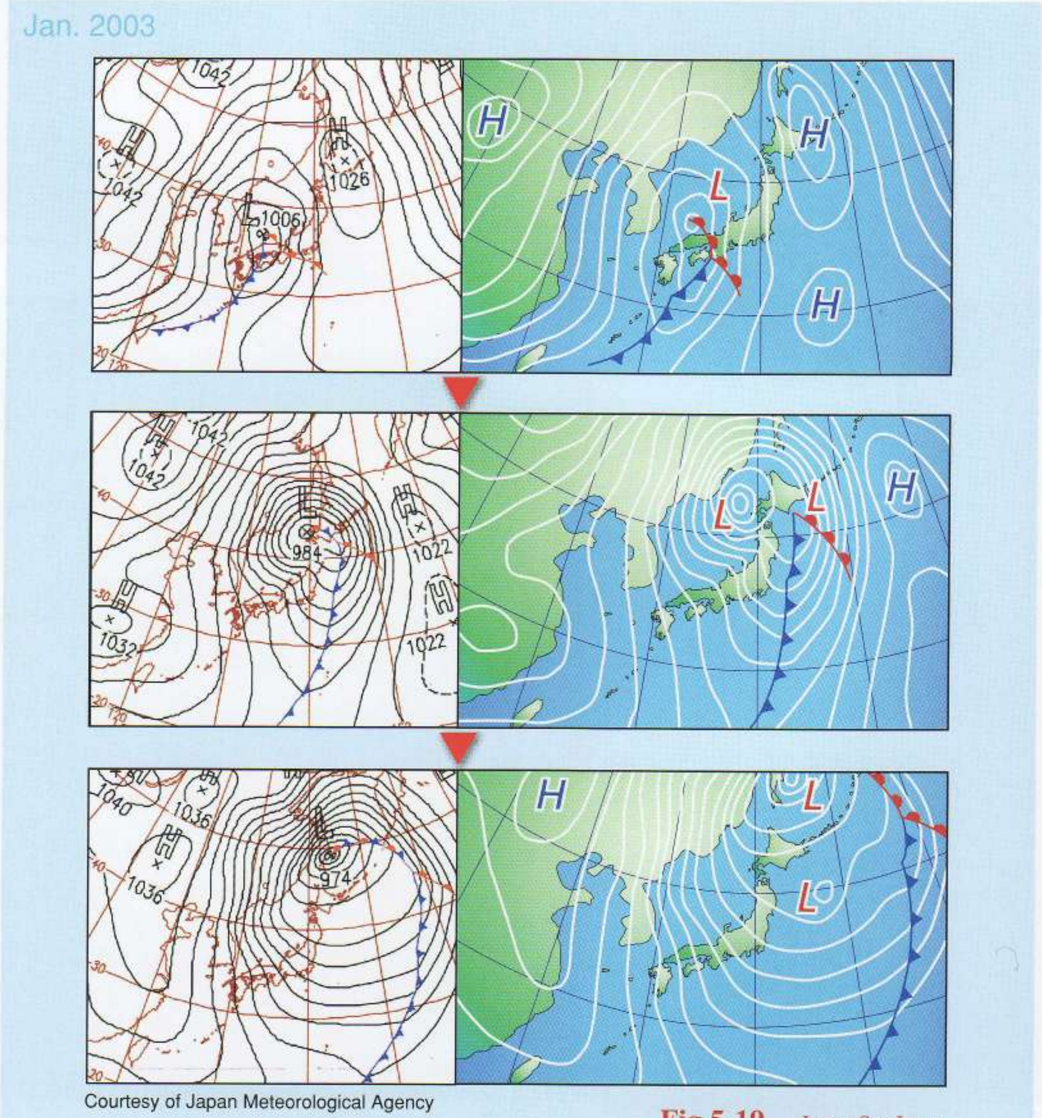


Fig.5-18 East China Sea Lows

Japan Sea Lows

The Japan Sea Lows originate in the same season and under the same atmospheric conditions as the East China Sea Lows, i.e. between winter and early spring in conditions of high pressure in the west and low pressure in the east. The Japan Sea Lows will develop rapidly as prominent troughs are formed in the Japan Sea when the winter atmospheric pressure pattern abates. Southerly winds blow towards the low and most areas of Japan are covered with warm air (Fig.5-19). If a high is present to the south of the Japanese coast, atmospheric temperature will rise, causing strong gusts with very high seas. This phenomenon is known as the vernal storm. However, the supply of warm air is temporary, and temperature drops abruptly once the winter atmospheric pattern accompanied by the cold north wind returns in the wake of the passing cold front.

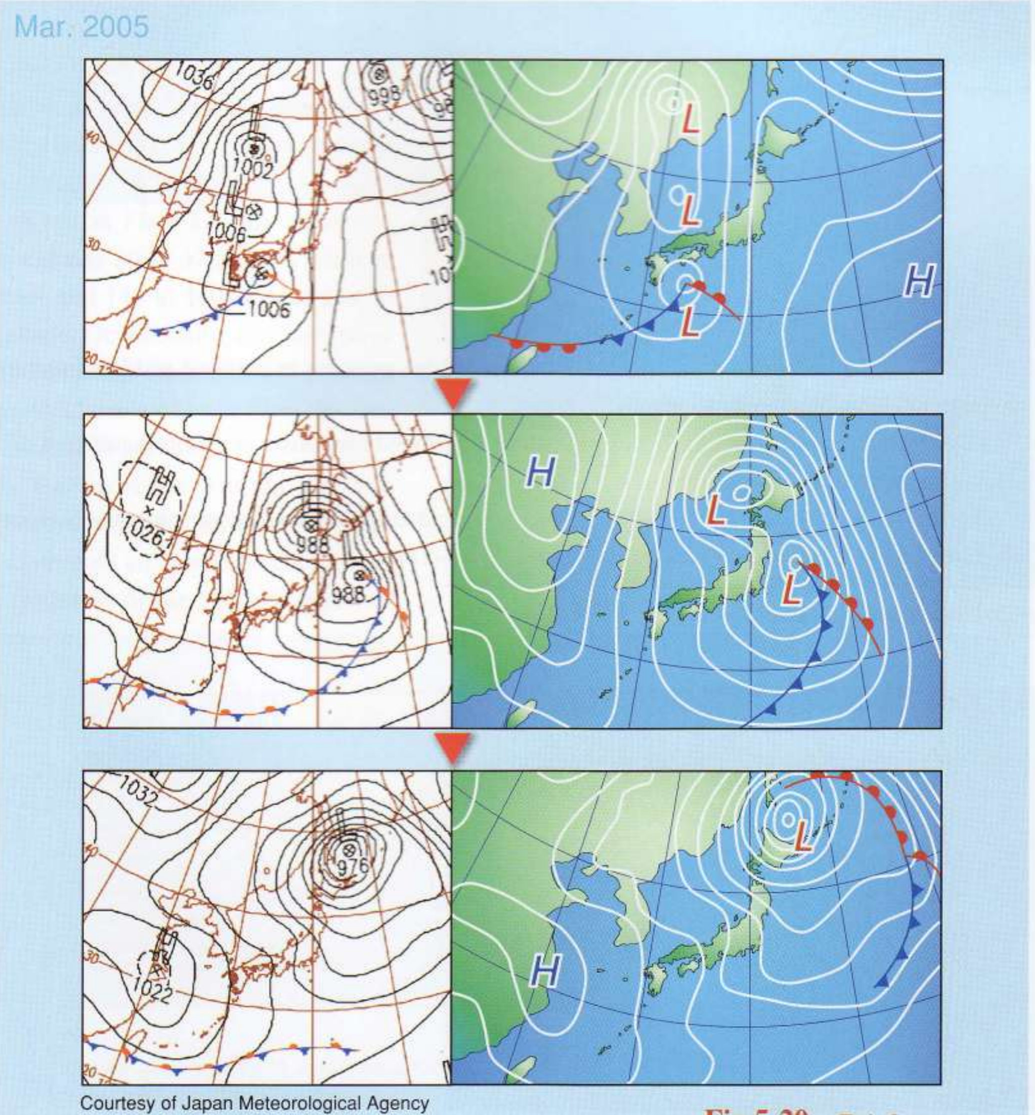


Courtesy of Japan Meteorological Agency

Fig.5-19 Japan Sea Lows

Twin Lows

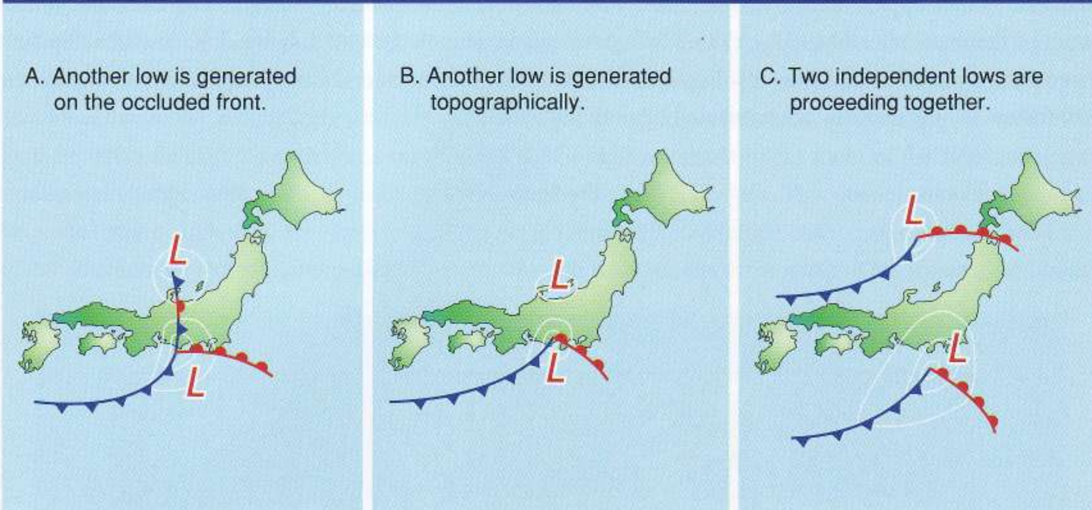
The Twin Lows appear in the season from November to March, one in the north, and the other in the south of the Japanese archipelago (**Fig.5-20**). After proceeding to the east side by side, they develop further and are joined to one low off the Sanriku coast. A strong monsoon nearly equivalent to a typhoon will follow behind this low accompanied by very high seas.



Courtesy of Japan Meteorological Agency

Fig.5-20 Twin Lows

Types of twin low



Winter atmospheric pressure configuration

The typical winter atmospheric pressure configuration of high pressure in the west and low pressure in the east appears from November to March.

When a continental high extends to cover Japan and a developed low exists in the northeast area off Japan, the winter monsoon grows stronger and blows longer.

The winter monsoon blows strong because the pressure gradient becomes sharper when the high in the west and the low in the east develop simultaneously (**Fig.5-21**).

Jan. 2003

Courtesy of Japan Meteorological Agency

Fig.5-21 Winter atmospheric pressure configuration

High-wave zone (off Nojima Saki)

In the sea area east of Japan (off Nojima Saki), marine casualties are frequent due to high waves caused by the winter monsoon, which prevails in vast sea area and can last a long time.

As the southern tip of the upper cold air passes over this sea area (See **Fig.5-22**), the turbulent air flow caused by convection currents becomes predominant due to the large difference in temperature between the warm sea surface in the Kuroshio Current and the cold air of the upper layer. This will further increase wave height.

As shown in **Fig.5-23**, this high-wave area extends 30 to 37 degrees north in latitude and 140 to 160 degrees east in longitude. Occasionally, this high-wave area appears in the southwest quadrant at a considerable distance from the center of a low (**Fig.5-24**).

This fact indicates that, to detect a high-wave area, the movement of upper-layer cold air should be checked on the isotherms of the 500 hPa upper-air chart.

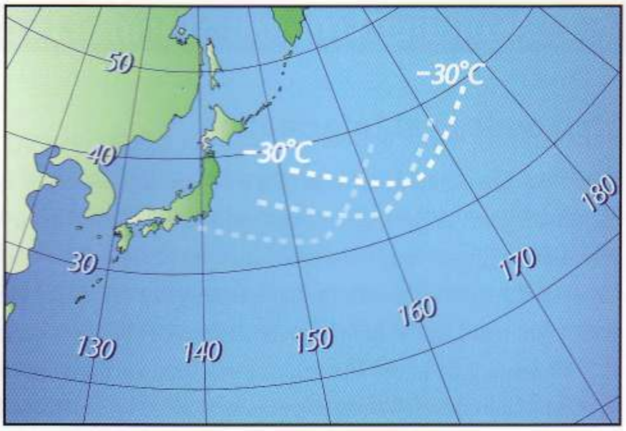


Fig.5-22 Southern tip of upper cold air

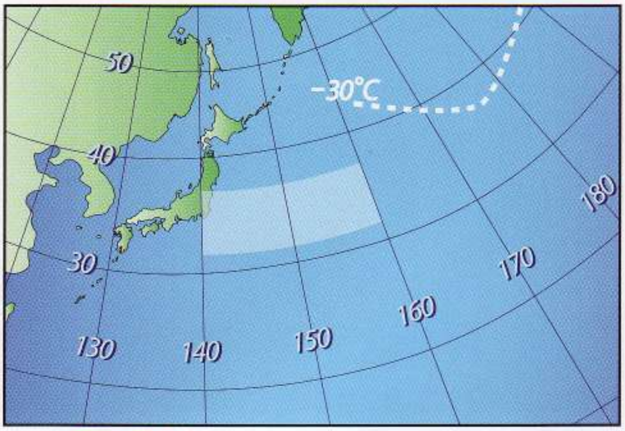


Fig.5-23 High-wave zone in the sea area east of Japan

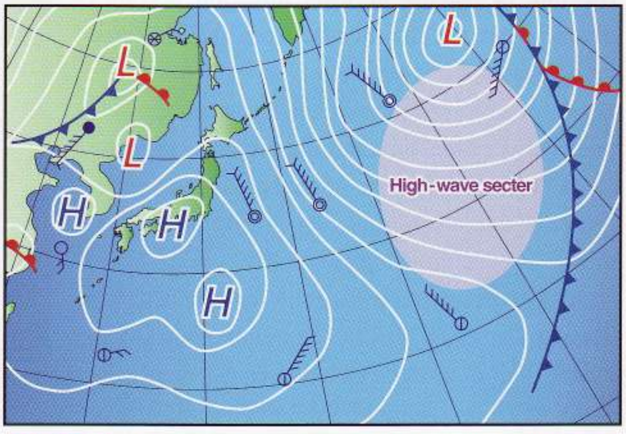


Fig.5-24 High-wave sector in the southwest quadrant of a low

5.2 Avoiding Tropical Storms (Typhoons)

Meteorological Information

When navigating under threat of a tropical depression or typhoon, a ship must collect information from meteorological organizations and then utilize these data. A rough method of detecting the center of a storm is known as Buys Ballot's Law: stand with your back to the wind; the center of low pressure will be from 15 to 30 degrees forward from your left hand (Fig.5-31) in the Northern hemisphere, and on your right hand in the Southern hemisphere. This law is also applicable to extratropical cyclones.

It is necessary to know the relative position of the ship to the target tropical depression or typhoon to minimize its effects. When a typhoon is moving northward and observed wind direction on board changes to clockwise, the ship is in the right-hand semicircle. If the wind direction changes to counter-clockwise, the ship is in the left-hand semicircle of a typhoon (Fig.5-25 and Fig.5-26).

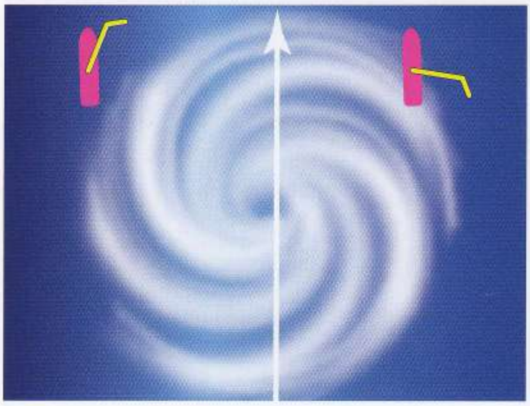


Fig.5-25 Wind direction of typhoon (in the forward part)

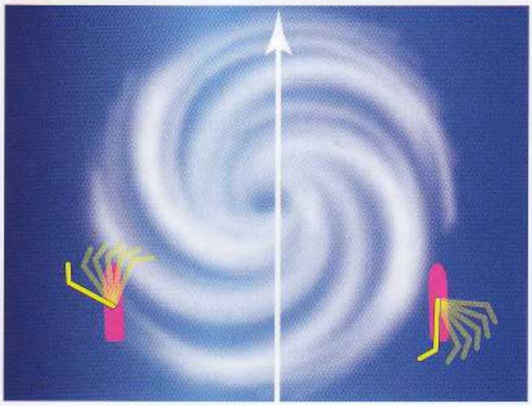


Fig.5-26 Change of wind direction

The rate of change in wind direction becomes greater when the distance between the ship and the center of the typhoon is smaller. Conversely, its rate of change becomes smaller when the distance between the ship and the center of typhoon grows larger. A large rate of change in wind direction also foretells abrupt and drastic directional change in wind direction (Fig.5-27).

With few exceptions, most ports and harbors along the southern coast of Japan are exposed to danger due to strong winds blowing towards the shore when a typhoon, directing northerly or northeasterly, is passing to the west of port.

Fig.5-27 Rate of wind direction change

Avoiding Tropical Storms (Typhoons)

1. Dangerous and navigable semicircles

The right-hand semicircle to the path of a typhoon (facing the direction toward which the typhoon is moving) is known as the dangerous semicircle; here, wind speed increases because wind direction and direction of typhoon movement are the same, and the ship may be blown towards the center of the typhoon (Fig.5-28). When a typhoon is located in the southern ocean, at a distance from Japan, its storm area has a circular form. As the typhoon approaches waters neighboring Japan, the storm area expands significantly, and tends to expand prominently in the eastern semicircle. Strong winds and high waves are formed in the typhoon's southeast quadrant.

Fig.5-30 shows that the high-wave area prevails in the southeastern quadrant. The left-hand semicircle to the path of a typhoon is called the navigable semicircle because wind decreases due to the forward motion of the typhoon (adverse to wind direction), and the wind blows the ship away from the typhoon path (See Fig.5-29). Even though it is called the navigable semicircle, it nevertheless accompanies the storm area, and sufficient care should be taken.

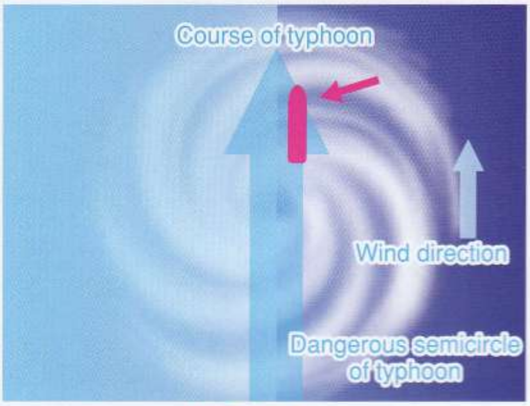


Fig.5-28 Dangerous semicircle

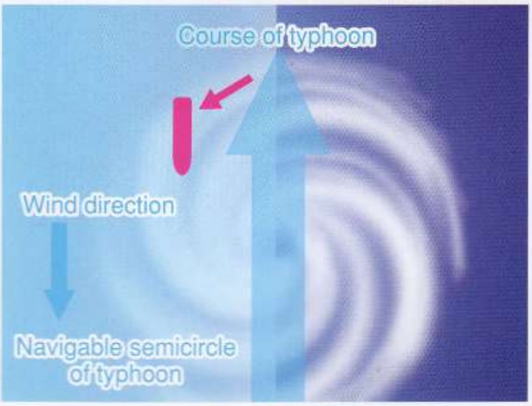


Fig.5-29 Navigable semicircle

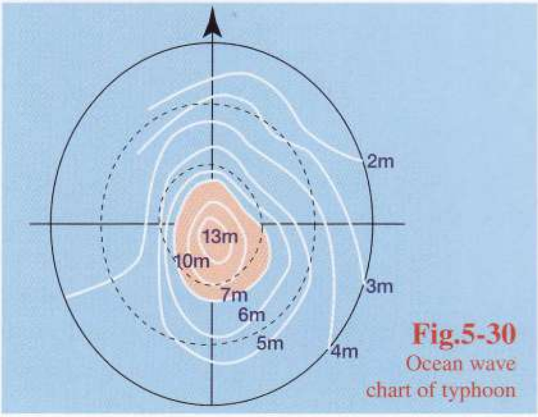


Fig.5-30 Ocean wave chart of typhoon

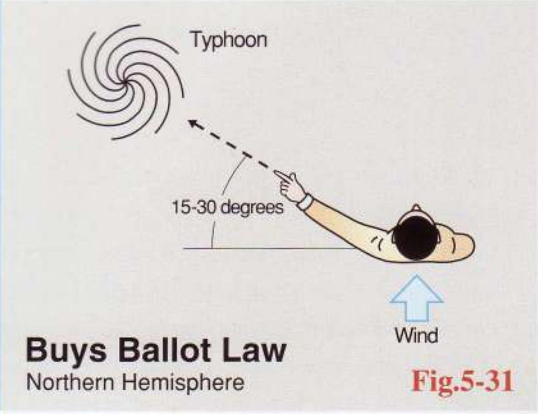


Fig.5-31

2. General rules for avoiding tropical storms (typhoons)

The general rules for avoiding tropical cyclones or typhoons are summarized as follows:

(As typhoons are mainly discussed in this chapter, the following rules apply only to ships in the Northern hemisphere.)

(a) If the wind changes to clockwise, the ship must be in the dangerous semicircle. If possible, the ship should place the wind on the starboard bow (45° relative), hold course and make as much way as possible to get out of the dangerous zone.

(b) If the wind backs the ship, the ship is in the navigable semicircle. The ship should place the wind on the starboard quarter (135° relative), hold course and make as much way as possible. (This method of avoidance is called **scudding**.)

(c) If the wind remains steady or nearly steady in terms of direction, the ship should be in the path of the typhoon, ahead of the storm's center. In this case, the master should decide in advance whether the ship is able to enter the navigable area of the typhoon safely or not. If this action is deemed practicable, the ship should place the wind 2 points on the starboard quarter (about 160° relative), hold course and make as much way as possible. When well within the navigable semicircle, scudding is recommended.

(d) If the ship is in the center, or near the center of the typhoon, the ship should heave-to with the wind on the starboard bow.

Heave-to: when the weather becomes so violent in the open sea that continued navigation will lead to difficulty or danger, the ship can heave-to (i.e. lie with the wind on the starboard bow and run ahead at the minimum possible speed for maintaining steerage way). The method by which engines are stopped and the ship is allowed to drift is known as **lying-to.**

Fig.5-32 shows the methods for avoiding typhoons in the Northern hemisphere; alphabetical symbols in the figure correspond with those above.

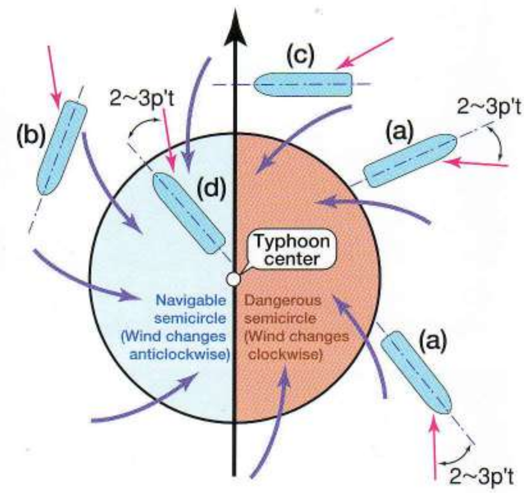


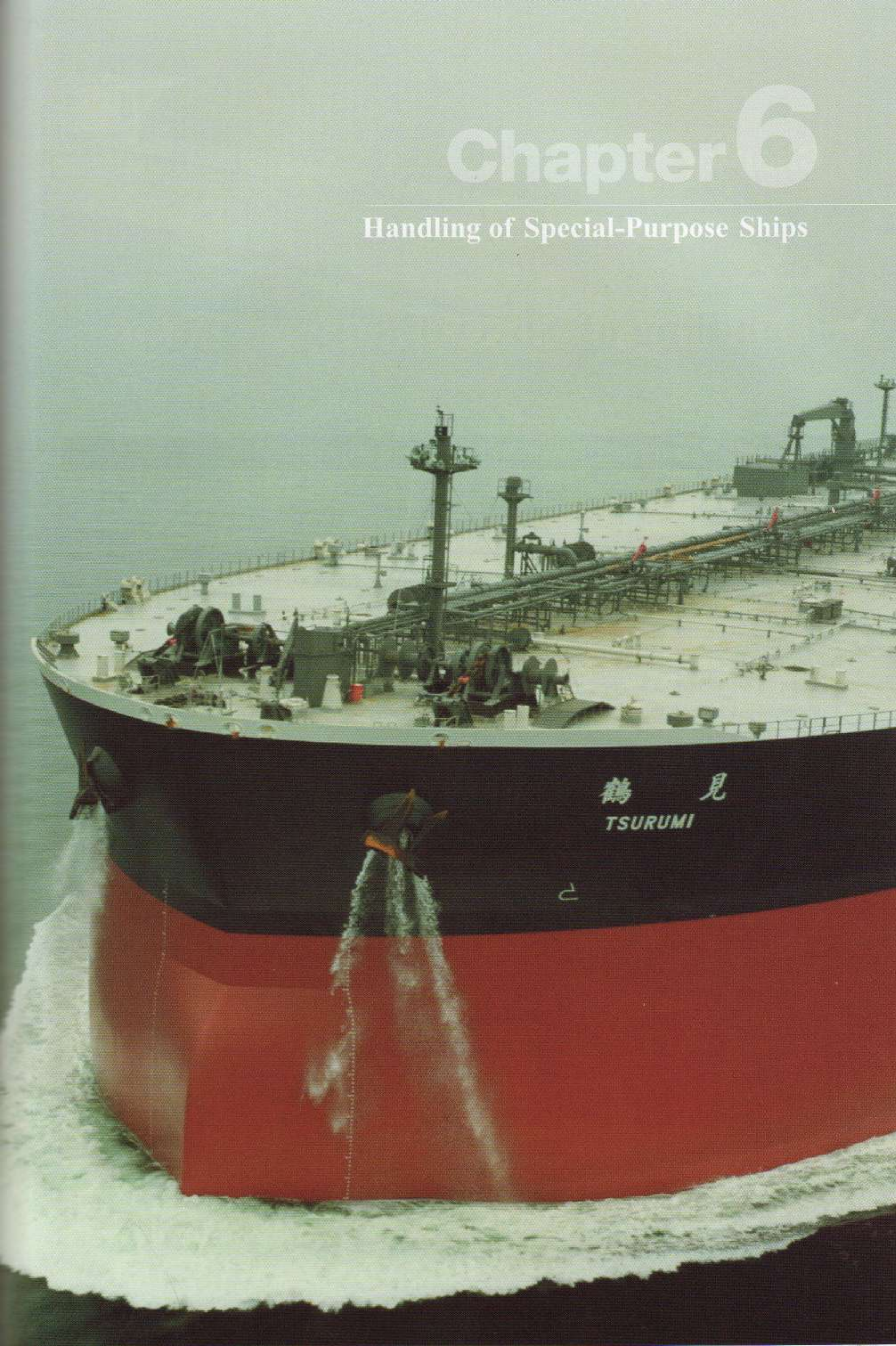
Fig.5-32 How to avoid typhoon

Today, the Meteorological Agency provides ships with information on oceanic meteorological conditions, such as surface weather charts, upper-air charts, ocean wave charts, photographs from weather satellites, and so on. All are easy to obtain.

It should be noted that much of the data from on-board weather observations are incorporated in the Meteorological Agency's weather reports. Therefore, for the purpose of providing ships with more accurate information on oceanic meteorological conditions, weather observations and reports will continue to be of vital importance. Seafarers are required not only to develop their meteorological knowledge, but also to seek to realize safe ship operations by making practical use of this knowledge.

Chapter 6

Handling of Special-Purpose Ships



Chapter 6

Handling of Special-Purpose Ships

6.1 Maneuverability of Very Large Ships

Introduction

In response to requests from the industrial world for rationalized transport and procurement expenses, very large ships have been designed and built in ever-greater numbers. These are primarily crude oil tankers and bulk carriers. The maneuvering characteristics of these very large ships include good turning ability but poor course-keeping and stopping abilities. When it comes to the safe navigation of very large ships, as typified by VLCCs, it is essential that every operator know the maneuvering characteristics of their ship, and that they master ship-handling techniques, including speed control. Based on the maneuvering capabilities of ships discussed in Chapter1, this chapter examines the handling of very large ships from a practical standpoint.

Turning Ability of Very Large Ships

The turning ability of very large ships is summarized in the following figures:

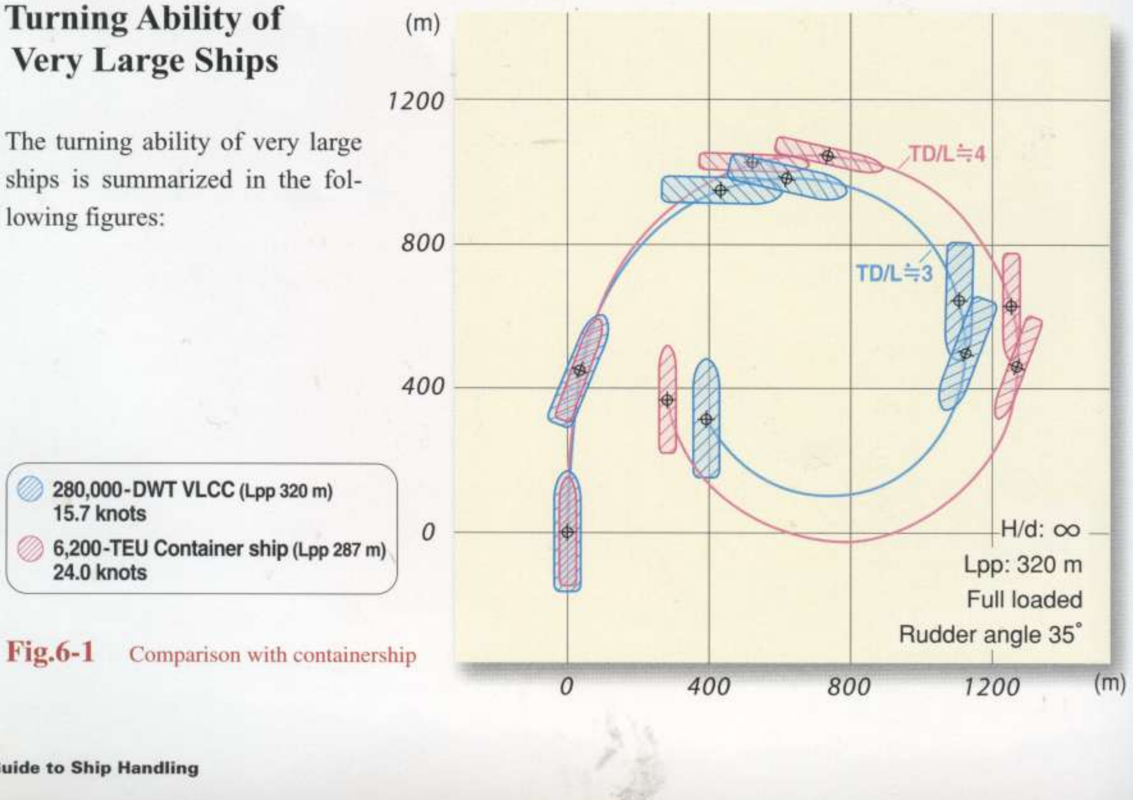


Fig.6-1 Comparison with containership

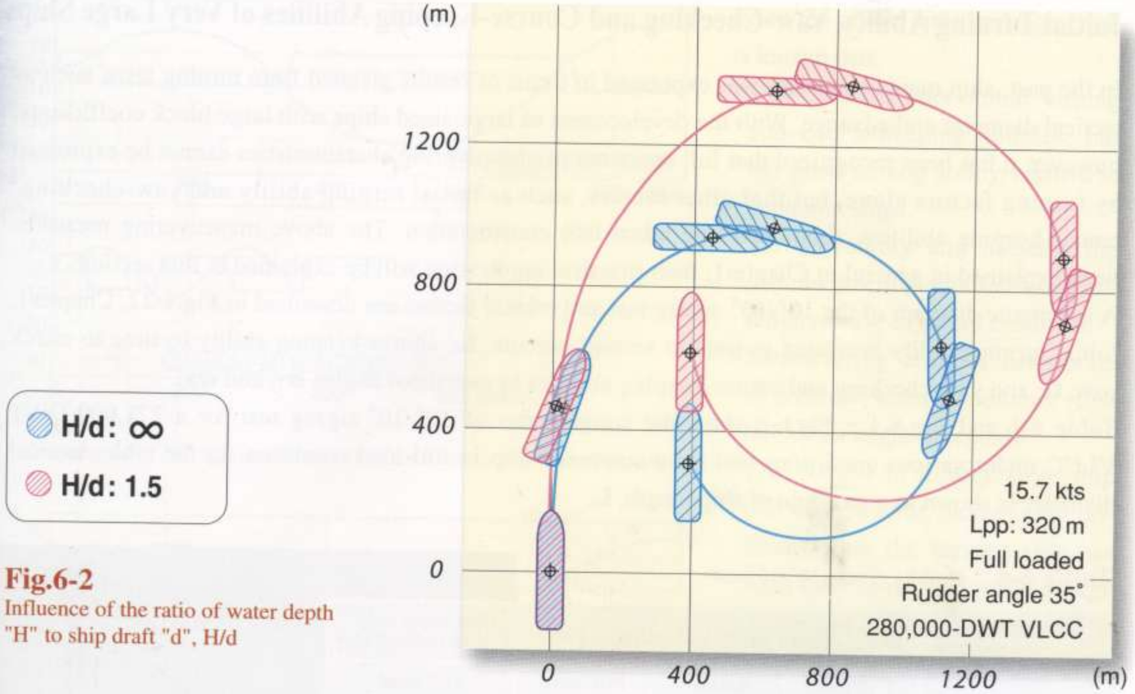


Fig.6-2
Influence of the ratio of water depth "H" to ship draft "d", H/d

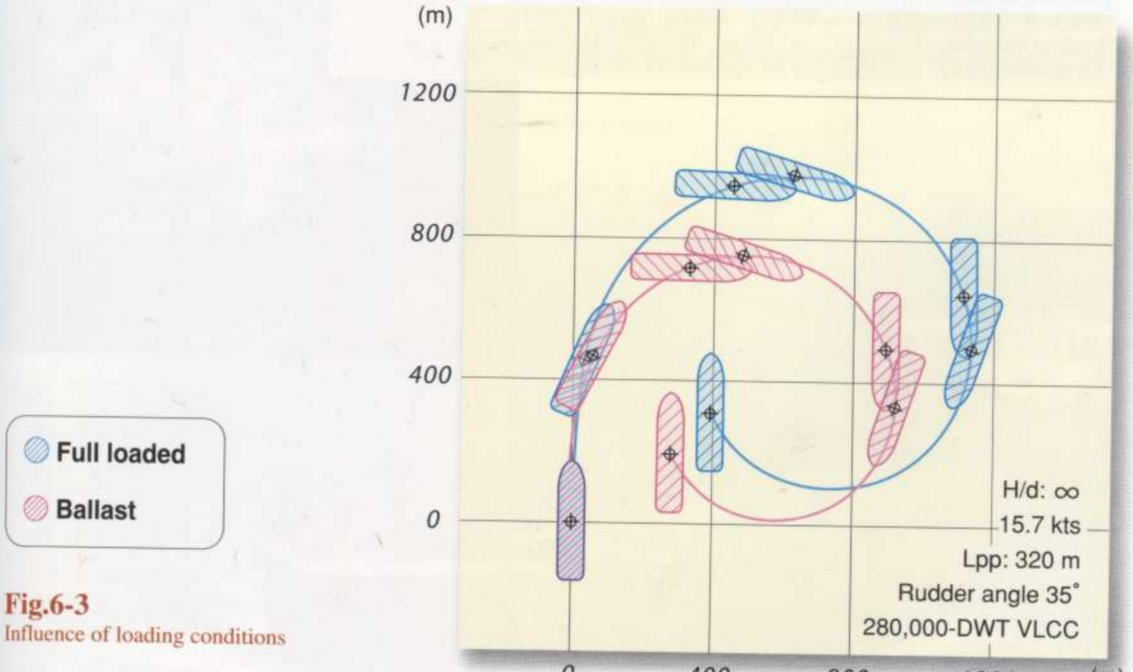


Fig.6-3
Influence of loading conditions

Initial Turning Ability, Yaw-Checking and Course-Keeping Abilities of Very Large Ships

In the past, ship maneuverability was expressed in terms of results gleaned from turning tests, such as tactical diameter and advance. With the development of large-sized ships with large block coefficients, however, it has been recognized that full spectrum of maneuvering characteristics cannot be expressed by turning factors alone, but that other factors, such as initial turning ability and yaw-checking/ course-keeping abilities, should also be taken into consideration. The above maneuvering measures were explained in general in Chapter1; their practical application will be explained in this section.

A schematic diagram of the 10°/10° zigzag test and related factors are described in **Fig.1-22**, Chapter1. Initial turning ability is related to time to second execute, $\mathbf{t_a}$; course-keeping ability to time to check yaw, $\mathbf{t_s}$; and yaw-checking and course-keeping abilities to overshoot angles α_1, and α_2.

Table 6-1 and **Fig.6-4 ~ Fig.6-6** show the comparisons of 10°/10° zigzag test for a 278,000-DWT VLCC under various conditions and for a container ship in full-load condition. In the table, tactical diameter is shown as a multiple of ship length, **L**.

Table 6-1 Results zigzag 10°/10° test

Ship type/ condition / Items	278,000-DWT VLCC L=320 m (15.7 kts)			Container ship L=278 m (24.0 kts)
	Full load $H/d=\infty$	Ballast $H/d=\infty$	Full load $H/d=1.5$	Full load $H/d=\infty$
Time to second execute, t_a, (sec)	68	43	117	42
Time to check yaw, t_s, (sec)	115	65	183	19
First overshoot angle, α_1 (deg.)	14	13	12	4
Tactical diameter, TD (multiple of L)	3.4	2.8	4.5	4.3

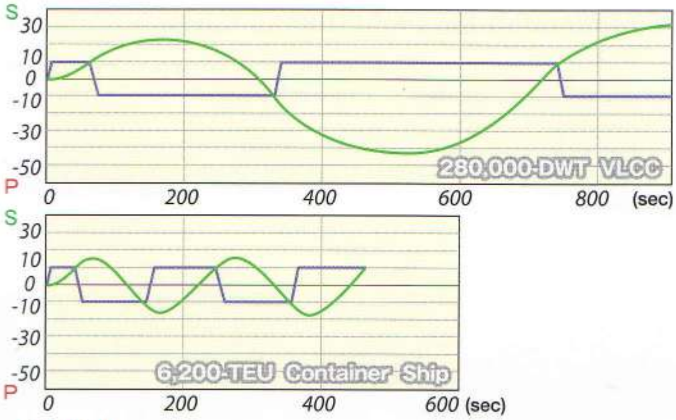


Fig.6-4
Comparison of 10°/10° zigzag test between VLCC and Container ship (full-load condition)

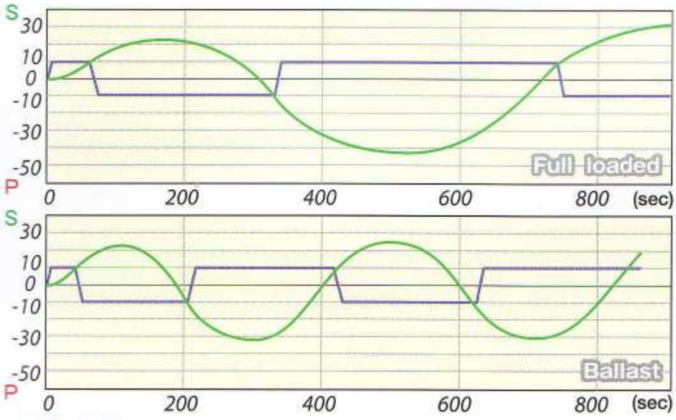


Fig.6-5
Comparison of 10°/10° zigzag test between VLCC in full-load and in ballast conditions

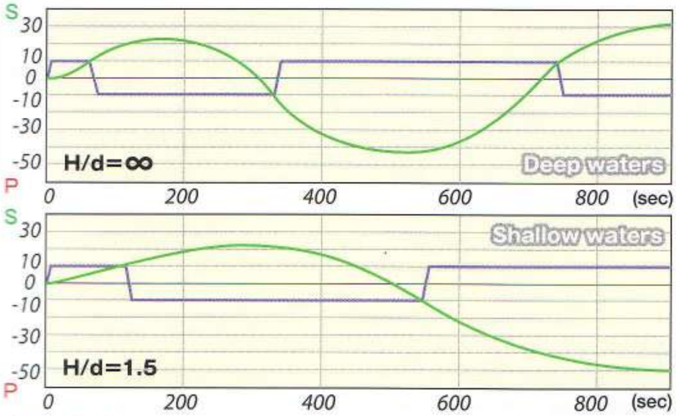
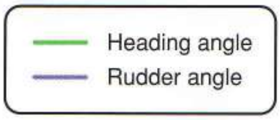


Fig.6-6
Comparison of 10°/10° zigzag test between in deep waters and in shallow waters

From the above table and figures, it is known that:

- VLCCs have poor initial turning and course-keeping abilities, but has good turning ability, relative to container ships.
- Turning ability and maneuvering abilities deteriorate in full-load condition relative to ballast condition.
- Maneuvering abilities deteriorate in shallow water conditions (first overshoot angle excepted).

The control of a very large ship will also become increasingly difficult when the turning rate has been fully developed using a large amount of rudder deflection. It is important to control the ship's turning rate by putting over the rudder gradually.



New Course Distance and Collision Avoidance Action

In respect to new course-keeping maneuvering, collision avoidance is simulated under various conditions for two full-loaded 280,000-DWT tankers making 15.7 knots and meeting on reciprocal courses. Applying requisite bridge-to-bridge distances, the results are summarized in the following figures:

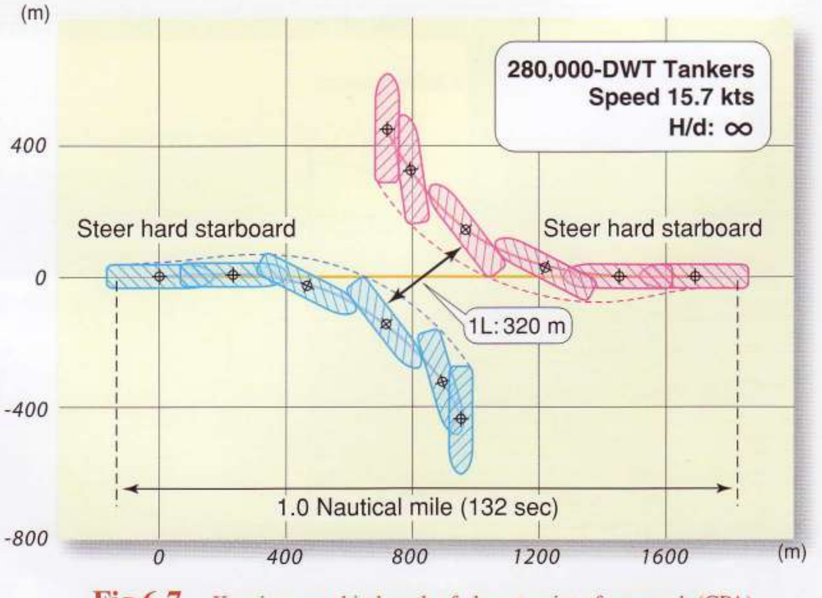


Fig.6-7 Keeping one ship length of closest point of approach (CPA)

As shown in **Fig.6-8**, sufficient care should be taken for initial evasive distance when navigating in shallow waters, such as the Malacca Strait.

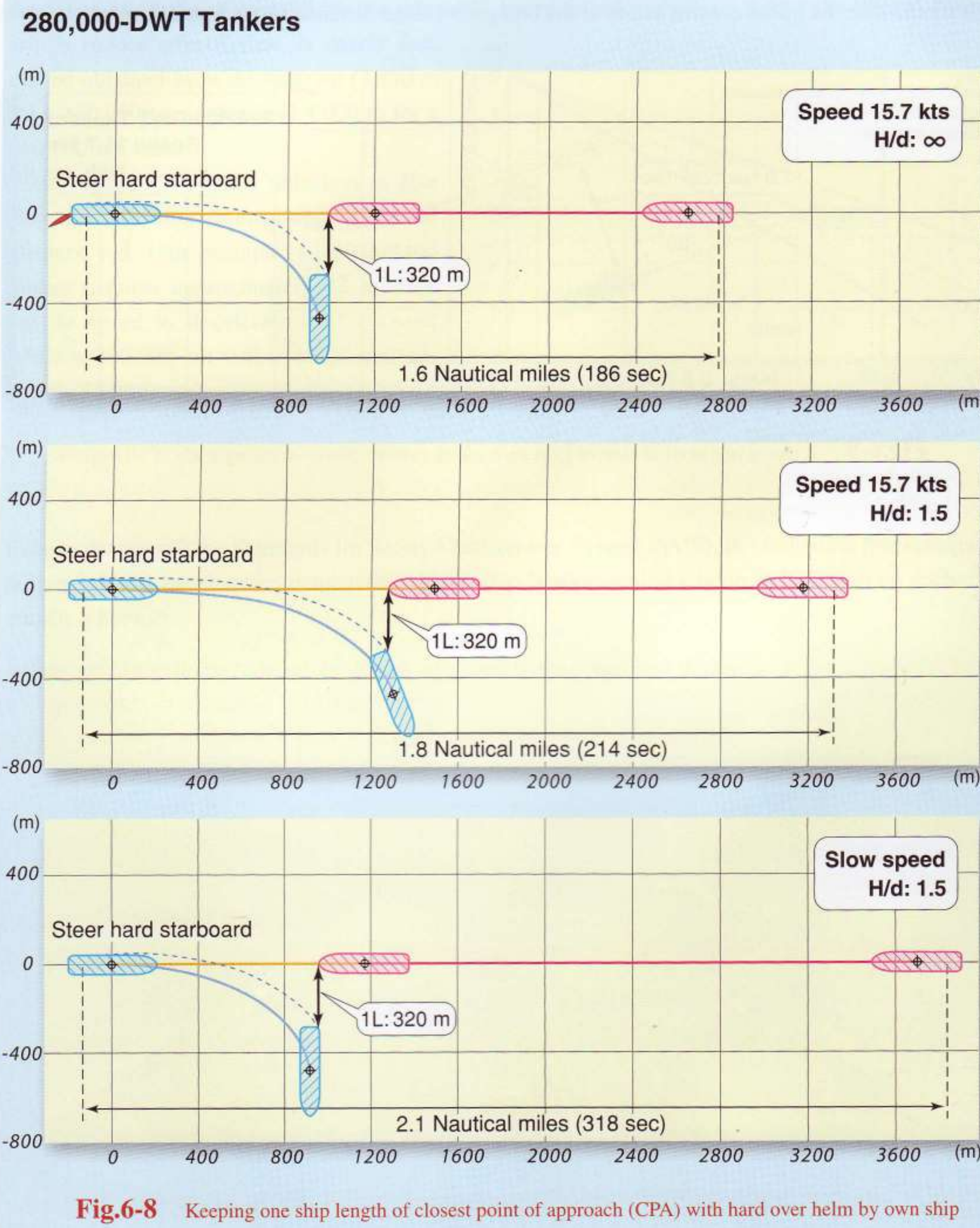


Fig.6-8 Keeping one ship length of closest point of approach (CPA) with hard over helm by own ship

Fig.6-9 shows a simulated result when passing each other by keeping one nautical mile of closest point of approach in open sea.

Each evasive course-changing angle has changed to 20° to starboard with using 10° rudder to starboard while controlling the turning rate.

Each should take the initial evasive action at the bridge-to-bridge distance of 3.8 nautical miles.

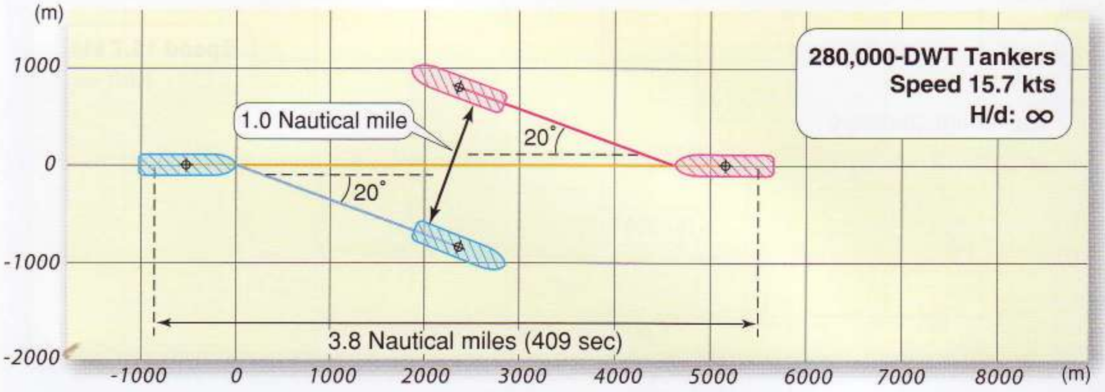


Fig.6-9 Keeping one nautical mile of CPA each taking evasive course-changing angle of 20 degrees

Speed Control

Assuming that a ship is approaching its berth using a deceleration maneuver, speed and distance covered are described in **Fig.6-10** after the main engine has been stopped and the ship is making 6 knots. Approximate distance covered by the time ship speed is reduced to 2.5 knots, the critical speed at which rudder effectiveness is nearly lost, can be obtained from the diagram (2,800 m for a 160,000-ton tanker; and 4,000 m for a 280,000-ton tanker).
Time required for speed reduction is also shown as a function of displaced weight and distance run. (For example, a 160,000-ton tanker requires approximately 22 minutes for its speed to decelerate to 2.5 knots; while a 280,000-ton tanker takes approximately 30 minutes.)

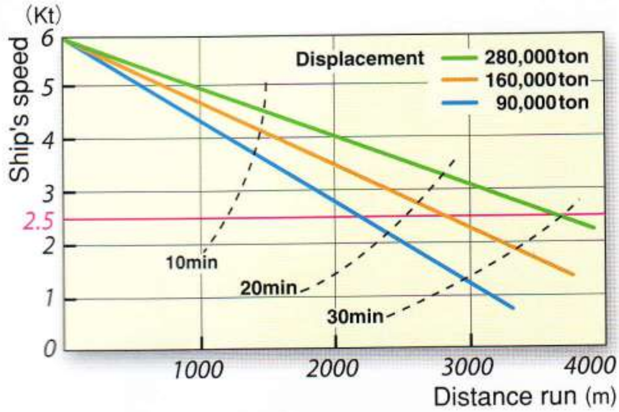


Fig.6-10 Deceleration diagram

In accordance with the Standards for Safety Management System (SMS), the following precautions are required during deceleration maneuvers when a ship is approaching a berth in harbor or an anchorage outside a harbor:

- Ship speed should be reduced gradually, adjusting to the remaining distance.
- Ship should not overshoot the target destination.
- Ship should be brought to a stop with directional control being kept stable.

It should be noted that headway and directional control are difficult to maintain during such maneuvers, a condition exacerbated by poor steering ability at low speed. The speed reduction scheme shown in **Fig.3-34** in Chapter 3 may prove helpful when it comes deceleration maneuvers.

The movement of very large ships cannot be controlled using conventional ship-handling techniques alone. As such, attention should be paid to maintaining directional control using verified numerical data and readings from a yaw rate meter.
Very large ships are characterized as "good turning ability, but extremely poor course-keeping and initial turning abilities."
It is hoped that you keep safe ship handling in mind, firmly grasping the above-mentioned maneuvering characteristics of very large ships.

6.2 Maneuverability of Pure Car Carriers (PCCs) – Wind Effects

Introduction

Such ships, typified by Pure Car Carriers or Car-ferries, are characterized as a special design characterized by a high freeboard, with a significant area of the hull and superstructure above water as compared to the underwater hull.

This means that wind has a significant impact on the hull and that the bow wave has a much greater effect on the large flared bow.

Particular attention should be paid to typhoons or approaching low fronts, as they can result in loss of maneuverability due to the ship being buffeted by strong winds and waves; deterioration of rudder effectiveness as the result of heavy rolling and pitching; and greatly reduced speed caused by propeller racing, which in turn may make it difficult to maintain control over the main engine. These vessels are also susceptible to anchor dragging due to strong winds.

Therefore, it is important to grasp wind effects and understand the maneuverability limits they impose.

Hull Structure Properties of PCCs

To maximize vehicle-carrying capacity, a PCC is designed as a rectangular-type hull structure with high freeboard, with an enormous area of hull and superstructure above water as compared to the underwater hull. Since the PCC hull form is distinct from those of tankers and container ships, PCCs are always vulnerable to the effects of wind, regardless of their load condition.

Principal particulars of the PCC are shown in **Table 6-2**.

Length over all (LOA)		190 m
Breadth extreme (B)		32.26 m
Depth moulded (D)		37.41 m (cargo deck top)
Draft	*Summer draft*	*10.325 m*
	Designed draft	8.325 m
	Ballast condition	7.50 m
Anchor weight (AC14 type)		8,325 kg
Cable	Weight	143.7 kg/m
	Length	687.5 m (12/13 shackles)

Table 6-2 Principal particulars of the model PCC (6400-unit capacity)

Typical symbols, such as **Aa** and **Ba** are defined as shown in **Fig.6-11**.

As shown in **Fig.6-11**, the projection of a full-sized PCC's midship above-water section has an approximate value ranging from 950 m^2 to 1,050 m^2; the value for the lateral plane of symmetry ranges from 5,500 m^2 to 6,200 m^2.

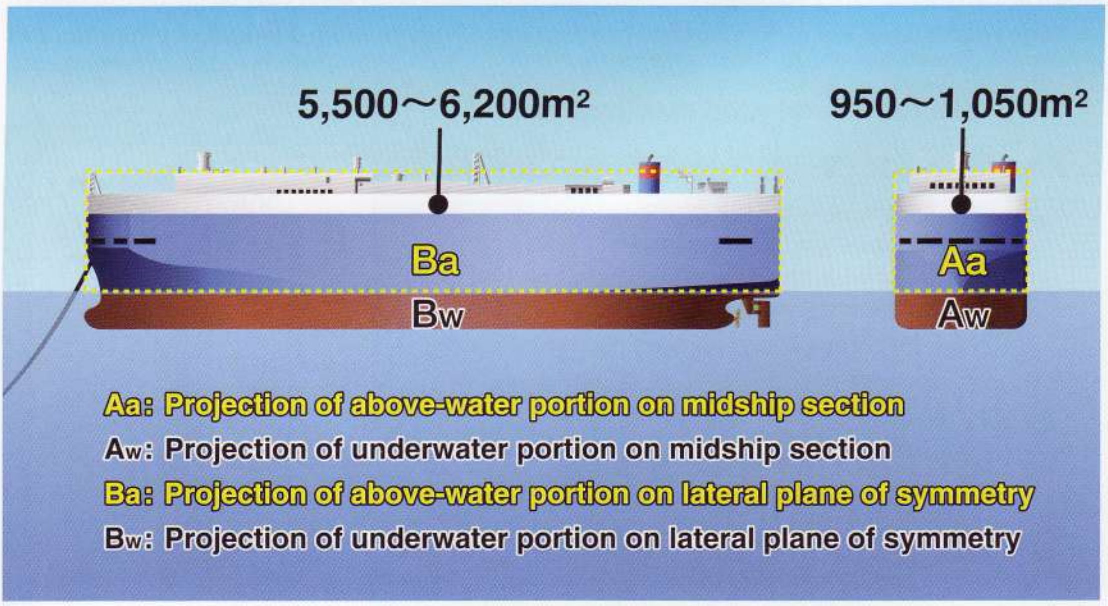


Fig.6-11 Front and side projections of above-water and underwater portions of PCCs

Table 6-3 compares a PCC, a container ship and a tanker, each in loaded condition. The ratio of the front projection of the above-water portion, **Aa**, is compared to that of the underwater portion, **Aw**, and the ratio of side projection of the above-water portion, **Ba**, to that of the underwater portion, **Bw**. The wind effect on a PCC is about 1.2 times (3.1/2.6≒1.2) on the front view and 1.5 times (2.9/1.9≒1.5) on the side view as compared to a container ship. The table also indicates that the wind effect on the PCC is about 2.6 times on the front view and 3.6 times on the side view as compared to a tanker. So, a PCC is highly susceptible to the effects of wind.

Ship \ Item	Front ratio (Aa/Aw)	Side ratio (Ba/Bw)
PCC (6,400-unit capacity)	3.1	2.9
Container ship (6,000-TEU)	2.6	1.9
Tanker (230,000-DWT)	1.2	0.8

Table 6-3 Principal particulars of the Model PCC (6,400-unit capacity)

Wind Effects on PCC while Underway

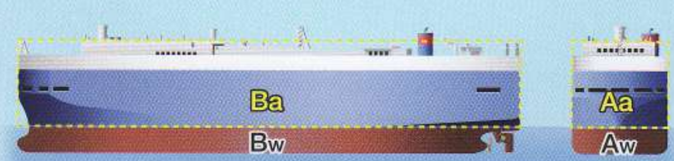
1. Wind force (Resultant wind force) on PCC

The wind force acting on each portion of the hull differs according to the shape of the hull and the relative wind direction. However, ship operators deal with each local wind force as an integrated value. This unified force is termed the resultant wind force acting on the working point. The resultant wind force acting on the hull is calculated by the formula devised by G. Hughes as shown in Fig.6-12. **Ca** in this equation is the resultant wind force coefficient, its values varying with the relative wind direction off bow. The curve obtained by plotting these values shows the same trend depending on the type of ship.

Simplified formula of wind resultant force (F)

$$F = 1/2 \cdot \rho \cdot Ca \cdot V^2 (Aa \cdot \cos^2\theta + Ba \cdot \sin^2\theta)$$

ρ : Specific density of air (0.125)
Ca : Resultant wind force coefficient
a : Distance of the center of wind force from bow (m)
C : Center of the wind force
Aa & Ba : Projection of above-water portion (m^2)



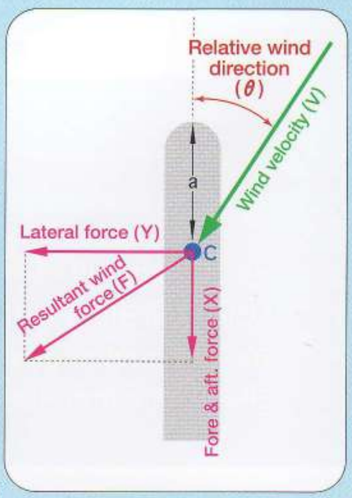


Fig.6-12 Simplified formula of wind resultant force and related elements

The resultant wind force coefficient of PCCs can roughly be obtained from **Fig.6-13**. The working point of wind force, located at a distance of **a** from the fore perpendicular (FP), moves with the wind direction. When the relative wind direction is near the direction of the bow, the working point is at the position near the bow, moving abaft as the angles of relative wind direction off bow increase.

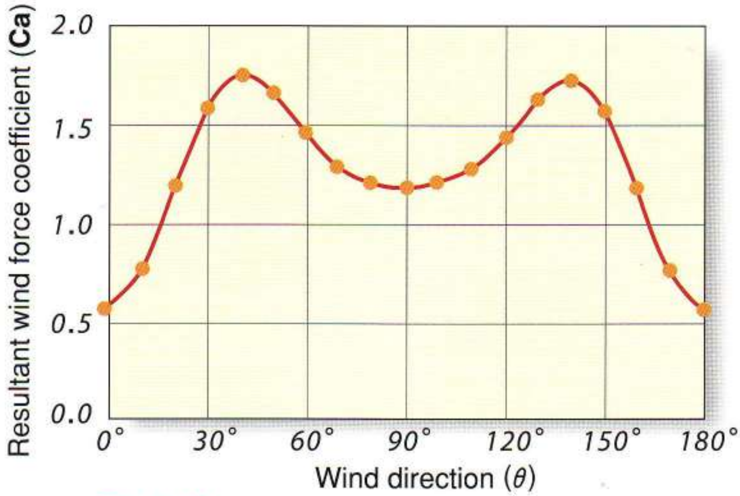


Fig.6-13 Resultant wind force coefficient (Ca) of PCCs

The resultant wind force acting on the working point varies with wind speed and direction, reaching a maximum when the beam wind is acting on the largest wind-affected area. In the case of the model PCC, as shown in **Fig.6-14**, it can reach 290 tons under a wind speed of 25 m/s and a relative wind direction of 90 degrees.

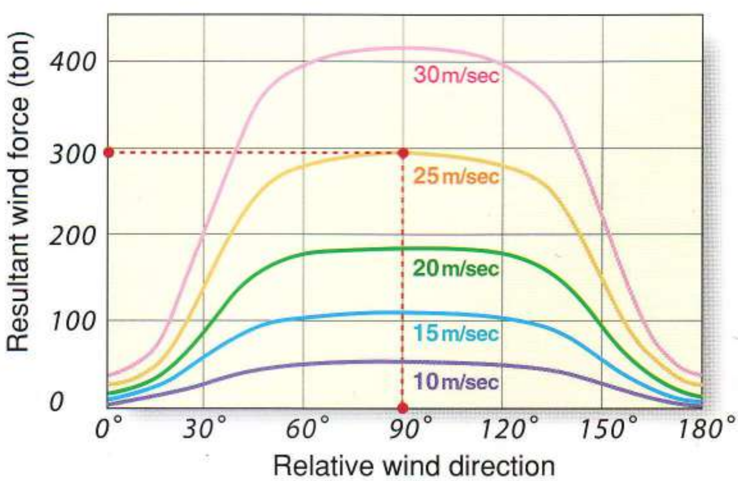


Fig.6-14 Resultant wind force vs. wind speed and relative wind direction

2. Leeway and check helm for maintaining straight course

When the wind begins to blow from the starboard bow while underway, turning moment to port is exerted due to the resultant wind force on the working point. However, when the wind shifts its direction abaft the beam, turning moment to starboard is exerted due to the backward shift of the working point (Fig.6-15). When the wind from the starboard bow continues blowing on the ship underway, its bow is swept away downwind by the turning moment to port. Due to the drifting of the hull to leeward, the fluid force from the port bow on the underwater hull causes the turning moment to starboard. If the working point of wind force is located abaft that of fluid force, the ship's bow tends to turn into the wind. Leeway is defined as the angle ($\beta°$) between the line of the ship's apparent course (the bow heading) and the line that the ship actually makes good through the water (Fig.6-16).

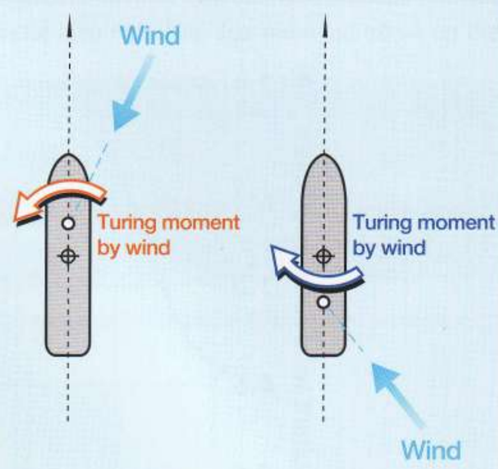


Fig.6-15 Turning moment by wind

When navigating a width-confined channel under the influence of wind and tidal current, prudent ship handling is required in consideration of leeway. For this purpose, the ship is required to take a little more windward course than the planned course in order that the ship's center of the gravity may remain on the planned course line.

Leeway will increase, as the wind speed grows stronger or the ship is making less speed.

In this case, ship handling is required to adjust leeway by checking the ship's position frequently. However, when navigating a narrow channel, the rudder angle to be deflected is limited to 15 degrees against the ship's maximum rudder angle of 35 degrees. Around 20 degrees of rudder angle must be reserved for safety reasons.

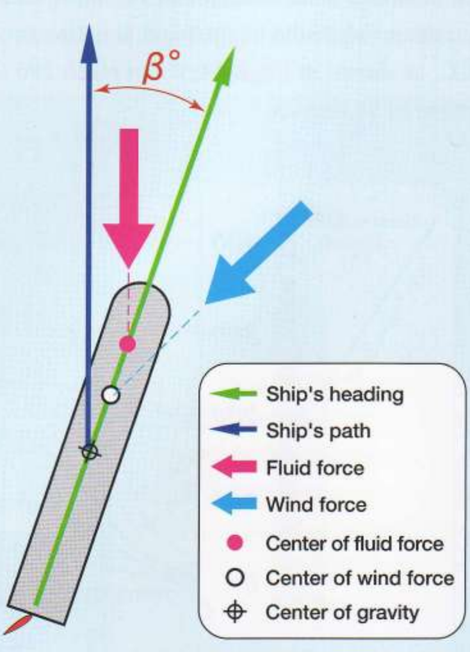


Fig.6-16 Definition of leeway, $\beta°$

3. Controllability limits of PCC in wind

When the wind speed is increasing or the ship is making less speed on the beam wind, the outcome of the magnitude of leeway with rudder held amidships is shown in Fig.6-17. For example, when a wind of 15 m/s is blowing and the ship is making 12 knots, leeway will approximately be 7 degrees, but when the ship speed decreases to 8 knots, leeway increases to 15 degrees.

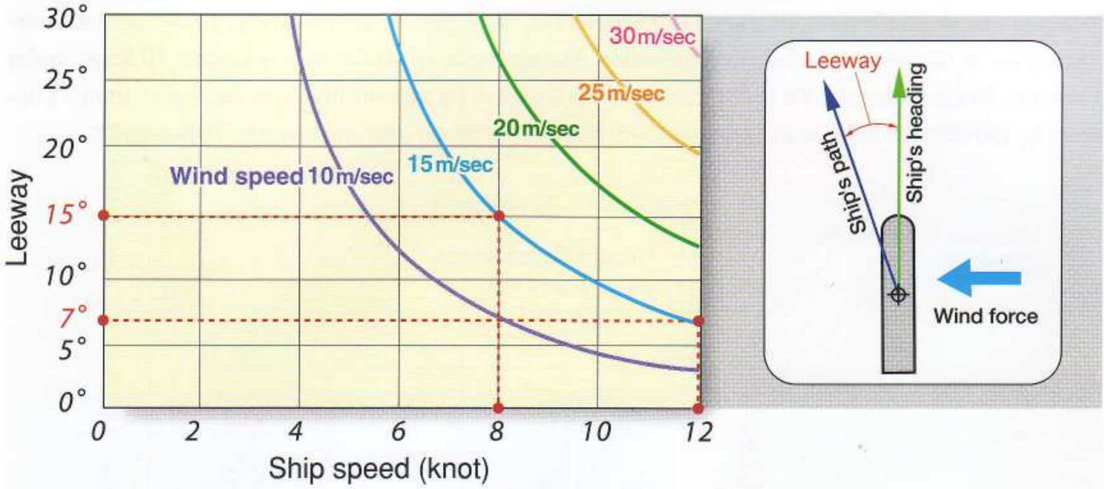


Fig.6-17 Leeway as functions of wind and ship speed (beam wind; rudder held amidships)

Table 6-4 shows the amount of check helm required to maintain a straight course. The ship will lose its controllability on a beam wind of 10 m/s with a ship speed of 4 knots. When making 6 knots, the ship is controllable under the same wind condition, but the required rudder deflections of check helm can reach 21 degrees.

Ship speed (kts) / Wid speed (m/sec)	4	6	8	10	12	15
10	∞	21°	12°	8°	5°	3°
15	∞	∞	27°	17°	12°	8°
20	∞	∞	∞	30°	21°	14°
25	∞	∞	∞	∞	33°	21°
30	∞	∞	∞	∞	∞	30°

∞: Rudder angle > 35 deg. (It means beyond control) Under control Beyond control

Table 6-4 Required check helm for keeping straight course

Fig.6-18 (a) and **Fig.6-18 (b)** show the controllability limits of a PCC in strong wind conditions. In the figures, the rudder deflections of check helm required to keep a straight course are shown as functions of wind direction, and the wind speed **Va** to ship speed **Vs** ratio, i.e. **Va/Vs**, from one to five.

Fig.6-18 (a) shows the controllability limit when the maximum rudder deflection is set to 35 degrees. The ship will be uncontrollable in the region from 70 to 160 degrees where the **Va** to **Vs** ratio is 5, and from 100 degrees to 135 degrees where the **Va** to **Vs** ratio is 4. In case of a 15-degree limitation on maximum rudder deflection, as shown in **Fig.6-18 (b)**, the region of controllability becomes much narrower than in the case of a 35-degree limitation. For example, when the ship is making 10 knots under a wind of 30 knots, i.e. the **Va** to **Vs** ratio is 3, the ship will be uncontrollable in the region from 75 degrees to 150 degrees off bow in case of a 15-degree limitation on maximum rudder deflection.

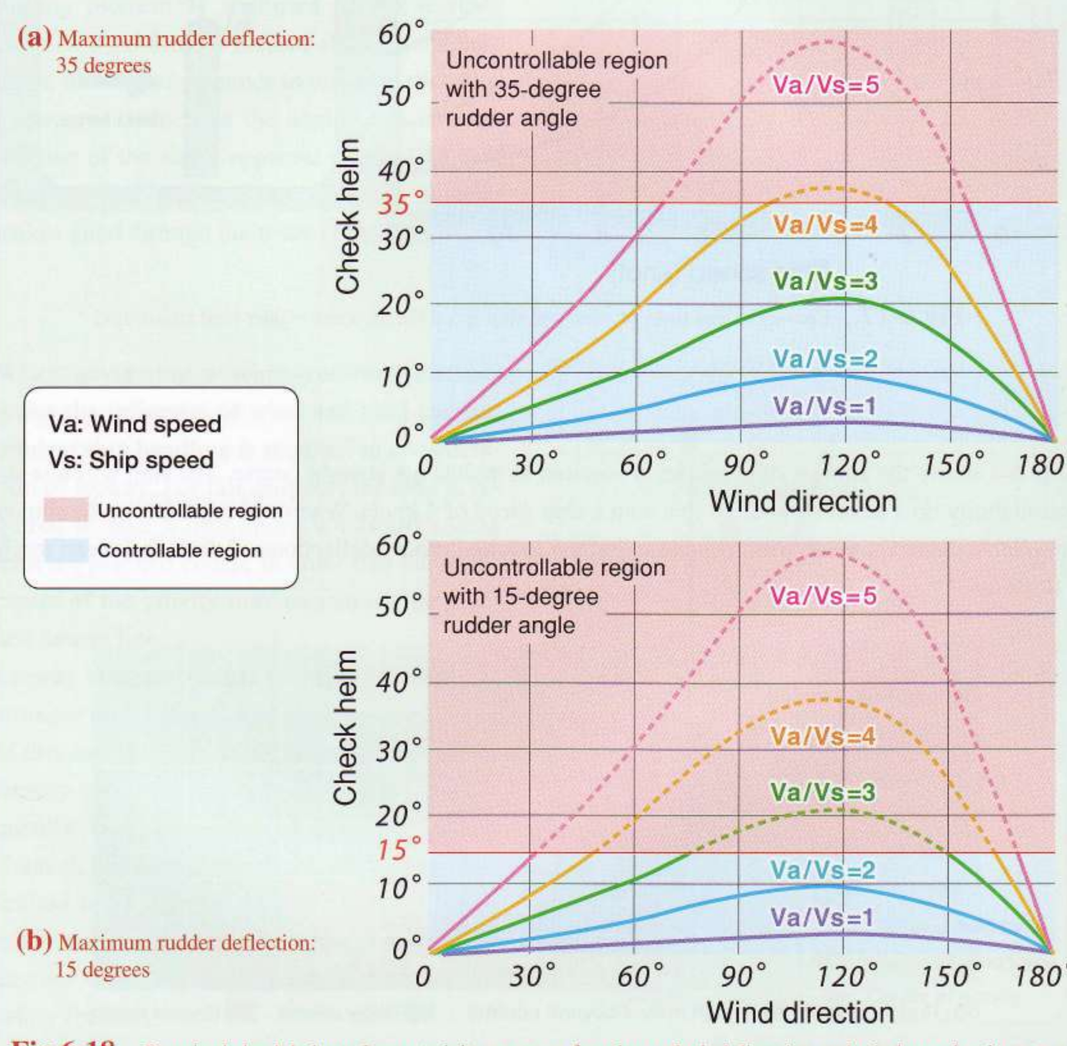


Fig.6-18 Required check helm to keep straight course as functions of wind direction and wind speed ratio (Va/Vs)

Fig.6-19 shows the controllability limits of various ship types when the maximum rudder deflection is limited to 30 degrees. As we can see, the PCC has a narrower region of controllability than other types of ship. For example, the critical wind speed on a tanker in ballast condition is *5.0* times as much as ship speed, while that on a PCC is approximately *3.6* times as much as ship speed.

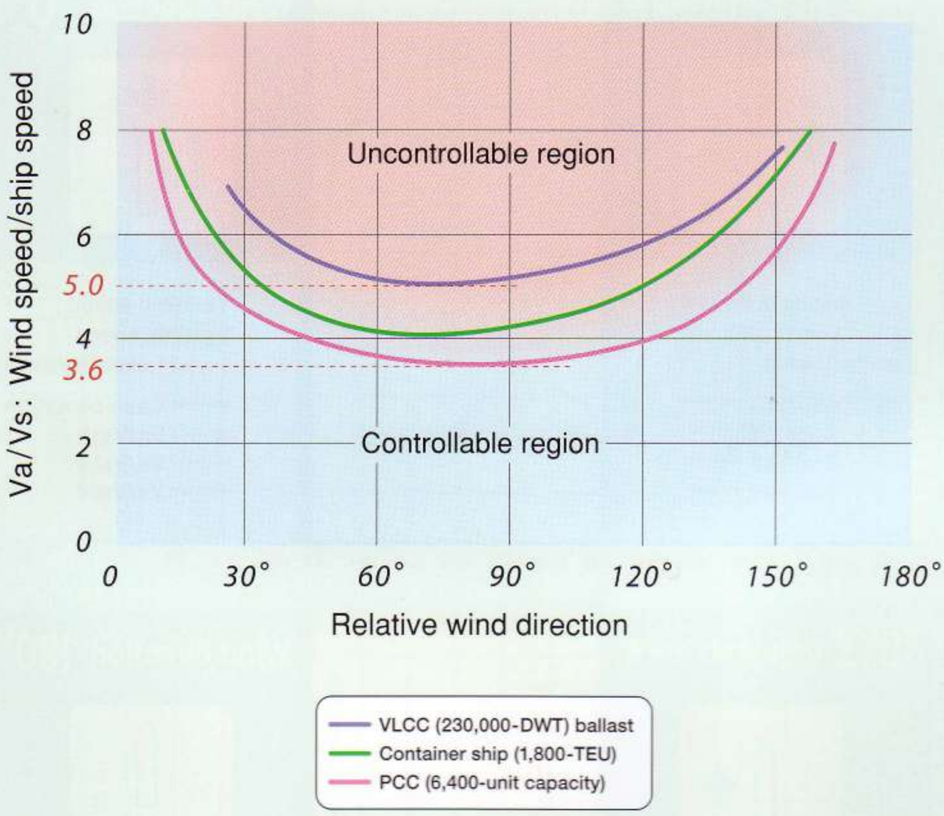


Fig.6-19 Controllability limits of various types of ship (30-degree rudder deflection)

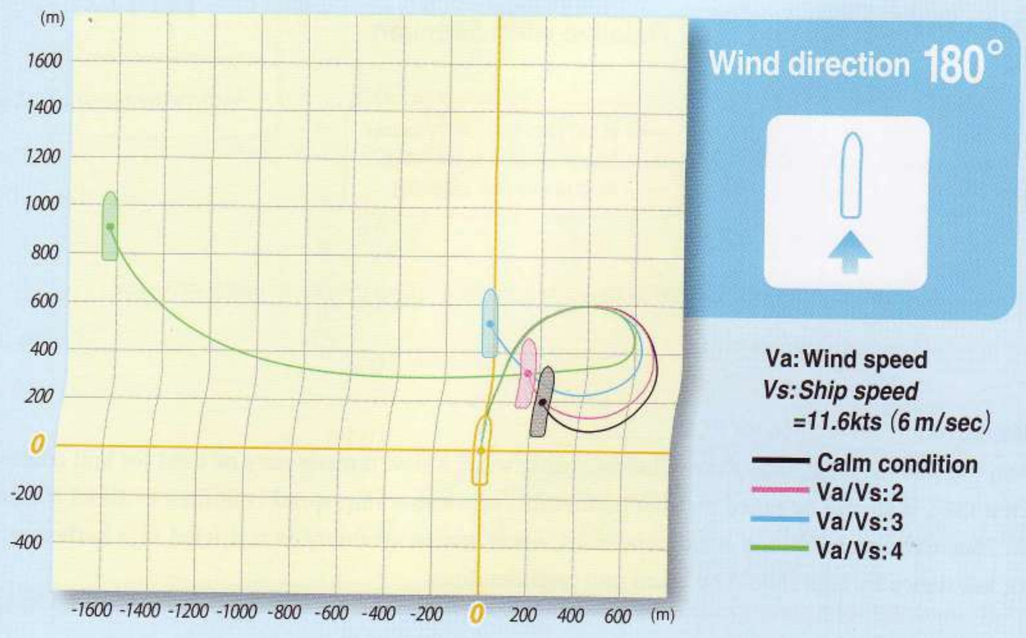
4. Maneuvering assistance for PCC

When the ship is swept away downwind by strong wind, a bow thruster may be used for hull control. In such a case, it should be noted that the permissible maximum ship speed is limited to about 4 knots or less. Moreover, under strong wind conditions where maneuverability is restricted in a harbor or fairway, assistance by tugs should be taken into consideration.

5. Turning of PCC under strong wind

With turning in calm conditions as reference, the turning of a PCC is investigated when the wind increases speed to 2, 3 and 4 times as much as initial ship speed. Each initial speed is set as 11.6 knots (6 m/s). **Fig6-20** shows the turning tracks, including the turning track in calm conditions, under the above wind speed conditions when the wind is blowing 0°, 90°, 180°, 270° from the approach course.

Simulations



As shown in these figures, turning ability of a PCC is greatly influenced by wind. As the Va to Vs ratio reaches 4, the ship can enter an uncontrollable region depending on relative wind direction, and some PCCs have extreme difficulties for executing turning maneuvers. Due to the unique maneuvering characteristics of the PCC as mentioned in this subsection, it is requested that PCCs be operated safely by taking maneuverability limits into consideration.

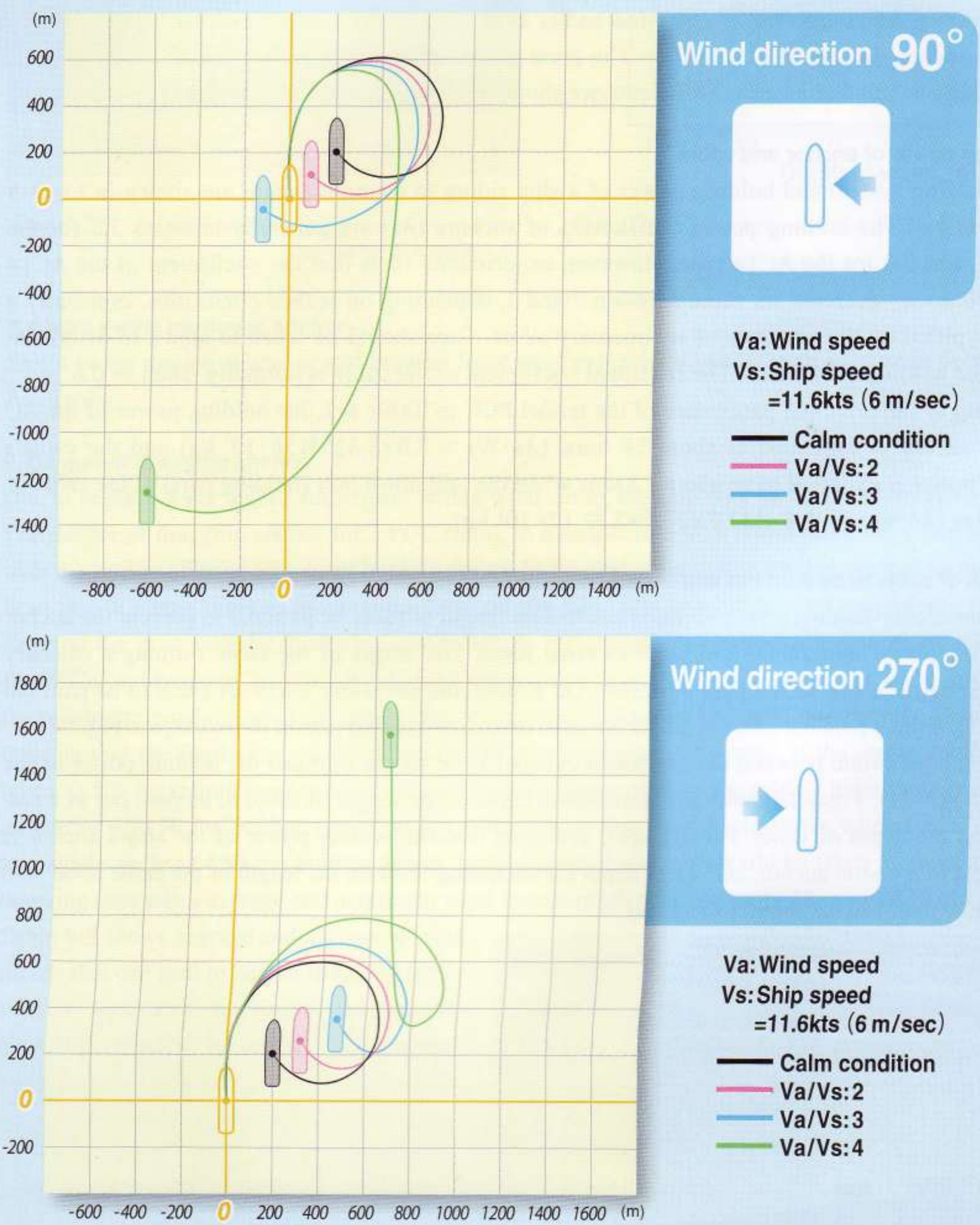
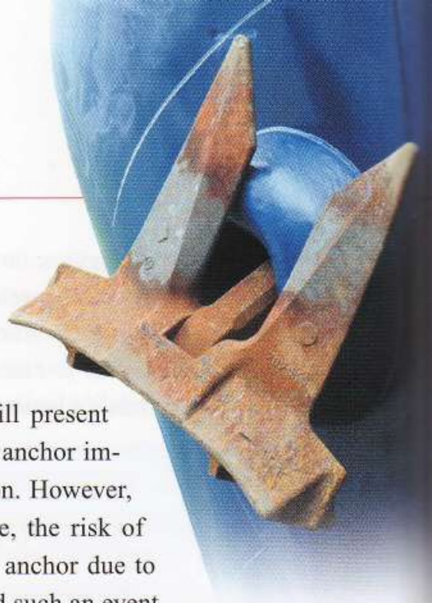


Fig.6-20 Turning of PCC under strong wind



Wind Effects on PCC at Anchor

1. Introduction

Anchoring has already been discussed in Section 3.1. This section will present concrete examples of the safe anchoring of wind-prone PCCs. A ship at anchor impacted by the wind will periodically swing around the anchored position. However, as the external forces exerted by the wind and/or tidal stream increase, the risk of dragging anchor rises. A PCC at anchor is in great danger of dragging anchor due to its very large wind-affected area. Sufficient care should be taken to avoid such an event.

2. Holding power of anchor and cable

The anchoring system and holding power of a ship riding to a single anchor are shown in **Fig.3-8** in Section 3.1. The holding power coefficients of anchors (λa) are generally taken as 3.5 for the JIS type, and 7.0 for the AC14 type. However, experiments show that the coefficient of the AC14 type anchor may decrease its value between 2 and 3, depending on seabed conditions, especially a seabed typified by the presence of sedimentary slime. Care should be taken to adjust to deterioration of the holding coefficient. The frictional coefficient of the cable is normally taken as 0.6.

According to the principal particulars of the model PCC in **Table 6-2**, the holding power of the AC 14 type anchor is estimated at about 58 tons, ($\lambda a \cdot Wa = 7.0 \times 8{,}325 \fallingdotseq 58 \cdot 10^3$ kg) and the cable's holding power is expected to be about 12 tons when the laid down part (holding part) of the cable is 5 shackles ($\lambda c \cdot wc \cdot l = 0.6 \times 143.7 \times 27.5 \times 5 \fallingdotseq 12 \times 10^3$ kg).

3. Length of cable to be paid out and catenary

Maximum anchor-holding power requires a sufficient length of cable be paid out to prevent the anchor from being pulled upward by horizontal external force. The length of the cable forming a catenary should be equal to that of the paid out cable, i.e. a minimum necessary length of cable to be paid out (**Fig.6-21**). Excess paid out cable is laid down and serves as a holding part of the cable (see **Fig.3-8**).

Assuming equilibrium between the horizontal external force on the ship and the holding power of the anchor (**Fig.6-21**), **Fig.6-22** shows the relationship between the length of cable to be paid out as a catenary and the depth of water. For example, assuming that the holding power of the ship's anchor is equivalent to a 60-ton anchor, and water depth for anchoring is 30 m, the length of the cable to be paid out is more than 190 m (about 7 shackles).

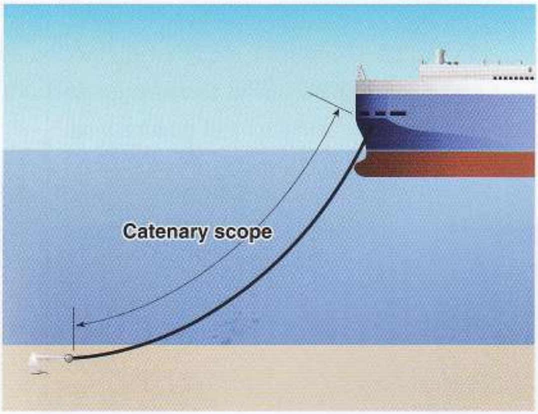


Fig.6-21 Equilibrium condition between external force and anchor-holding power

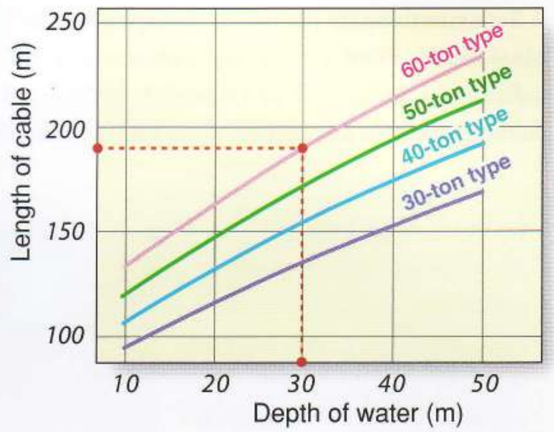


Fig.6-22 Water depth and length of cable to be paid out

4. Ship's swing motion at anchor

Ship's swing motion at anchor and impulse force were explained together with a figure in Section 3.1, Anchoring.

5. Danger of dragging anchor

Due to impulse force and/or subsequent strong wind stress, the ship may be at risk of dragging anchor. The danger of dragging anchor for a PCC riding to a single anchor is investigated for a ship equipped with the anchor offering 50 tons of holding power. In the case where cable tension reaches its maximum limit due to swing motion, the impulse force on the cable can be estimated by multiplying the wind force on the front view by the swing coefficient, **n**. The values for swing coefficient, **n**, are taken as 5 for PCCs, and between 2.5 and 3.5 for other ships. Given an average wind speed of 13 m/s, critical and the maximum wind speeds will statistically be about 16.2 m/s and 18.2 m/s, respectively. Calculations indicate that the front view of a PCC will suffer a wind force of 9.8 tons. If the swing coefficient is taken as 5, a maximum tension of 49 tons (5×9.8) will be exerted on the cable. Under these conditions, an anchor with 50-ton holding power will be vulnerable to dragging. Accordingly, when a PCC is riding to a single anchor of 50-ton holding power, precautionary measures should be taken to prevent anchor dragging case when average and maximum wind speeds reach approximately 13 m/s and 18 m/s.

Table 6-5 shows average and maximum wind speeds that can lead to anchor dragging (categorized according to swing coefficient). When the wind is becoming stronger and wind speed reaches alert levels, measures for avoiding dangerous situations should be taken; these include increasing anchor-holding power by paying out more cable or by taking refuge offshore with the anchor hove up.

Swing coeffcient	Av. wind speed (m/sec)	Max. wind speed (m/sec)
n=3	16.9	23.6
n=4	14.6	20.5
n=5 (PCC)	13.1	18.3
n=6	11.9	16.7

Gust factor: 1.4

Table 6-5 Dangerous wind speed of dragging anchor

6. Safe measures for preventing dragging anchor

Measures for avoiding dragging anchor refer to the means by which to control a ship's swing motion as indicated in Section 3.1 of Chapter 3, while a full length of cable is paid out to increase an anchor's holding power. In this section, these measures are shown with brief explanations and illustrations.

(a) Swing-check anchor

A swing-check anchor is used together with another anchor lowered to around one-and-half depths of water on its cable. This method can reduce the magnitude of swing motion by about 50 percent.

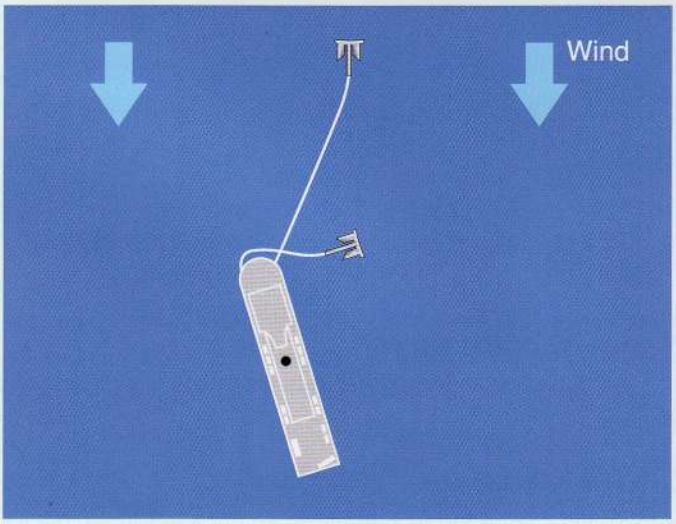


Fig.6-23 Swing-check anchor

(b) Two-anchor mooring

In strong wind conditions, swing motion can also be controlled by mooring to two anchors instead of riding to a single anchor, a measure that reinforces holding power. The open angle between the anchors should be greater than 60 degrees. Two-anchor mooring is effective when there is little change in wind direction, but abrupt directional change in wind direction as in a typhoon may put the ship at risk of fouling its anchor.

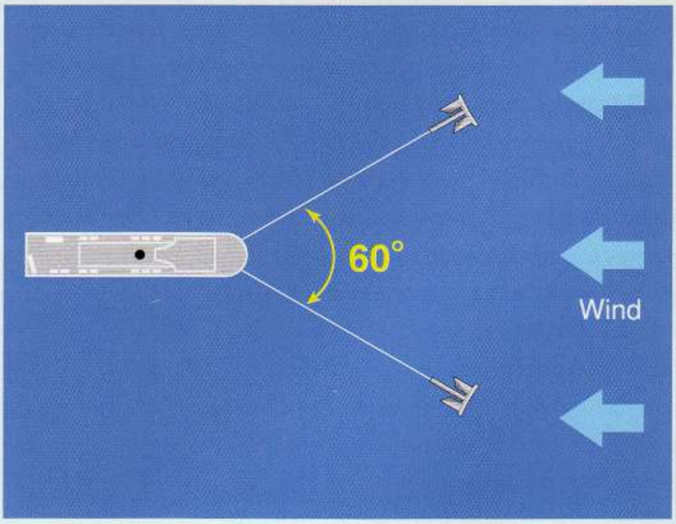


Fig.6-24 Two-anchor mooring

(c) Adjusting ship's trim-by-the-head

Trimming-by-the-head, a measure that shifts the center of gravity forward as far as possible, is another means for reducing the risk of anchor dragging.

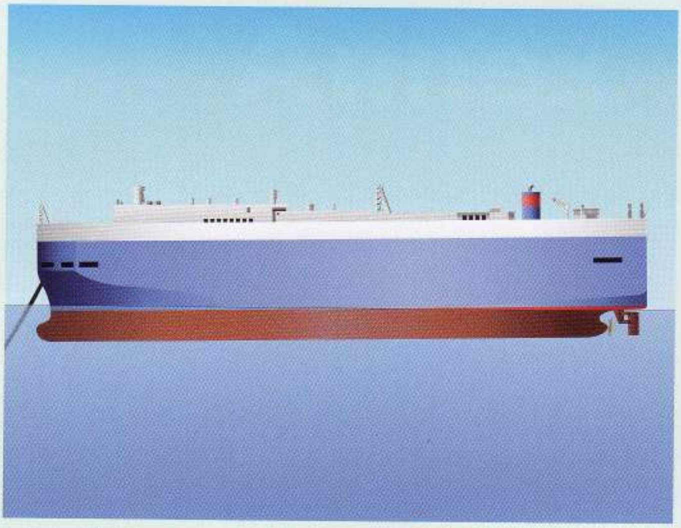


Fig.6-25 Trimming-by-the-head

(d) Using bow thruster

Use of a bow thruster can reduce swing motion considerably; the bow thruster is used to match the ship's heading with wind direction as much as possible.

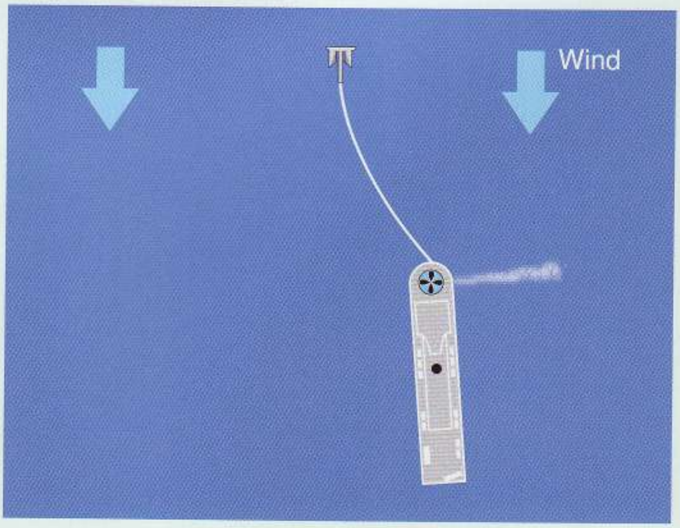


Fig.6-26 Using bow thruster

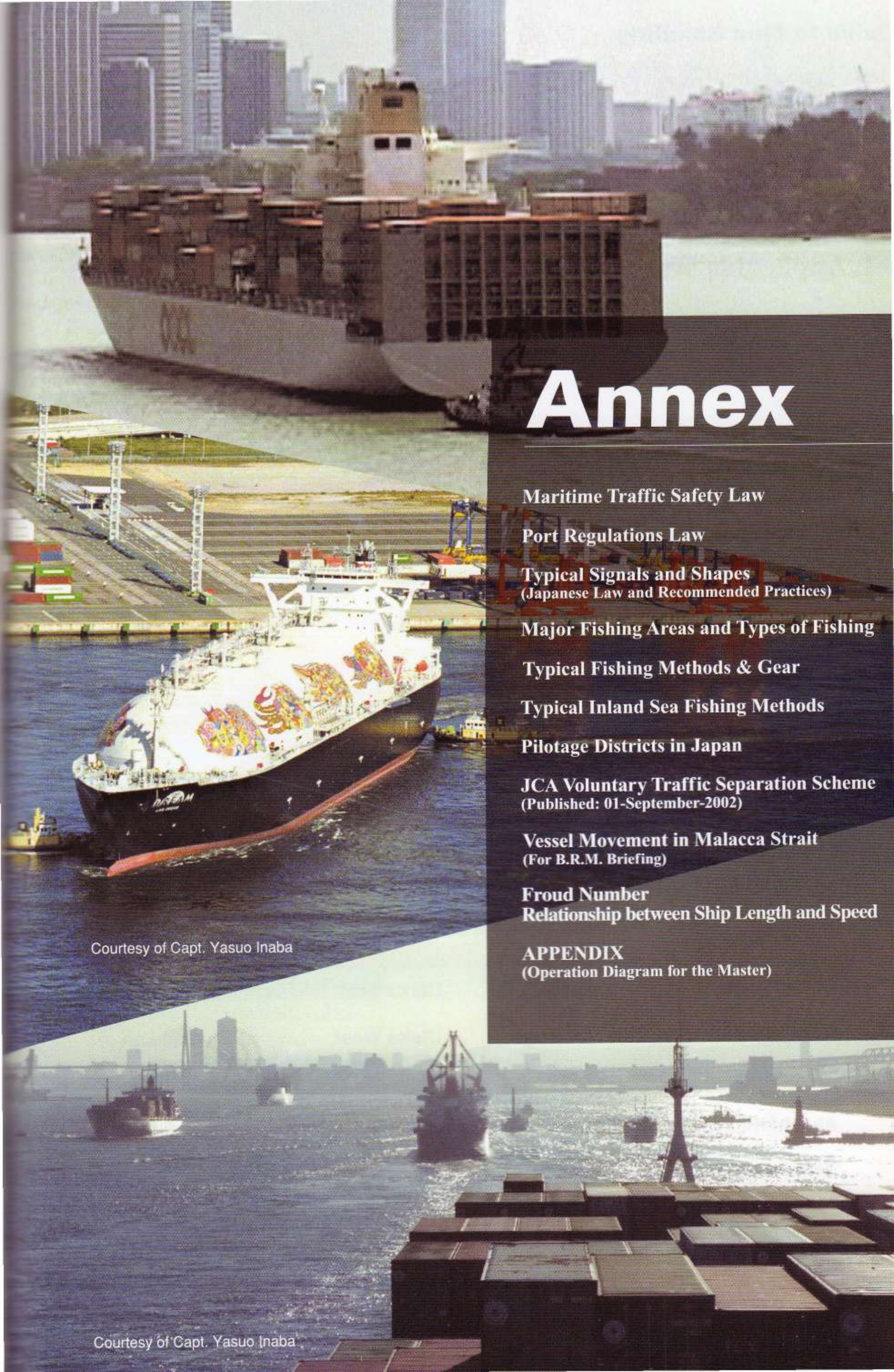
Summary for Maneuverability of Pure Car Carriers (PCCs)

Because the modern Pure Car Carrier (PCC) has the disproportionately large above-water hull and superstructure compared to its underwater hull, wind force has a disproportionate impact on the ship, leaving it in danger of losing maneuverability under its own power and equipment.

When such a ship is navigating stormy seas, ship operators should understand the limits on maneuverability caused by the wind. It is also important that avoidance of danger be undertaken at the earliest possible moment.

This is especially important when a ship is reducing speed to enter or leave port, when the effect of the wind is magnified.

Depending on the situation, the ship operator is requested to place a priority on safe operation of the ship, such as requesting tug assistance if necessary.



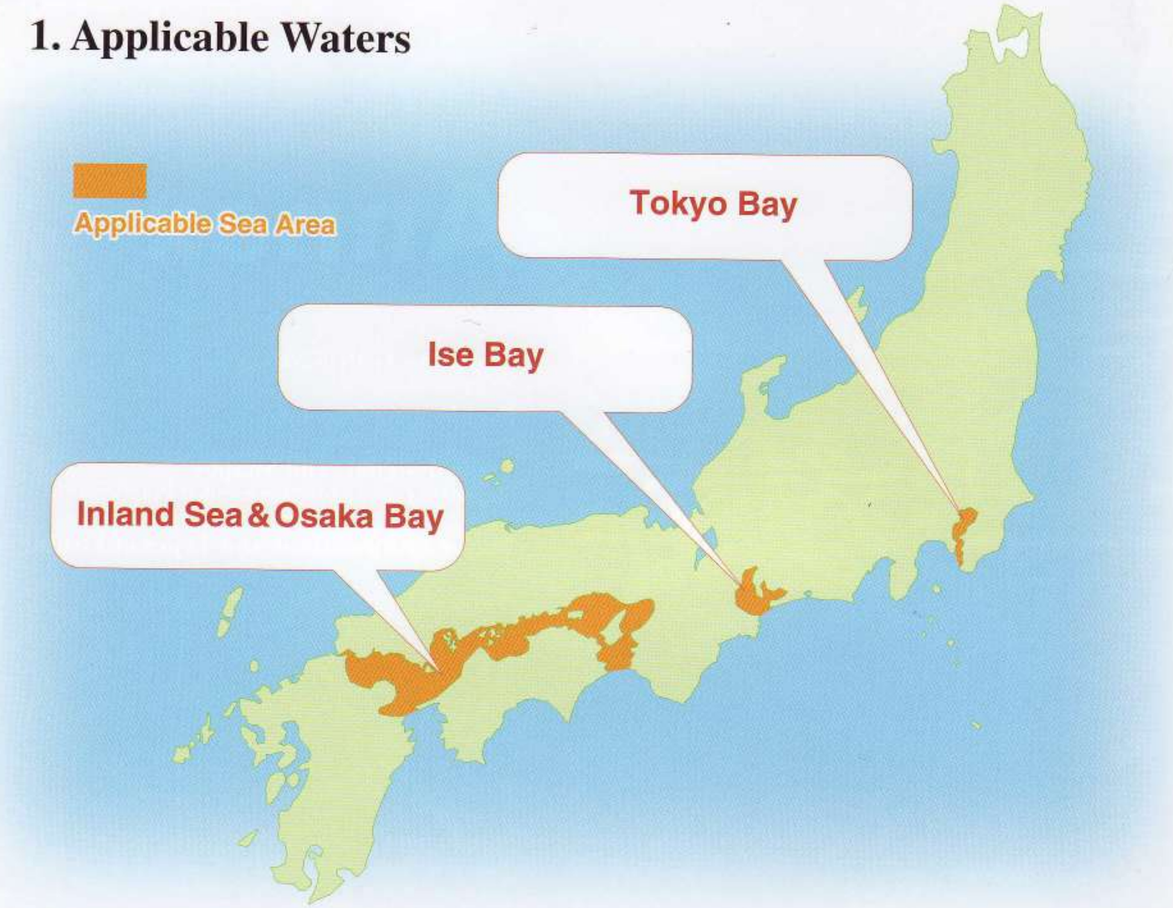
Annex

Courtesy of Capt. Yasuo Inaba

Courtesy of Capt. Yasuo Inaba

Maritime Traffic Safety Law

1. Applicable Waters



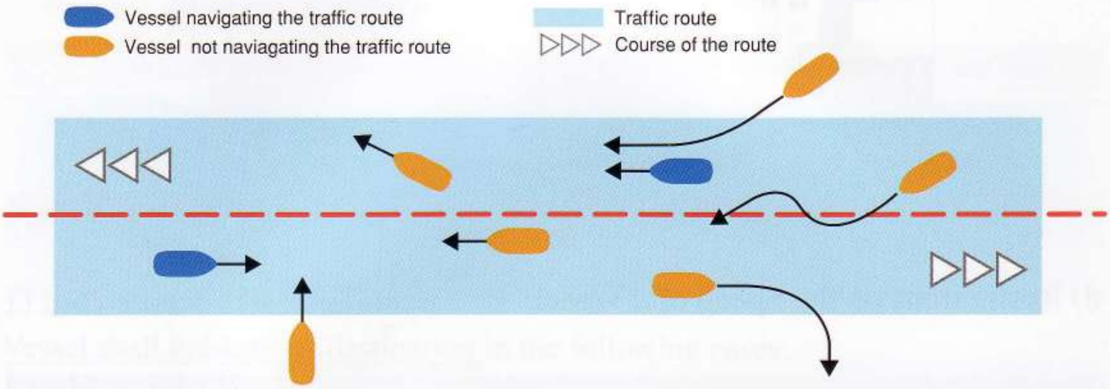
2. Traffic route

Traffic route	Location	Traffic route	Location
Uraga Suido	Tokyo Bay	**Utaka East**	Inland Sea
Nakanose	Tokyo Bay	**Utaka West**	Inland Sea
Irago Suido	Ise Bay	**Mizushima**	Inland Sea
Akashi Kaikyo	Inland Sea	**Bisan Seto North**	Inland Sea
Bisan Seto East	Inland Sea	**Bisan Seto South**	Inland Sea
		Kurushima Kaikyo	Inland Sea

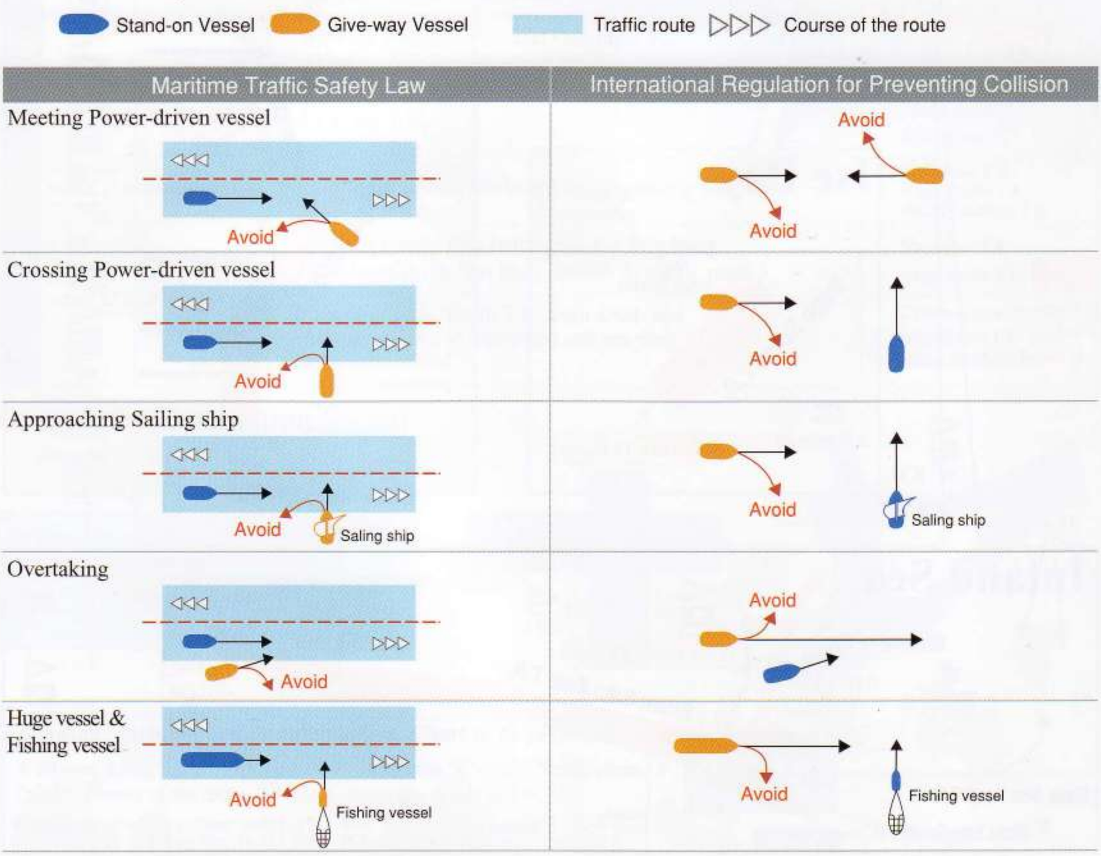
3. Modes of Navigation

❶ General Steering and Sailing Rules

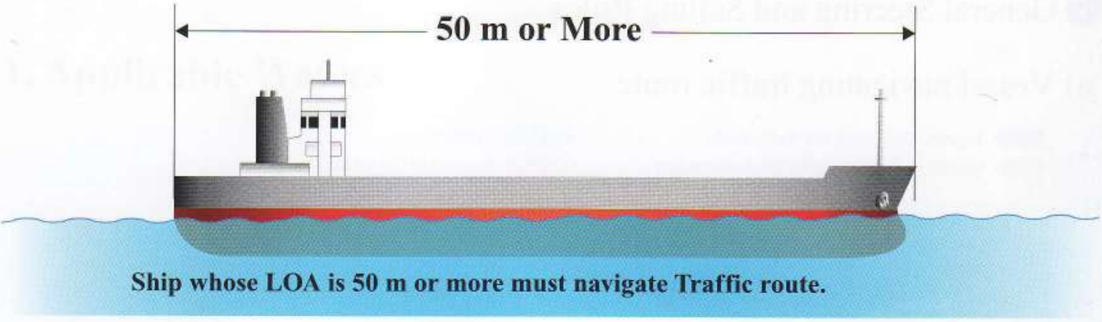
a) Vessel navigating traffic route



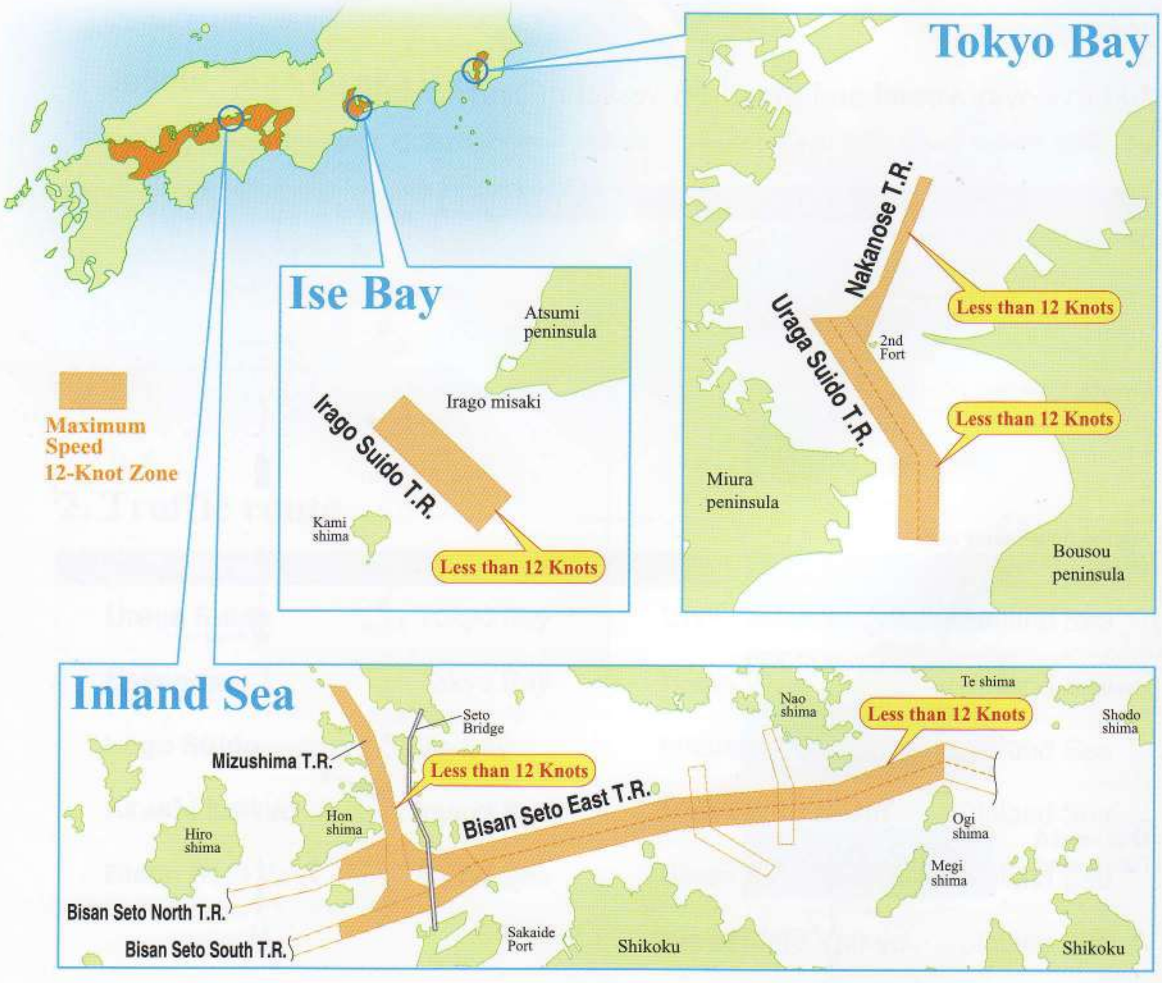
b) Give-way vessel and Stand-on vessel in Traffic route



c) Obligation to Naviagation Traffic Routes



d) Restrictions on the Speed of a Vessel



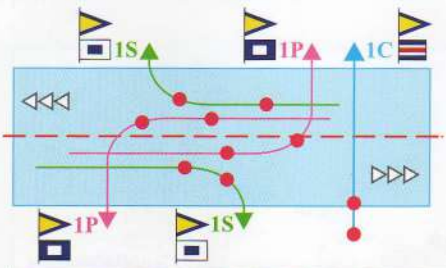
e) Signalling when Overtaking Another Vessel

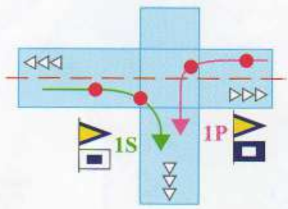
f) Indication of Destination

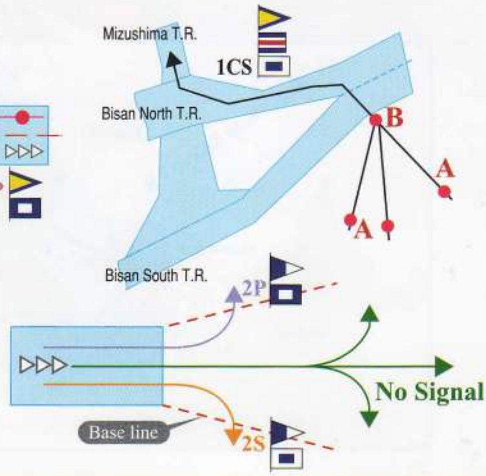
Vessel shall indicate its destination in the following cases:

	Day	Night	Case	Applicable Area
1S			Altering course to Starboard and clearing T.R. Altering course to Starboard and entering another T.R.	Tokyo Bay Ise Bay Inland Sea
1P			Altering course to Port and clearing T.R. Altering course to Port and entering another T.R.	Uraga T.R. Inland Sea
1C			Crossing T.R.	Uraga Suido T.R. Inland Sea
2S			Altering course to Starboard before passing Exit buoy.	Nakanose T.R. Irago Suido T.R. Akashi Kaikyo T.R.
2P			Altering course Port before passing Exit buoy. (Exit buoy is the first buoy outside of traffic route.)	Nakanose T.R. Irago Suido T.R.
1CS		A B	Crossing Bisan South T.R. from south and Altering course to Starboard and entering Mizushima T.R.	Crossing zone Mizushima T.R. and Bisan South/North

Criteria for Destination Signal





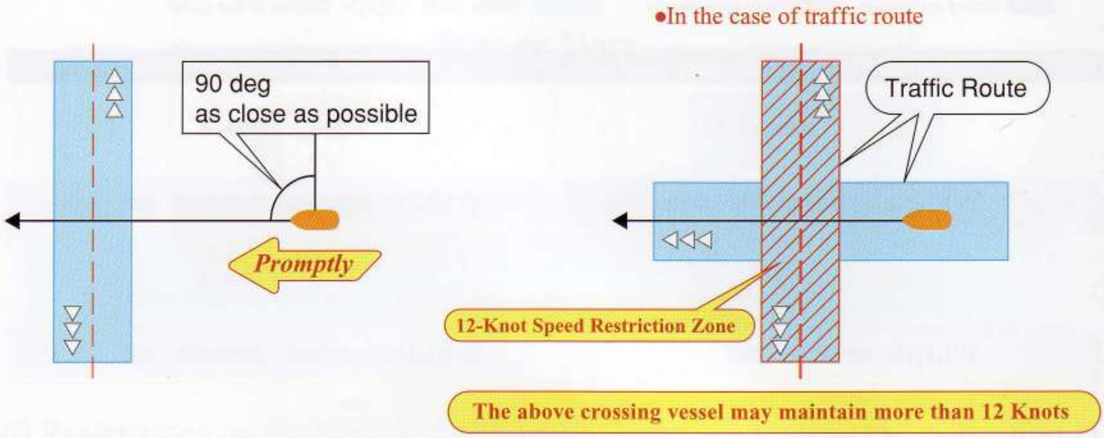


Following Maritime Traffic Information Chart to be prepared.

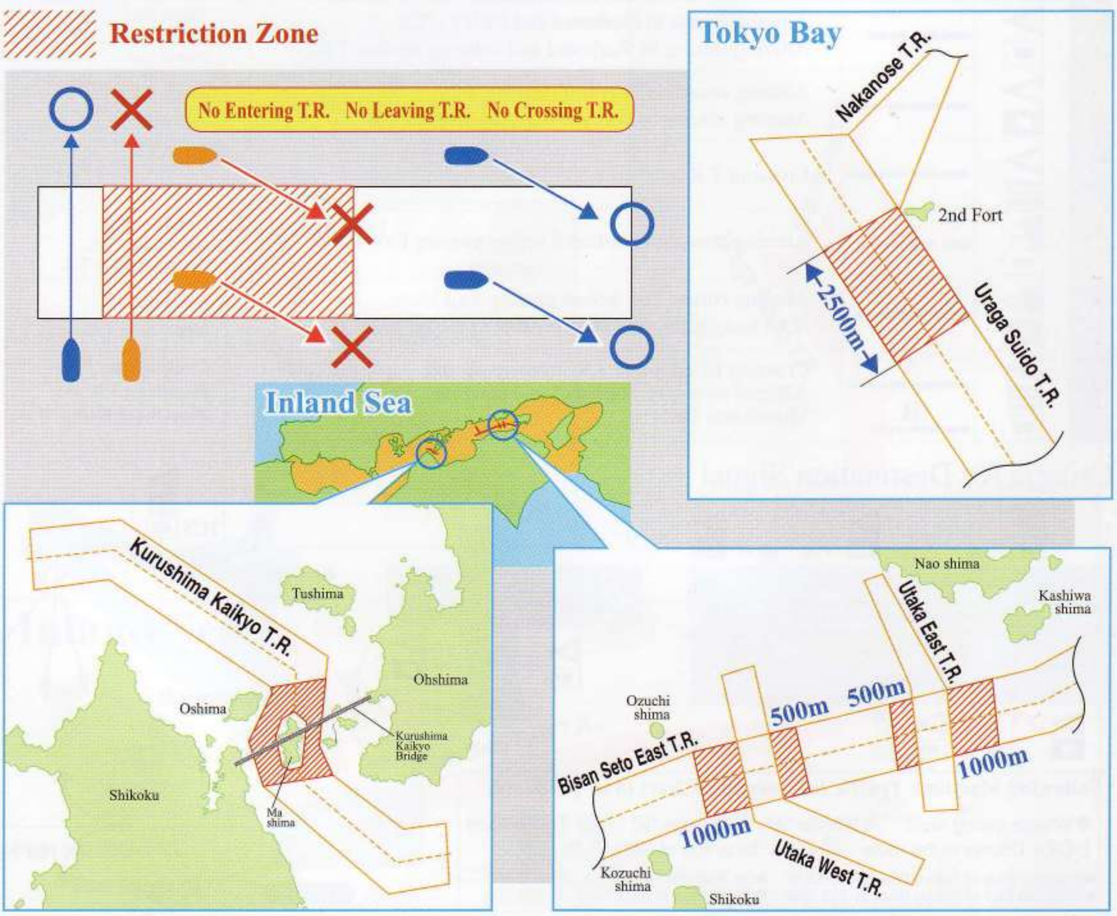
● Whistle during night. **A** Whistle "A" **B** Whistle "B" Traffic route
▷▷▷ Course of the route - - - - Base line at exit of T.R.

- Southern Part of Tokyo Wan H-301-BW
- Northern Part of Tokyo Wan H-302-BW
- Ise Wan (Ise bay) H-302-BW
- Osaka Wan (Osaka bay) H-305-BW

g) Modes of Crossing Taffic Routes



h) Restriction on Entering or Leaving or Crossing Traffic Route



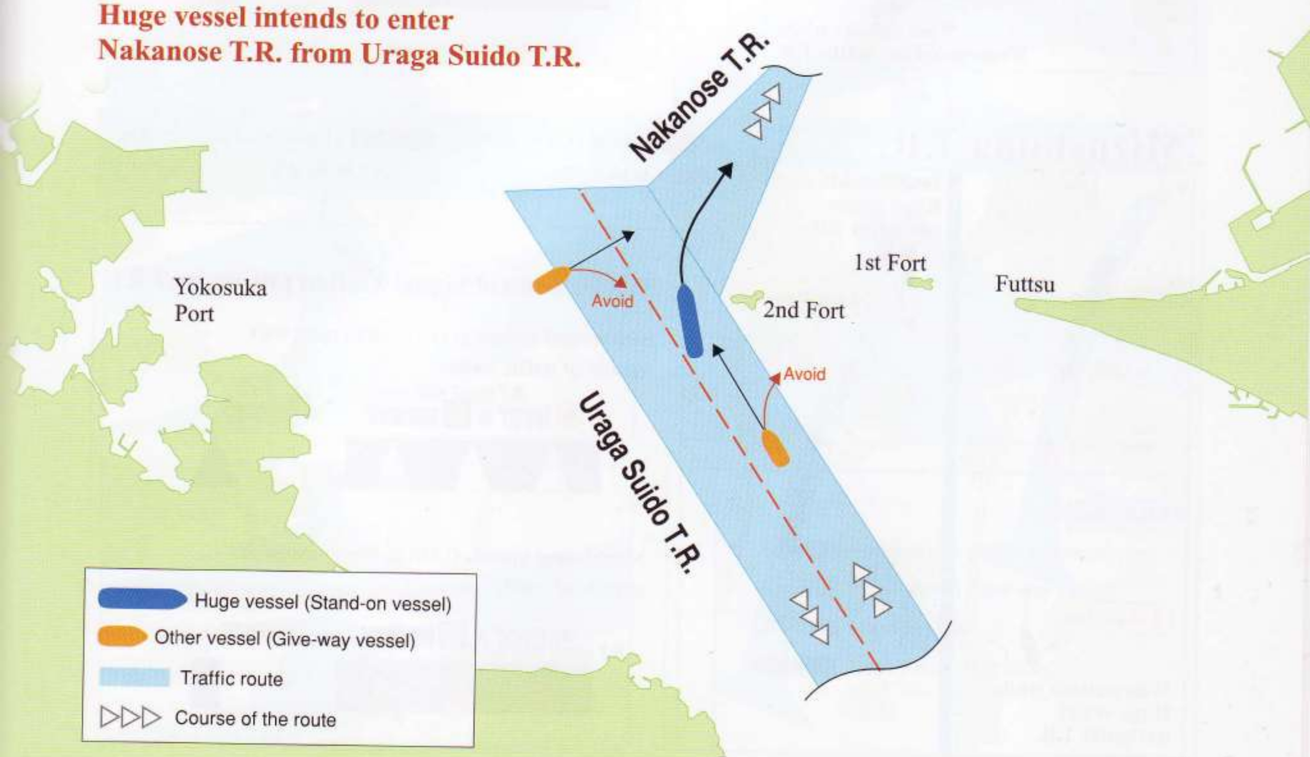
i) Prohibition of Anchorage

No vessel allowed to anchor within the traffic route

2 Special Regulations for Specific Traffic Route

a) Huge vessel vs Other vessel

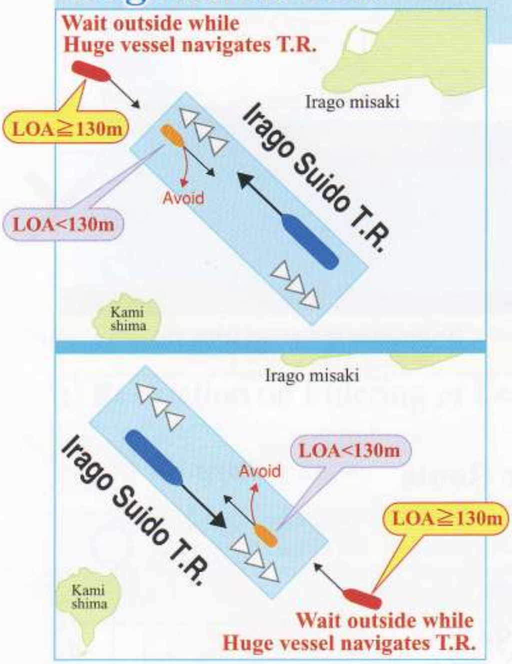
Huge vessel intends to enter Nakanose T.R. from Uraga Suido T.R.



b) Huge vessel VS vessel whose LOA is 130m or more in Irago Suido T.R.
Huge vessel VS vessel whose LOA is 70m or more in Mizushima T.R.

Irago Suido T.R.

130m ≦ LOA < 200m
Huge vesse (LOA≧200m)
LOA < 130m



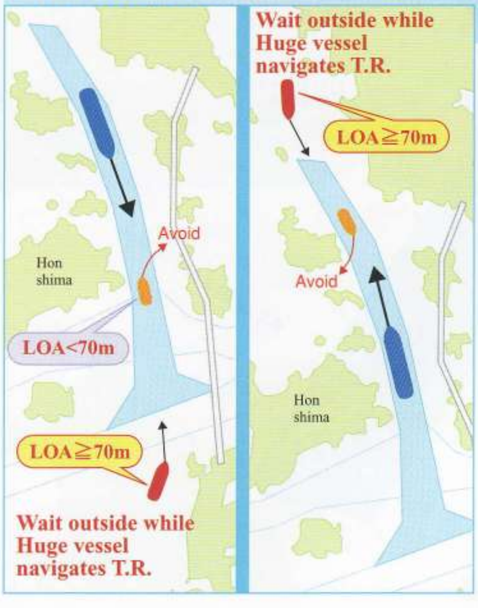
Traffic control Signal Station (Irago Suido)

SE bound vessels (LOA≧30m) must wait outside of traffic route.

NW bound vessels (LOA≦130m) must wait outside of traffic route.

Mizushima T.R.

70M ≦ LOA < 200m
Huge vessel (LOA≧200m)
LOA < 70m

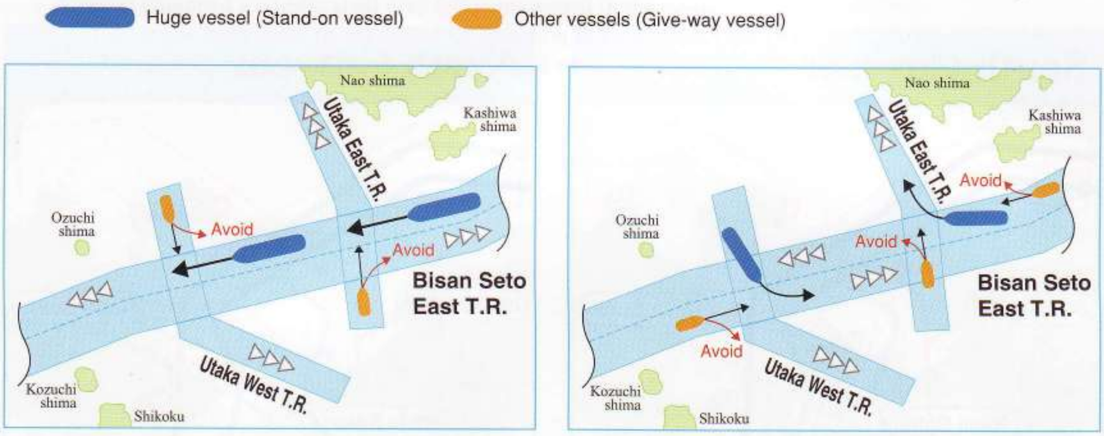


Traffic control Signal Station (MizushimaT.R.)

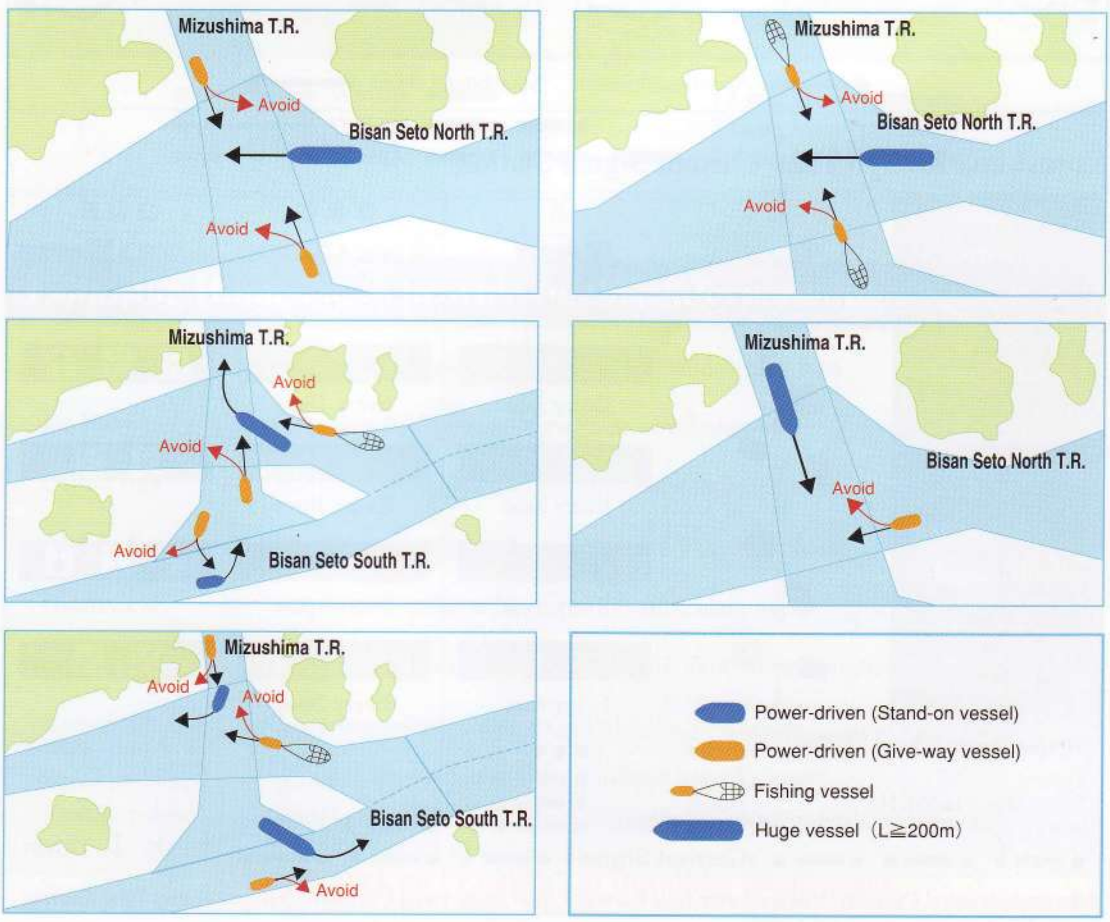
Southbound vessels (LOA≧70m) must wait outside of traffic route.

Northbound vessels (LOA≦70m) must wait outside of traffic route.

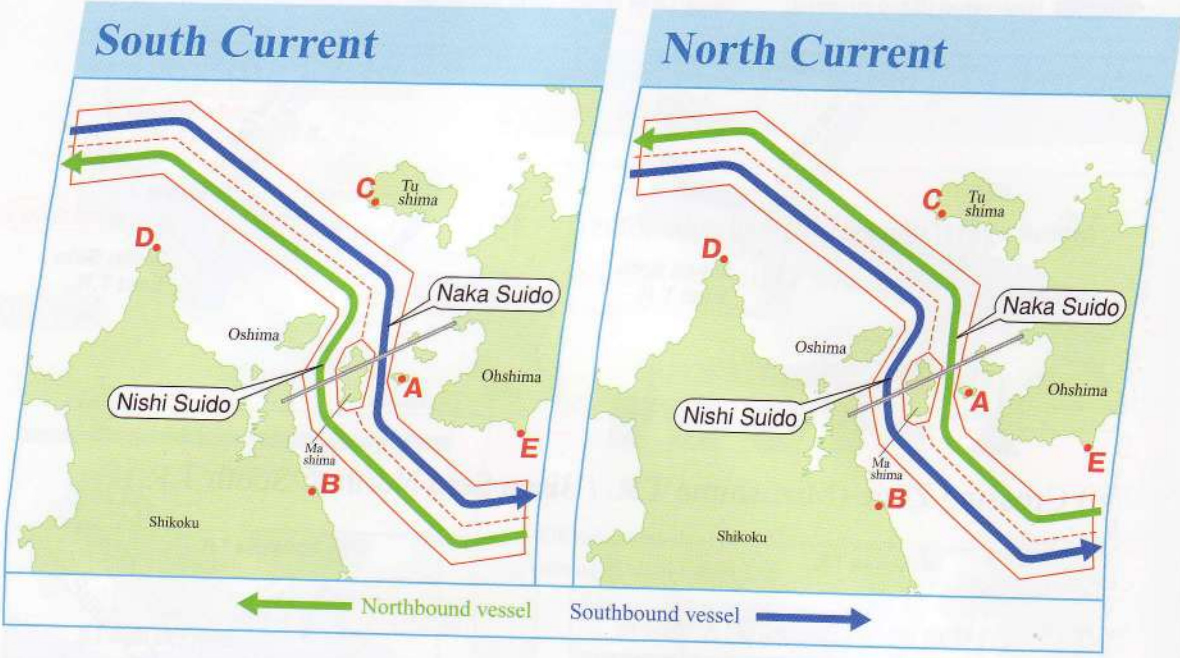
c) Crossing Zone (Bisan Seto East & Utaka East & West T.R.)



d) Crossing Zone (Mizushima T.R. /Bisan Seto North & South T.R.)



e) Kurushima Kaikyo Traffic Route



Kurushima Kaikyo Tidal Current Signal Station

Location	A	A	B & C	D & E
Service	DAY	NIGHT	DAY & NIGHT	DAY & NIGHT
Signal Station	Nakatoshima	Nakatoshima	Ohama Tsushima	Osumi-no Hana Nagase-no Hana
South Current		Every 3sec	Every 10sec	S 3 ↑
End of South Current		Every 8sec	Every 20sec	S ×
North Current		Every 3sec	Every 10sec	N 2 ↓
End of North Current		Every 8sec	Every 20sec	N ×

Ohama Radio Signal Station

Type : A2
Frequency : 1665KHz
Power : 25W

South : •••
Last of South : •−•• •••
North : •−•
Last of North : •−•• •−•

•−• •−• •−• +Current Signal+ •−• •−• •−•

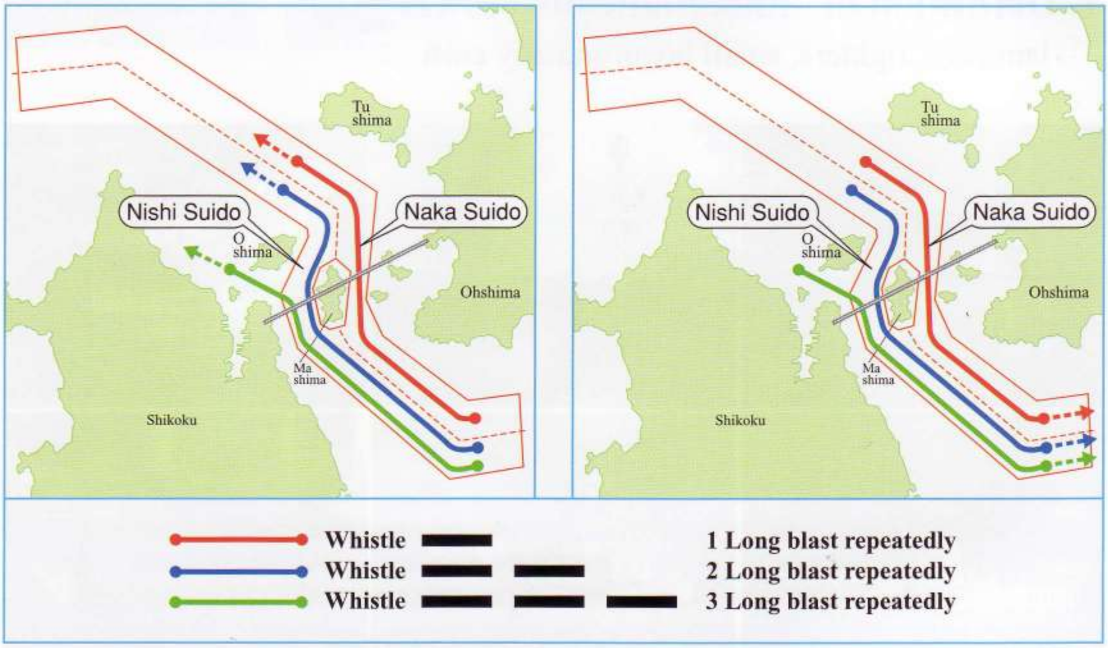
N : North Current
S : South Current
Number : Knot
↑ : Up ↓ : Down

Naka Suido (Central Channel) = Navigate with Tidal Current / Nishi Suido (West Channel) = Navigate against Tidal Current

f) Kurushima Traffic Route Whistle Signal at Direction Change of Tidal Current

A vessel equipped a whistle shall give following signal in the event

1) Notice has been given by the signal for direction change of tidal current
2) Direction change of tidal current is anticipated while passing Naka Suido or Nishi Suido



Following Home Pages provide further information

Tokyo Bay	http//www6.kaiho.mlit.go.jp/tokyowan//index.htm
Ise Bay	http//www6.kaiho.mlit.go.jp/isewan/index.htm
Osaka Bay	http//www6.kaiho.mlit.go.jp/osakawan/index.htm
Akashi Kaikyo	http//www.kaiho.mlit.go.jp/06kanku/kouanweb/english/akashi.gif
Bisan Seto	http//www.kaiho.mlit.go.jp/06kanku/kouanweb/english/bisan.gif
Inland Sea	http//www.kaiho.mlit.go.jp/06kanku/kouanweb/english/e-kouro.jpg
Kurushima Srait	http//www.kaiho.mlit.go.jp/06kanku/kouanweb/english/kurushima.gif
Kanman Strait	http//www6.kaiho.mlit.go.jp/kanmon/index.htm http//www.kaiho.mlit.go.jp/06kanku/kouanweb/english/kanmon.gif

Please click on "English" at the above home pages.

Port Regulations Law

1. Definition of "miscellaneous vessels"

- launches, lighters, small boats and any craft.

Miscellaneous vessels should avoid those other than miscellaneous vessels when in port.

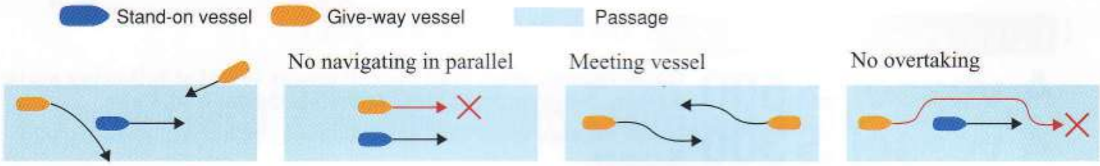
2. Restriction on Entry at Night

- Most of ports do not allow entry after sunset and before sunrise.

3. Obligation of Passage

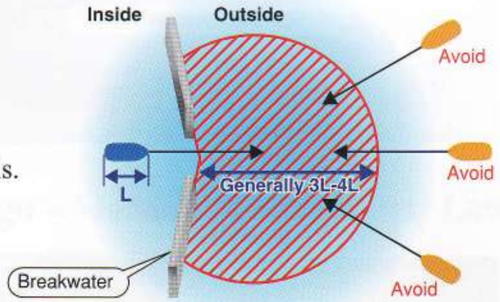
- A vessel other than miscellaneous vessels must navigate the passage except in an emergency.

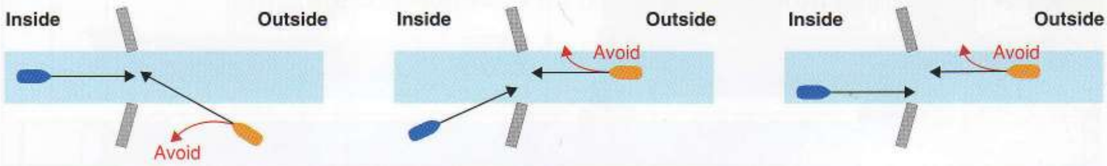
4. Rules for Navigation in Passage



5. Vicinity of Port Entrance

- Entering vessel shall avoid clearing vessel.
- This regulation is applied to power-driven vessels.
- Entering vessel shall remain more than 3-4 times LOA of clearing vessel.





Note

International Regulation for Preventing Collision at sea is applied in following case:

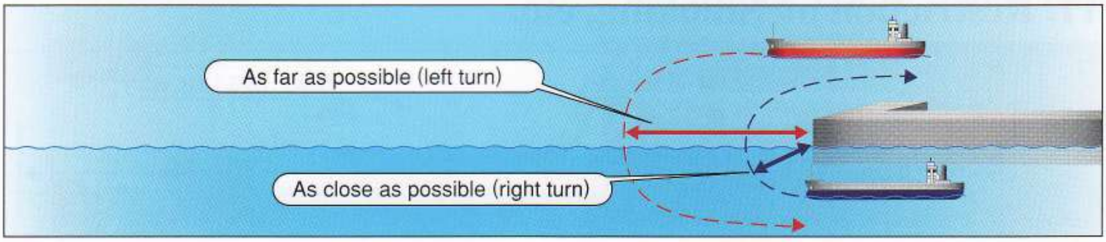
*1: This is not an entering vessel.

*2: This is not a clearing vessel.

6. Safe Speed

Area : Within a port / near boundary of port.
Reduce speed. Do not be a hazard to other vessels.

7. At the end of breakwater, quay, or any other structure or vessel



8. Small vessel (Keihin, Nagoya, Yokkaichi, Osaka, Kobe, Kanmon only)

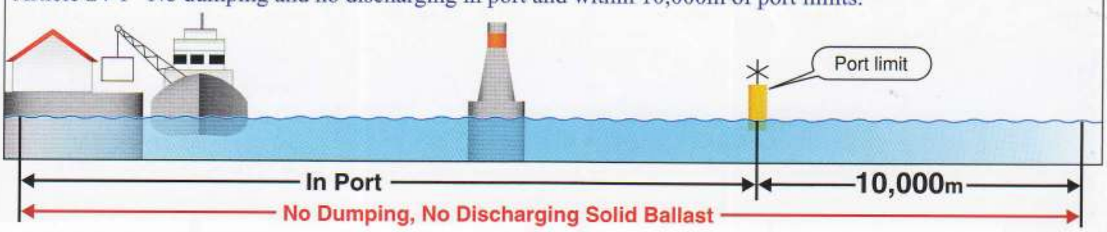
Definition of "small vessels"

A vessel ≦ 500 Gross tonnage other than miscellaneous vessel at following ports: **Keihin, Nagoya, Yokkaichi (partly), Osaka and Kobe.**

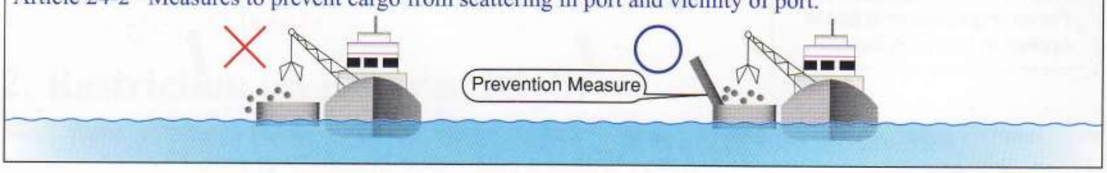
A vessel ≦ 300 Gross tonnage other than miscellaneous vessel at following port: **Kanmon.**

9. Maintenance of Channel

Article 24-1 No dumping and no discharging in port and within 10,000m of port limits.



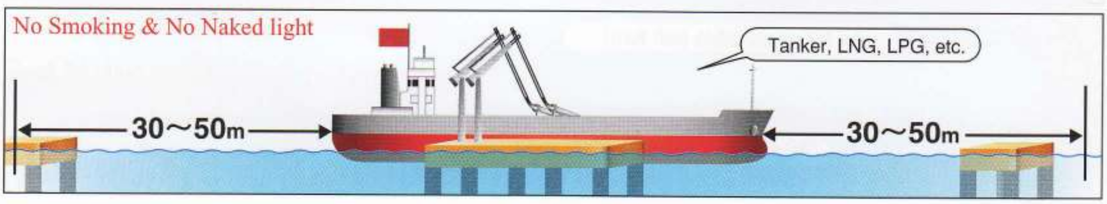
Article 24-2 Measures to prevent cargo from scattering in port and vicinity of port.



10. Fire Alarm

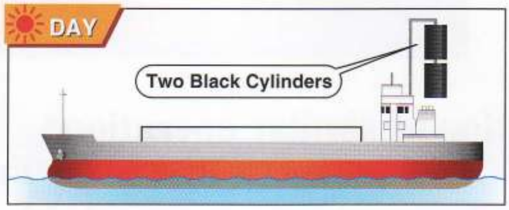
- In case of fire in port, Sound 5 (five) prolonged blasts except when underway.

11. Restriction on Smoking, etc.

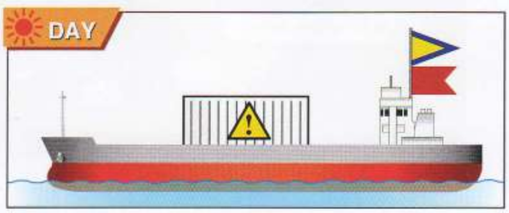


Typical Signals and Shapes
(Japanese Law and Recommended Practices)

1. Huge Vessel Length≧200m –Maritime Traffic Safety Law

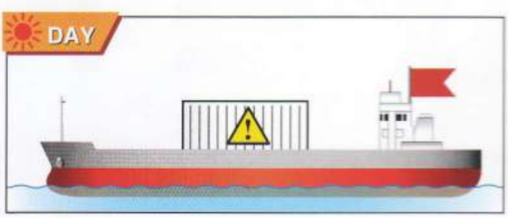


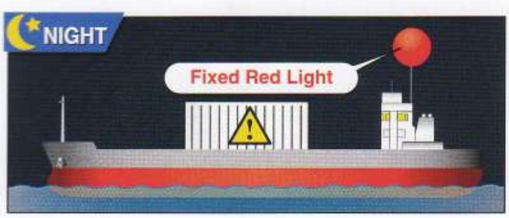
2. Vessel carrying Dangerous Cargo –Maritime Traffic Safety Law



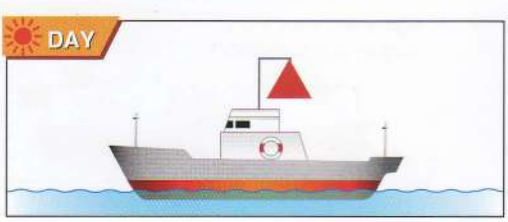
Note A vessel which exhibits the above light or shape in port does not need to exhibit signal and shape according to "Regulations for the Carriage and Storage of Dangerous Goods in Ships"

3. Vessel carrying Dangerous Cargo in Port –Regulations for the Carriage and Storage of Dangerous Goods in Ships

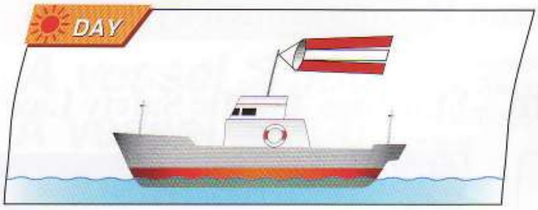




4. Vessel employed for performing Emergency work –Maritime Traffic Safety Law

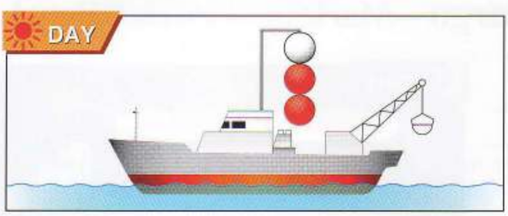


5. Escort Boat –*Maritime Traffic Safety Law*



6. Vessel engaging in construction or similar operation* –Maritime Traffic Safety Law

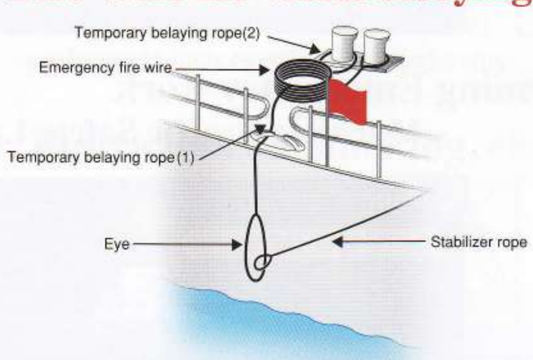
*such as dredging, underwater operation and mine clearance operation.



Special Signals and Shapes (Reference)

Deep Draft Vessel	Quarantine	Singapore Immigration

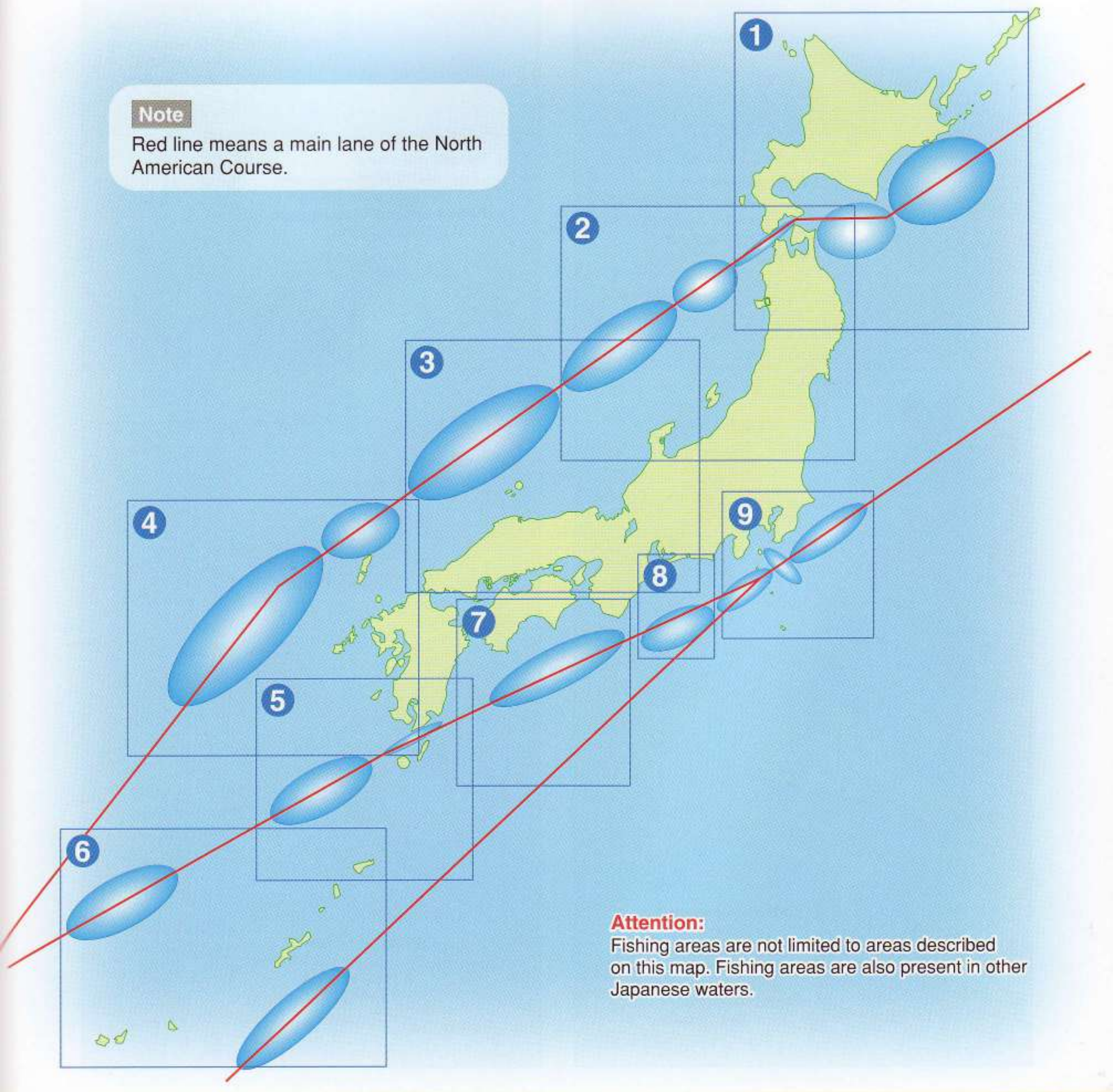
Fire Wire for vessel carrying Dangerous Cargo



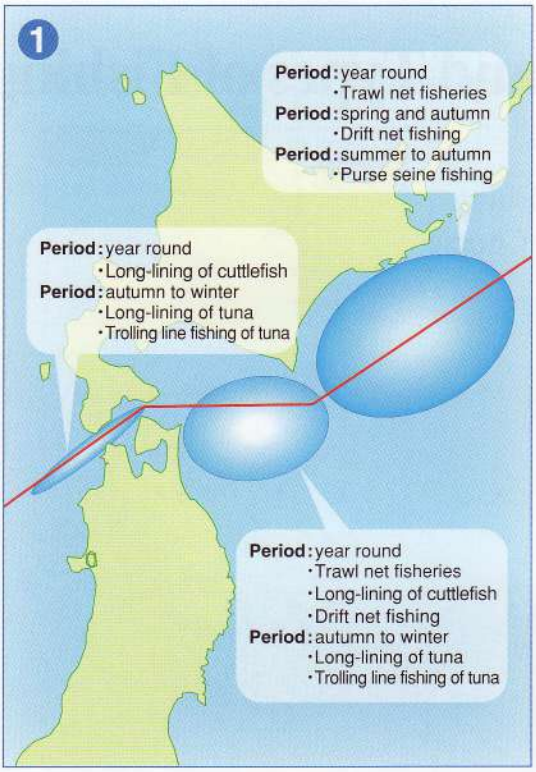
•Dangerous Cargo Carrier

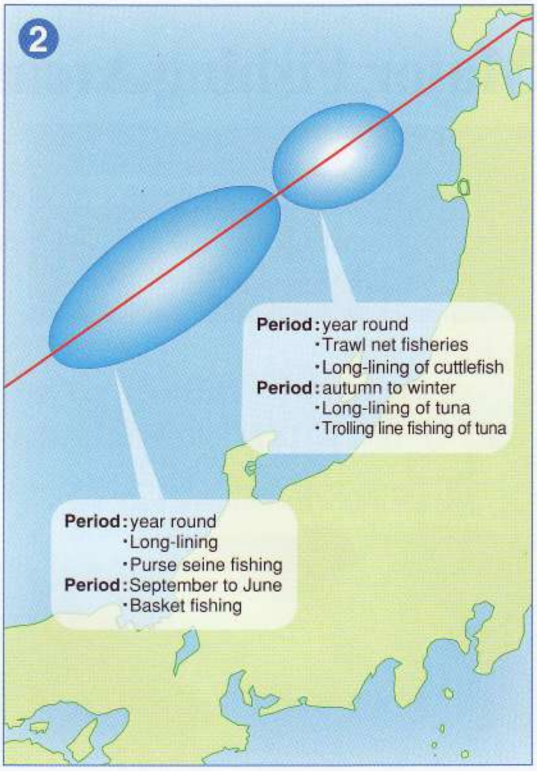
Major Fishing Areas and Types of Fishing

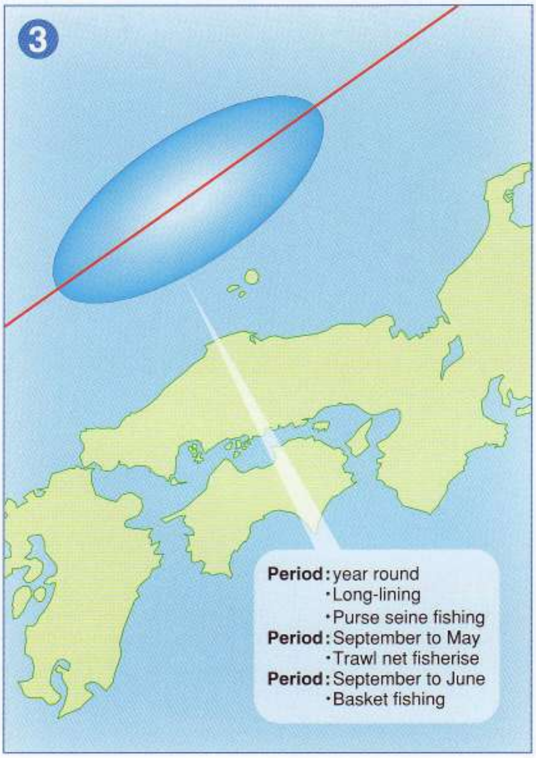
The major fishing areas and type of fishing in the vicinity of the North American Course around Japanese waters.

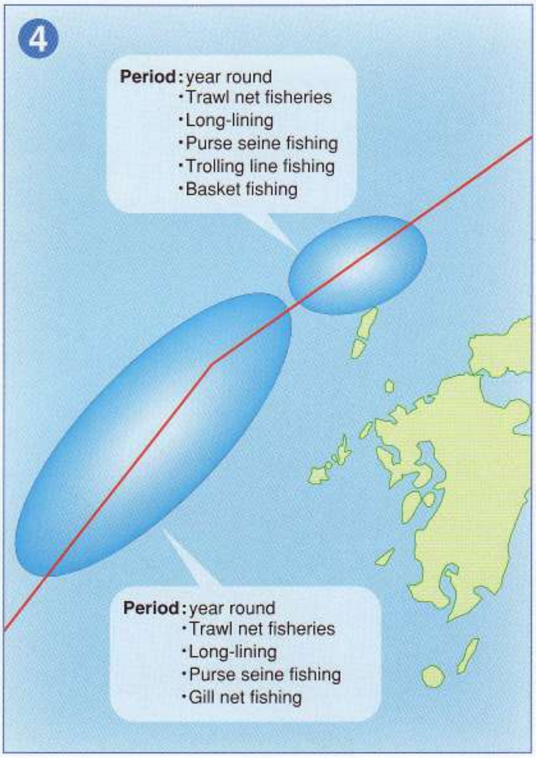


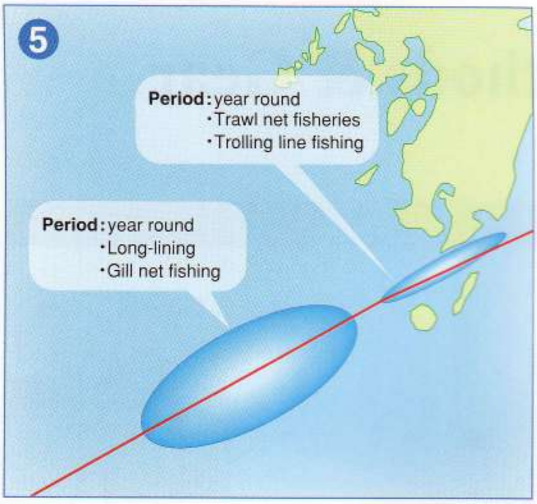
Annex

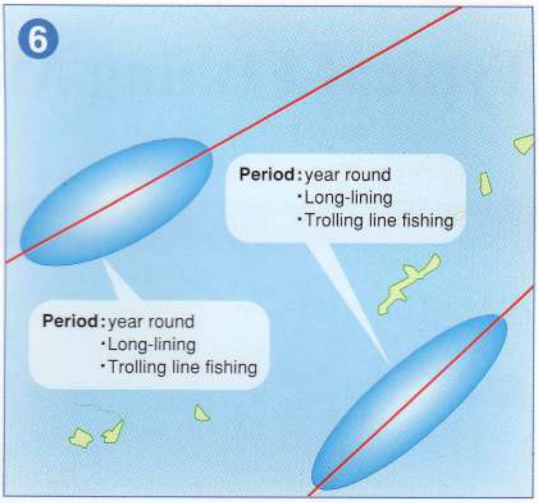

1
Period: year round
·Trawl net fisheries
Period: spring and autumn
·Drift net fishing
Period: summer to autumn
·Purse seine fishing
Period: year round
·Long-lining of cuttlefish
Period: autumn to winter
·Long-lining of tuna
·Trolling line fishing of tuna
Period: year round
·Trawl net fisheries
·Long-lining of cuttlefish
·Drift net fishing
Period: autumn to winter
·Long-lining of tuna
·Trolling line fishing of tuna

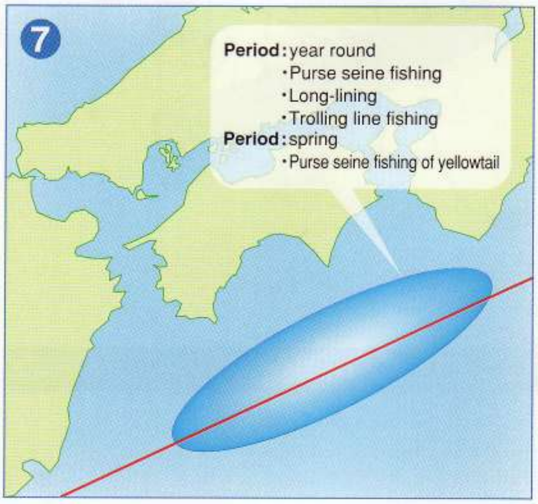

2
Period: year round
·Trawl net fisheries
·Long-lining of cuttlefish
Period: autumn to winter
·Long-lining of tuna
·Trolling line fishing of tuna
Period: year round
·Long-lining
·Purse seine fishing
Period: September to June
·Basket fishing

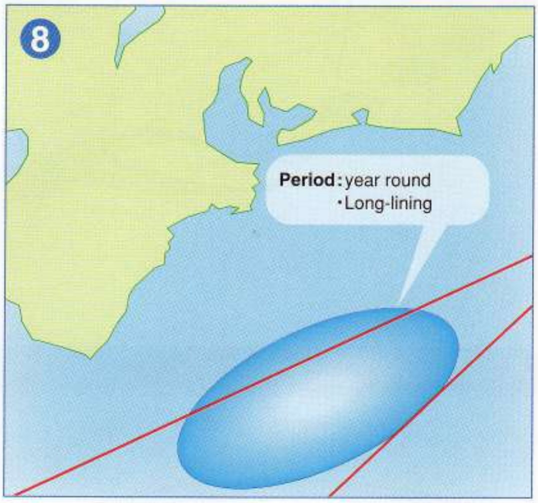

3
Period: year round
·Long-lining
·Purse seine fishing
Period: September to May
·Trawl net fisherise
Period: September to June
·Basket fishing

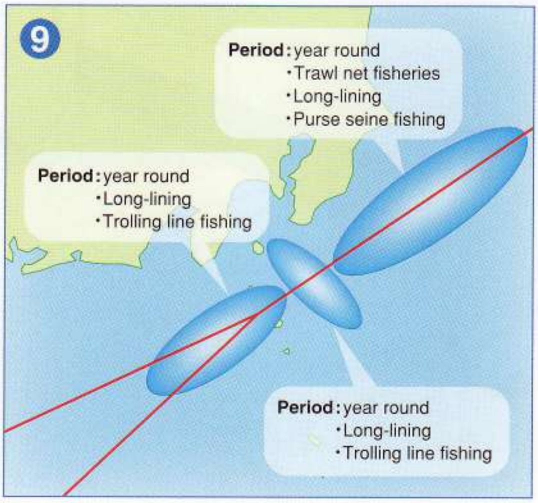

4
Period: year round
·Trawl net fisheries
·Long-lining
·Purse seine fishing
·Trolling line fishing
·Basket fishing
Period: year round
·Trawl net fisheries
·Long-lining
·Purse seine fishing
·Gill net fishing









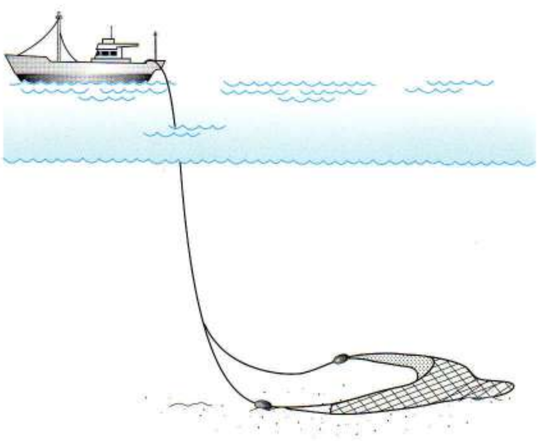


Attention:

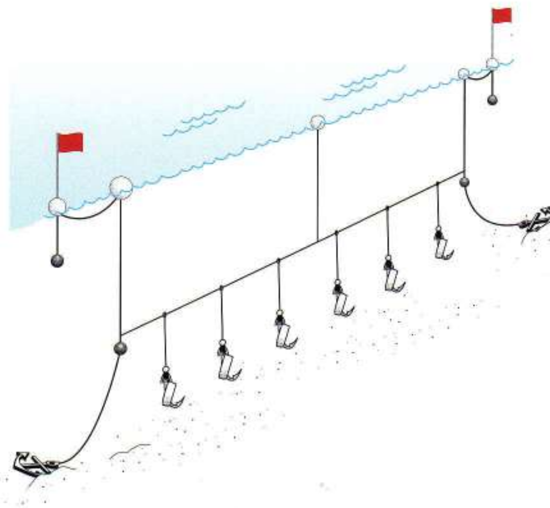
Fishing areas are not limited to areas described on this map. Fishing areas are also present in other Japanese waters.

Typical Fishing Methods & Gear

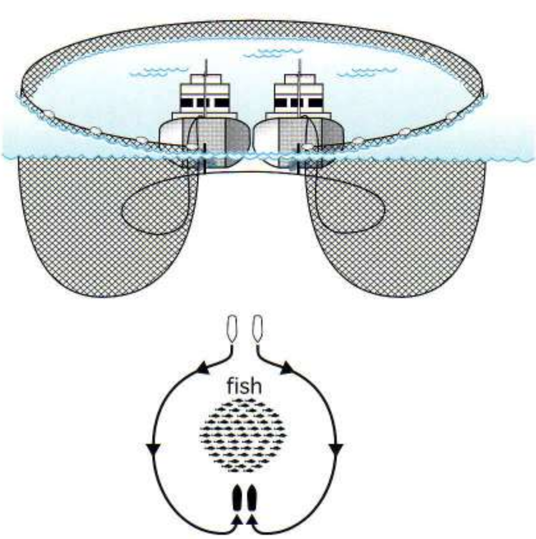
A. Trawl net fisheries —— 底曳網漁業



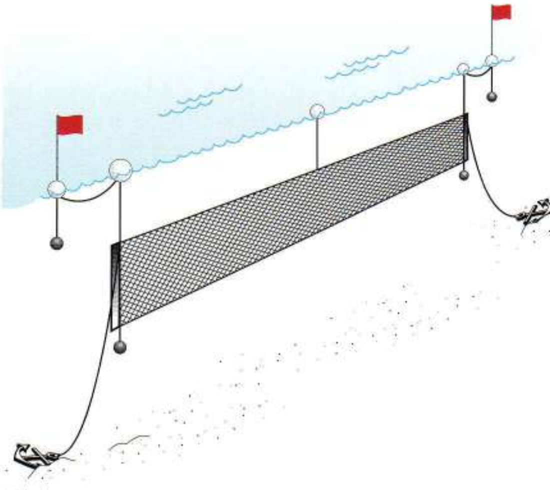
B. Long-lining —— はえ縄漁業



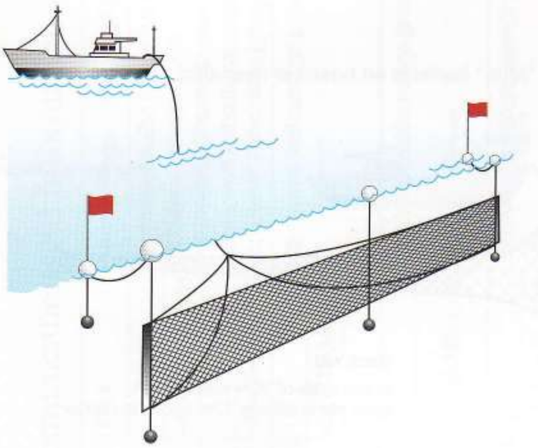
C. Purse seine fishing —— まき網漁



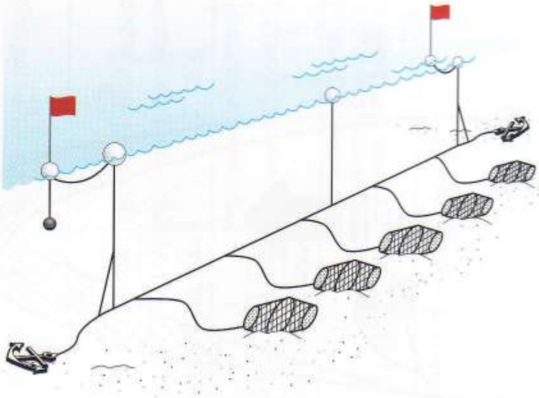
D. Gill net fishing —— さし網漁業



E. Drift net fishing —— 流し網漁業



F. Basket fishing —— かご漁業

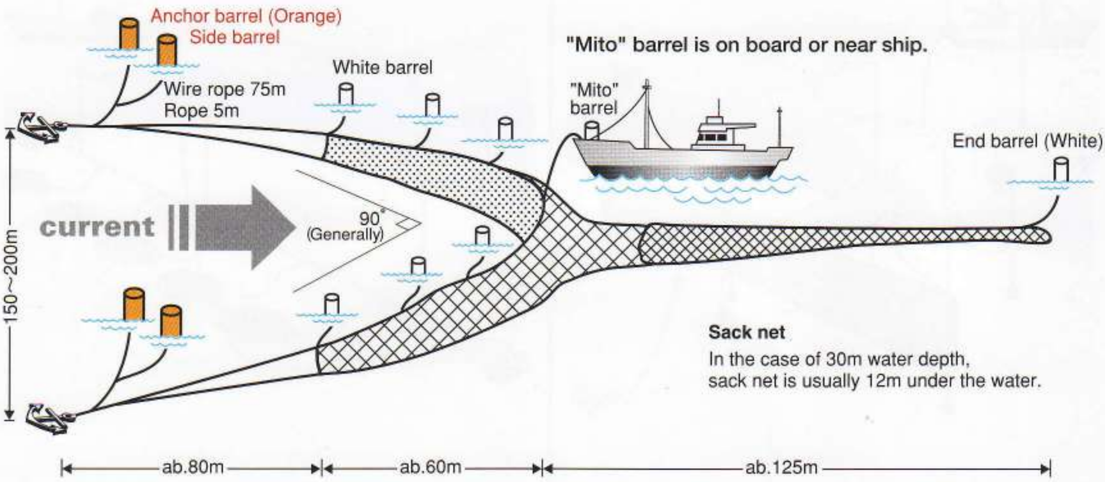


G. Trolling line fishing —— 曳縄漁業

Typical Inland Sea Fishing Methods

Komase Net こませ網

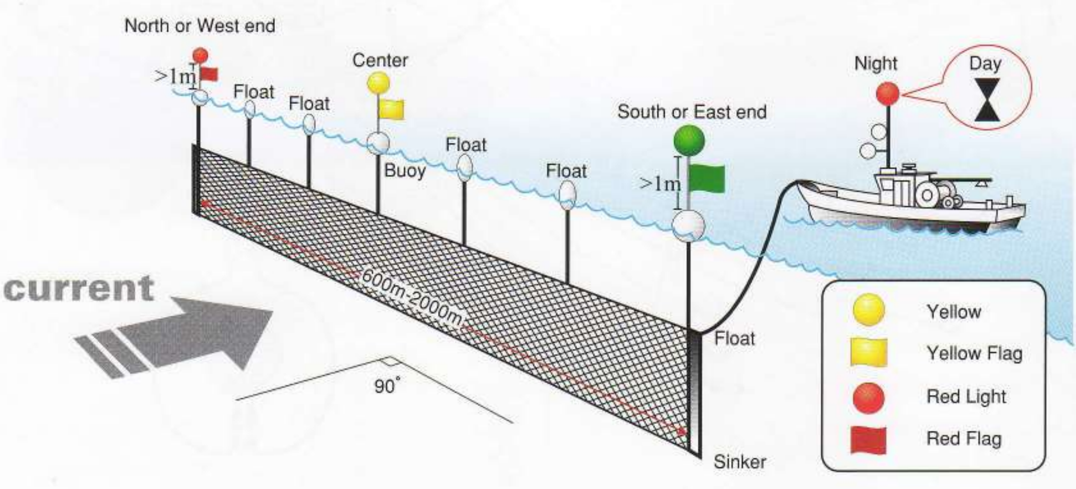
Fishing Season : January-November
Peak Season : February-August
Fishing Area : Bisan Seto East/North/South Traffic route and vicinity of the above routes.
Time of Fishing : From slack tide till next slack tide.



Drifting net for Spanish Mackerel さわら流し網

Fishing Season : Spring-Autumn
Peak Season : May & June
Fishing Area : Inland sea
Time of Fishing : ab.2 hours

Special Signal
Setting net : Yellow flashing light
Lifting net : White light
Swinging white light indicates safe side.

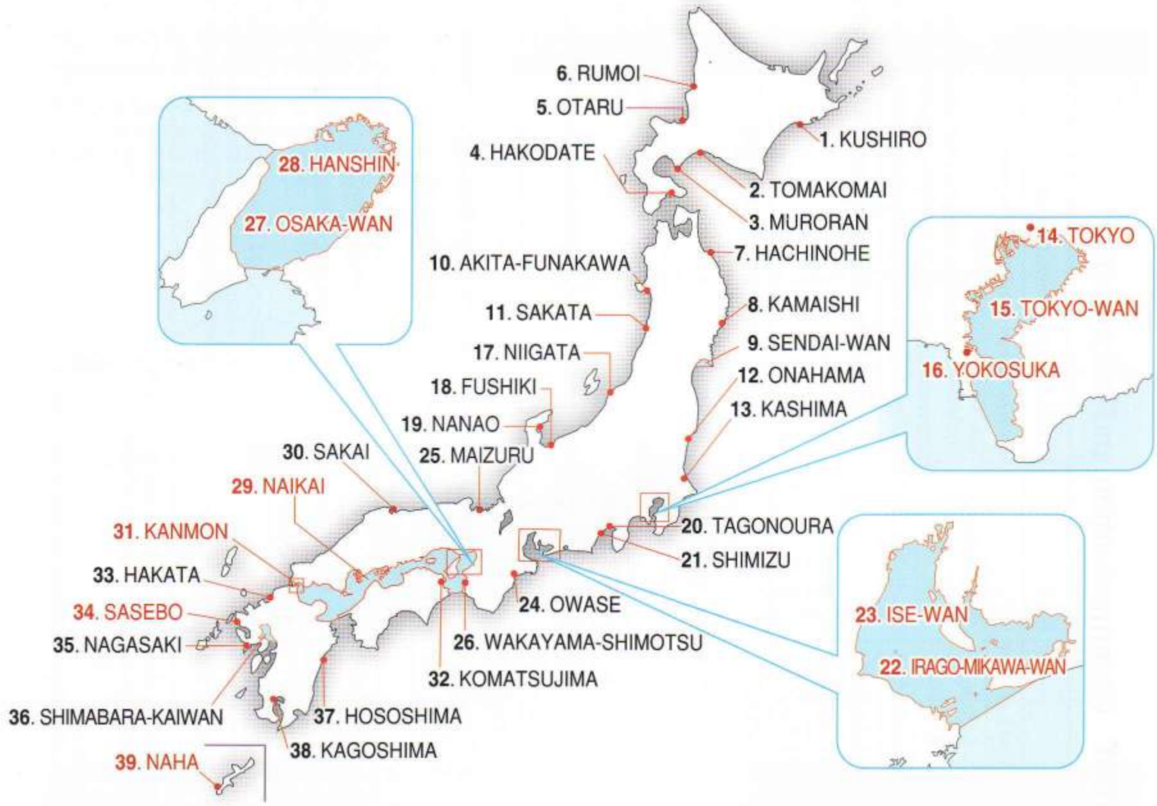


Traffic Advisory Service Center Communication and Information

	Call Sign			TEL	FAX	Home Page Information
Tokyo Bay	TOKYO MARTIS	Contact	VHF Ch.16/13/14/22	+81-46-843-8622~24		http://www6.kaiho.mlit.go.jp/tokyowan/
		Information Service	Traffic Control	+81-46-843-0621	+81-46-844-2055	http://www.toukaibou.or.jp/
			Restriction	+81-46-843-0621		http://www6.kaiho.mlit.go.jp/tokyowan/schedule/scheduleindex.htm http://www6.kaiho.mlit.go.jp/tokyowan/pullship/pullship.htm
			Weather	+81-46-844-4521	+81-46-844-2055	http://www6.kaiho.mlit.go.jp/tokyowan/weather-pc/weatherindex.htm
Ise Bay	ISEWAN MARTIS	Contact	VHF Ch.16/13/14/22	+81-531-34-2445~6		http://www6.kaiho.mlit.go.jp/isewan/leaflet/english/english.htm
		Information Service	General Weather	+81-531-34-2666	+81-531-34-2888	
				+81-531-34-2333		
Nagoya Port	NAGOYA HARBOR RADAR	Contact	VHF Ch.16/13/14/22	+81-52-398-0712		http://www6.kaiho.mlit.go.jp/nagoyako/
		Information Service	All Information	+81-52-398-0714	+81-52-398-1379	
Osaka Bay	OSAKA MARTIS	Contact	VHF Ch.16/14/22	+81-799-82-3030~1		http://www.kobe-kaibouken.or.jp/web/jap/recommen/osaka_Entrance.html
		Information Service	Traffic Control	+81-799-82-3043	+81-799-82-3046	
			Restriction	+81-799-82-3044	+81-078-332-6307	http://www.kaiho.mlit.go.jp/06kanku/kouanweb/english/akashi.gif
			Weather	+81-799-82-3040		
Inland Sea	BISAN MARTIS	Contact	VHF Ch.16/13/14/22	+81-877-49-2220~1		
		Information Service	Traffic Control	+81-877-49-5166	+81-877-49-1199	http://www.kaiho.mlit.go.jp/06kanku/kouanweb/english/bisan.gif
			Weather	+81-877-49-1041	+81-877-49-1149	http://www.kobe-kaibouken.or.jp/
			Fishing Net		+81-877-49-3344	
Kurushima Strait	KURUSHIMA MARTIS	Contact	VHF Ch.16/13/14/22	+81-898-31-9000		http://www6.kaiho.mlit.go.jp/kurushima/
		Information Service	Traffic Control	+81-898-31-3636	+81-898-31-4646	http://www.kaiho.mlit.go.jp/06kanku/kouanweb/english/kurushima.gif
			Weather	+81-898-31-8177	+81-898-31-4646	
Kanmon Strait	KANMON MARTIS	Contact	VHF Ch.16/14/22	+81-93-372-0099		http://www6.kaiho.mlit.go.jp/kanmon/index_top.html
		Information Service	All Information	+81-93-381-3399	+81-93-372-2741	http://www.kobe-kaibouken.or.jp/web/jap/recommen/kanmon.html http://www.kaiho.mlit.go.jp/06kanku/kouanweb/english/kanmon.gif

Common RECOMMENDATION OF THE ROAD IN TOKYO BAY AND OTHER BAYS AND STRAITS IN JAPANESE WATERS
http://www.kaiho.mlit.go.jp/syoukai/soshiki/toudai/navigation-safety/download/download_info06.htm
Japan Coastguard Laws & Regulations
http://nippon.zaidan.info/seikabutsu/2001/00500/contents/00002.htm
http://www.kaiho.mlit.go.jp/syoukai/soshiki/toudai/navigation-safety/download/down_bc/english/part2.htm

Pilotage Districts in Japan



Pilot Districts & Telephone/Facsimile Numbers

No.	Pilot district	TEL	FAX	Remarks	No.	Pilot district	TEL	FAX	Remarks
1	KUSHIRO	0154-52-6352	0154-52-6358		21	SHIMIZU	0543-52-2191	0543-51-0527	
2	TOMAKOMAI	0144-34-3070	0144-34-6210		22	IRAGO-MIKAWA-WAN	0569-23-0713	0569-22-9054	Irago Channel
3	MURORAN	0143-22-4049	0143-23-8085		23	ISE-WAN	052-651-9111	052-652-4501	Nagoya
4	HAKODATE	0138-40-8435	0138-40-8435		24	OWASE	0597-22-7766	0597-22-7563	
5	OTARU	0134-22-5380	0134-33-0228		25	MAIZURU	0773-75-5376	0773-76-4828	
6	RUMOI	0164-42-4128	0164-42-4128		26	WAKAYAMA-SHIMOTSU	073-431-8713	073-432-3438	
7	HACHINOHE	0178-28-9421	0178-28-4975		27	OSAKA-WAN	078-321-7411	078-392-8091	Osaka Bay
8	KAMAISHI	0193-22-1868	0193-24-3940		28	HANSHIN	078-392-4898	078-332-2159	Osaka/Kobe
9	SENDAI-WAN	022-364-1727	022-362-5519		29	NAIKAI	078-391-7191	078-391-7180	Inland Sea
10	AKITA-FUNAKAWA	018-845-3178	018-845-7661		30	SAKAI	0859-44-0108	0859-44-6702	
11	SAKATA	0234-35-1963	0234-35-1964		31	KANMON	093-332-2384	093-332-5234	Kanmon Strait
12	ONAHAMA	0246-53-4809	0246-53-3273		32	KOMATSUJIMA	08853-2-4789	08853-3-3799	
13	KASHIMA	0299-82-5515	0299-82-6205		33	HAKATA	092-291-4494	092-271-3373	
14	TOKYO	03-3453-1691	03-3453-4025	Tokyo	34	SASEBO	0956-22-9059	0956-25-1508	
15	TOKYO-WAN	045-681-4081	045-662-1260	Yokohama/Chiba	35	NAGASAKI	095-823-6465	095-823-3071	
16	YOKOSUKA	046-835-6211	046-835-7355	Uraga Channel	36	SHIMABARA-KAIWAN	0944-53-1405	0944-51-3529	
17	NIIGATA	025-244-2320	025-244-9551		37	HOSOSHIMA	0982-50-0701	0982-50-0664	
18	FUSHIKI	0766-44-0173	0766-44-3391		38	KAGOSHIMA	099-260-7707	099-260-7717	
19	NANAO	0767-53-1192	076-276-9932		39	NAHA	098-868-1613	098-868-9785	
20	TAGONOURA	0545-33-0734	0545-32-1260						

Red letter : Compulsory Pilotage District

Compulsory Pilotage (Pilotage and Navigation Law)

The compulsory pilotage areas in Japan are broadly divided into two categories; i.e., the compulsory areas in ports and those in waters including channels, straits and adjacent port(s).

AREA		VESSEL
Port Areas Category A	**Yokosuka** **Sasebo** **Naha**	(*) · Vessels of foreign registry with gross tonnage 300 tons or more, · Vessels of Japanese registry with gross tonnage 300 tons or above engaged in international voyages or · Vessels of Japanese registry with gross tonnage 1,000 tons or above engaged in domestic service.
	Yokohama-Kawasaki	· Vessels with gross tonnage 3,000 tons or above. · Vessels carrying dangerous goods are the same as (*).
	Kanmon (Berthing/Unberthing vessels)	· Vessels with gross tonnage 3,000 tons or above. Vessels loaded with dangerous goods and · Vessels entering/leaving sections 1 - 4 of Wakamatsu are the same as (*).
Waters Category B	**Tokyo Bay** (including Ports of Tokyo, Chiba and Kisarazu) **Ise-Mikawa Bay** (including Ports of Nagoya, Yokkaichi, Kinuura and Mikawa) **Osaka Bay** (including Ports of Kobe, Osaka, Hannan and Akashi Strait) **Bisan Seto** (including Port of Mizushima) **Kurushima Strait** **Kanmon Channel** (Passing vessels)	· Vessels with gross tonnage 10,000 tons or above.

Note Japan Coast Guard recommends following safety measures in addition to above Compulsory Pilotage Requirement.

Uraga Suido Traffic Route and Naka-no-Se Traffic Route and Adjacent waters

The following vessels should take a pilot on board:

(1) A vessel entitled to fly the flag of a foreign country.

(2) A vessel entitled to fly the Japanese flag, commanded by a master who does not have sufficient sea-going service and experience of navigating in Tokyo Bay (Tokyo Wan).

Irago Suido Traffic Route and Adjacent Waters

The following vessels should take a pilot on board:

(1) A vessel entitled to fly the flag of a foreign country.

(2) A vessel entitled to fly the Japanese flag of 130 m or more in length over all prescribed by the Maritime Traffic Safety Law as a vessel carrying dangerous cargo.

5th Regional Coast Guard Headquarter recommends vessels take the following safety precautions

The following vessels should take a pilot on board:

(1) A vessel entitled to fly the flag of a foreign country.

(2) A vessel entitled to fly the Japanese flag, commanded by a master who does not have sufficient sea-going service and experience of navigating in Akashi Kaikyo Traffic Route.

Bisan Seto South Traffic Route, Uko East Traffic Route, Uko West Traffic Route, Mizushima Traffic Route and Adjacent Waters

The following vessels entitled to fly the flag of a foreign country should take a pilot on board:

(1) A vessel carrying dangerous cargo prescribed by the Maritime Traffic Safety Law.

(2) A vessel commanded by a master who navigates Seto Inland Sea for the first time.

Kurushima Kaikyo Traffic Route and Adjacent Waters

The following vessels entitled to fly the flag of a foreign country should take a pilot on board:

(1) A vessel carrying dangerous cargo prescribed by the Maritime Traffic Safety Law.

(2) A vessel commanded by a master who navigates Seto Inland Sea for the first time.

JCA Voluntary Traffic Separation Scheme

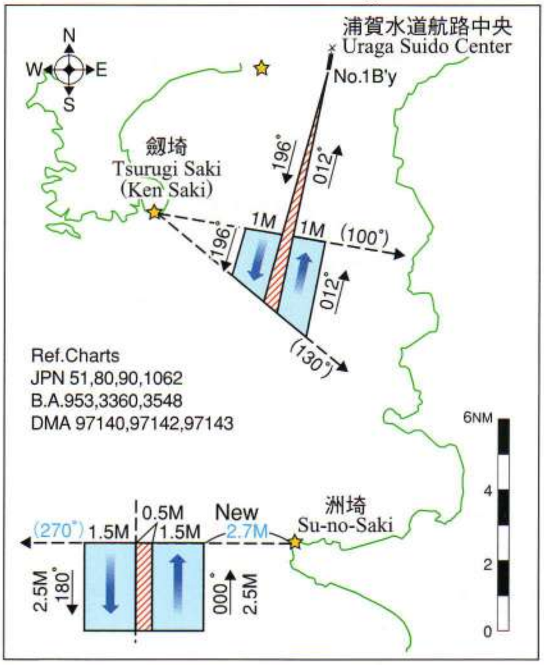
(Published: 01-September-2002)

Mode of Navigation in Traffic Separation Area and its Vicinity (Voluntary)
When navigating a traffic separation area, vessels shall, in principle, follow the rules as shown below

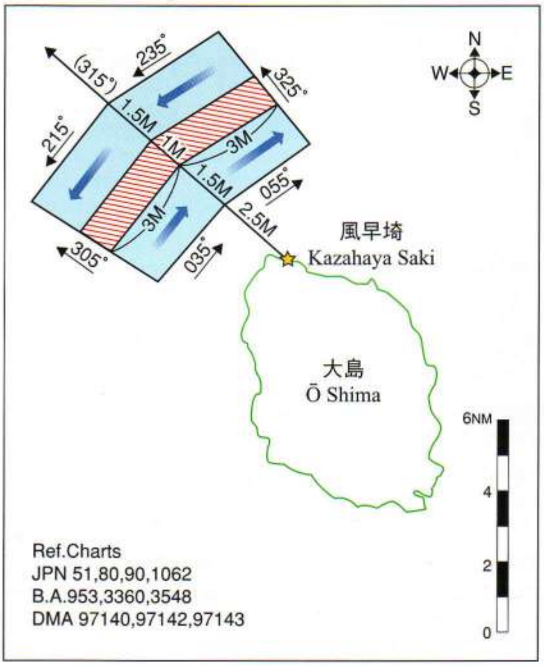
The traffic separation schemes in this text do not apply to the traffic separation schemes referred to in Article 10 Paragraph (a) of the International Regulations for Preventing Collisions at Sea.

1. A vessel using a traffic separation scheme shall proceed in the appropriate traffic lane in the general direction of traffic flow designated for that lane.
2. A vessel using a traffic separation scheme shall so far as practicable keep clear of the separation zone.
3. A vessel using a traffic separation scheme shall normally join or leave a traffic lane at the termination of the lane, but when joining or leaving from the side shall do so at as small an angle to the general direction of traffic flow designated as practicable.
4. A vessel shall avoid crossing traffic lanes. If she is obliged to do so, the vessel shall cross as nearly as practicable at a right angle to the general direction of traffic flow designated for that lane.
5. A vessel not using a traffic separation scheme shall avoid it by as wide a margin as is practicable.
6. A vessel, other than a crossing vessel, shall not normally enter a separation zone except in case of emergency to avoid immediate danger.
7. A vessel navigating in areas near the terminations of traffic separation schemes shall do so with particular caution.
8. A vessel requiring no passage through a deep water route shall so far as practicable keep clear of the deep water route.

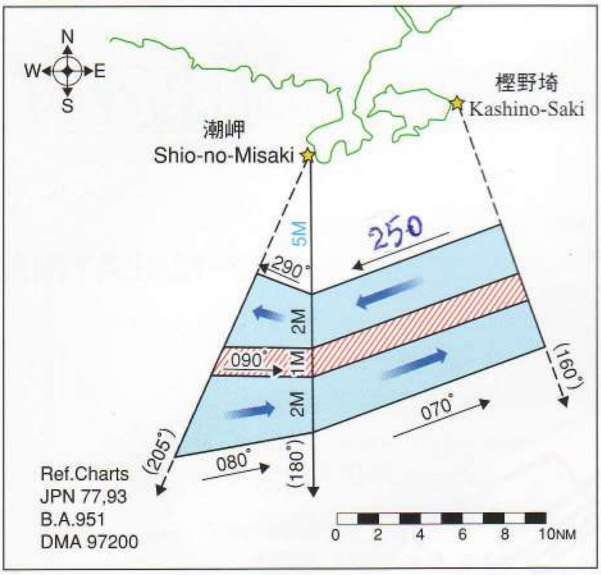
Off Su-no-Saki and Tsurugi Saki



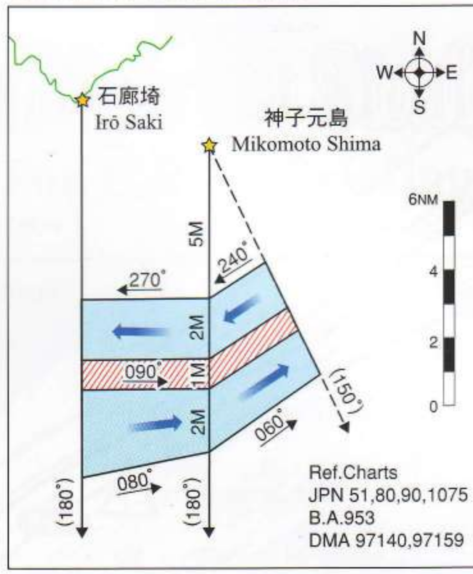
Off Kazahaya Saki



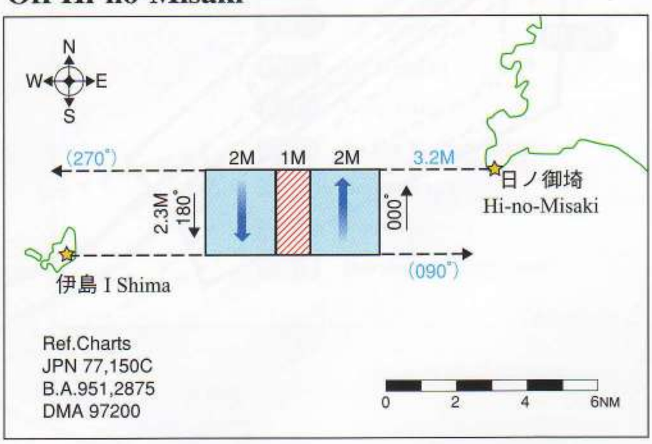
Off Shio-no-Misaki



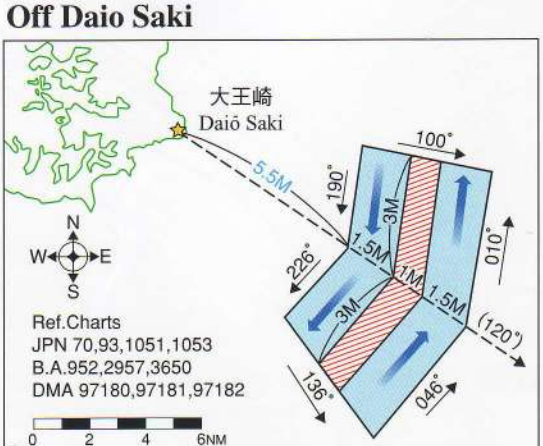
Off Mikomoto Shima



Off Hi-no-Misaki



Off Daio Saki



Irago Suido Entrance Deep Water Route


Fig 7
Fig 8
PORT KLANG
BUKIT JUGRA
MALAYSIA
Fig 9
PORT DICKSON
CAPE RACHADO
Fig 10
Fig 6
MALACCA
TG TO
RUPAT
BENGKALIS
SUMATERA
PADANG

Vessel Movement in Malacca Strait

(For B.R.M. Briefing)

Westbound

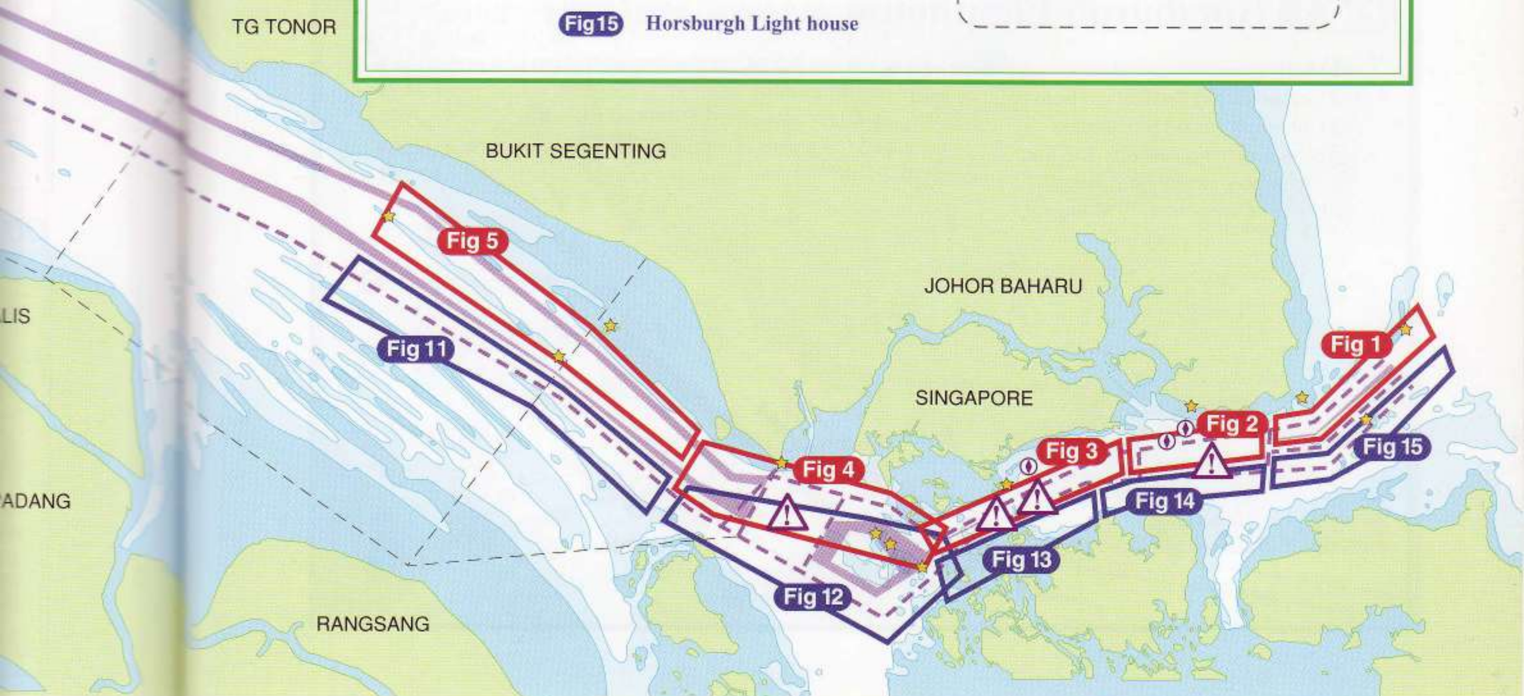
- Fig 1 Horsburgh Light House
- Fig 2 Johor Fairway
- Fig 3 Singapore Strait
- Fig 4 Raffles-Pu Iyu Kecil
- Fig 5 Off Pu Pisang
- Fig 6 Off Dumai, Port Dickson
- Fig 7 One Fathom Bank

Eastbound

- Fig 8 One Fathom Bank
- Fig 9 Tg. Medang
- Fig10 Tg. Gabang
- Fig11 Long Bank
- Fig12 Pu Iyu Kecil ~ Takong
- Fig13 Singapore
- Fig14 Johor Fairway
- Fig15 Horsburgh Light house

Symbol

- Crossing Area
- Conspic lighthouse
- Pilot Station
- Separation zone
- 20m contour
- 10m contour



Westbound

Symbol

- Crossing Area
- Conspic lighthouse
- Pilot Station
- Separation zone
- 20m contour
- 10m contour
- Own ship (Large vessel)
- Other ship
- Group of fishing vessels
- Buoy

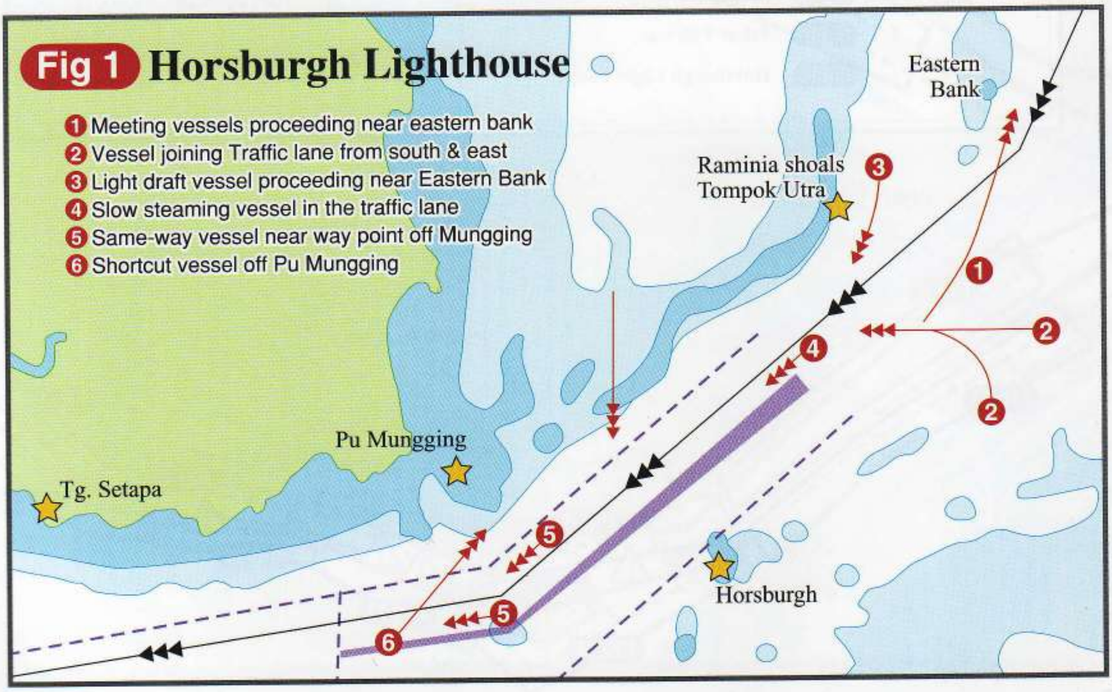


Fig 1 Horsburgh Lighthouse

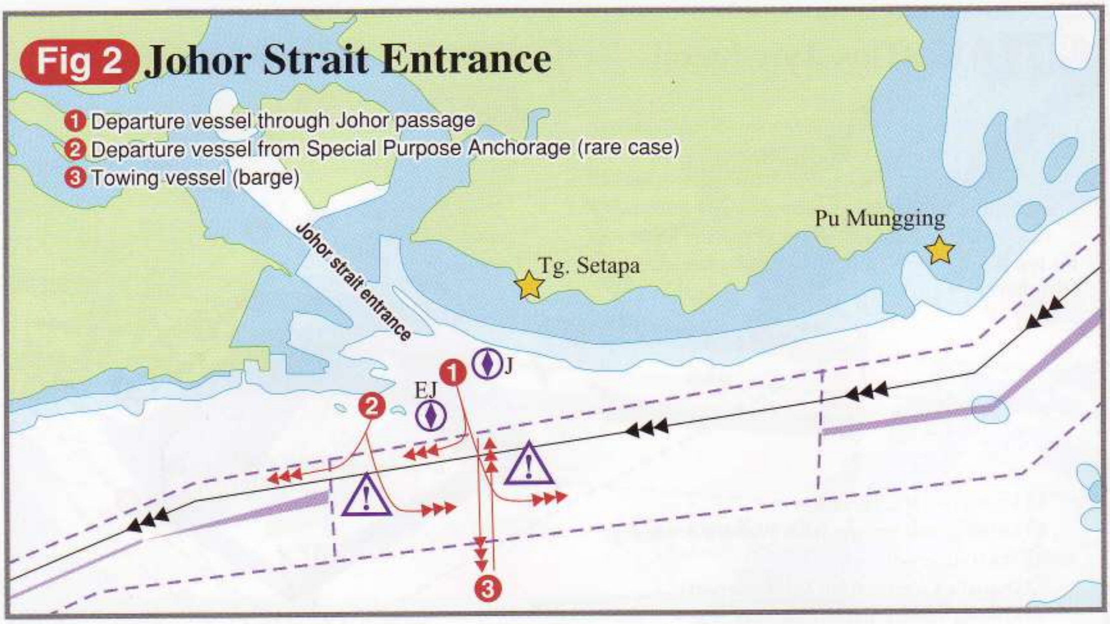


Fig 2 Johor Strait Entrance
1 Departure vessel through Johor passage
2 Departure vessel from Special Purpose Anchorage (rare case)
3 Towing vessel (barge)
Johor strait entrance
Tg. Setapa
Pu Mungging
EJ
J

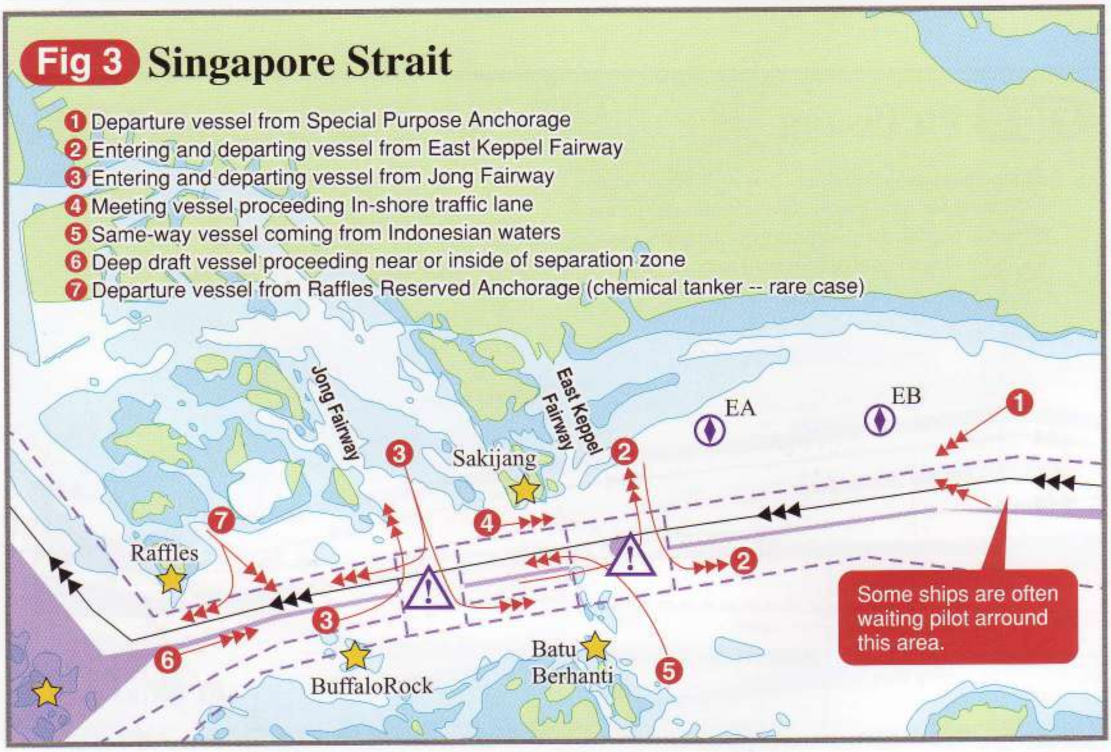


Fig 3 Singapore Strait
1 Departure vessel from Special Purpose Anchorage
2 Entering and departing vessel from East Keppel Fairway
3 Entering and departing vessel from Jong Fairway
4 Meeting vessel proceeding In-shore traffic lane
5 Same-way vessel coming from Indonesian waters
6 Deep draft vessel proceeding near or inside of separation zone
7 Departure vessel from Raffles Reserved Anchorage (chemical tanker -- rare case)
Jong Fairway
East Keppel Fairway
Sakijang
EA
EB
Raffles
BuffaloRock
Batu Berhanti
Some ships are often waiting pilot arround this area.

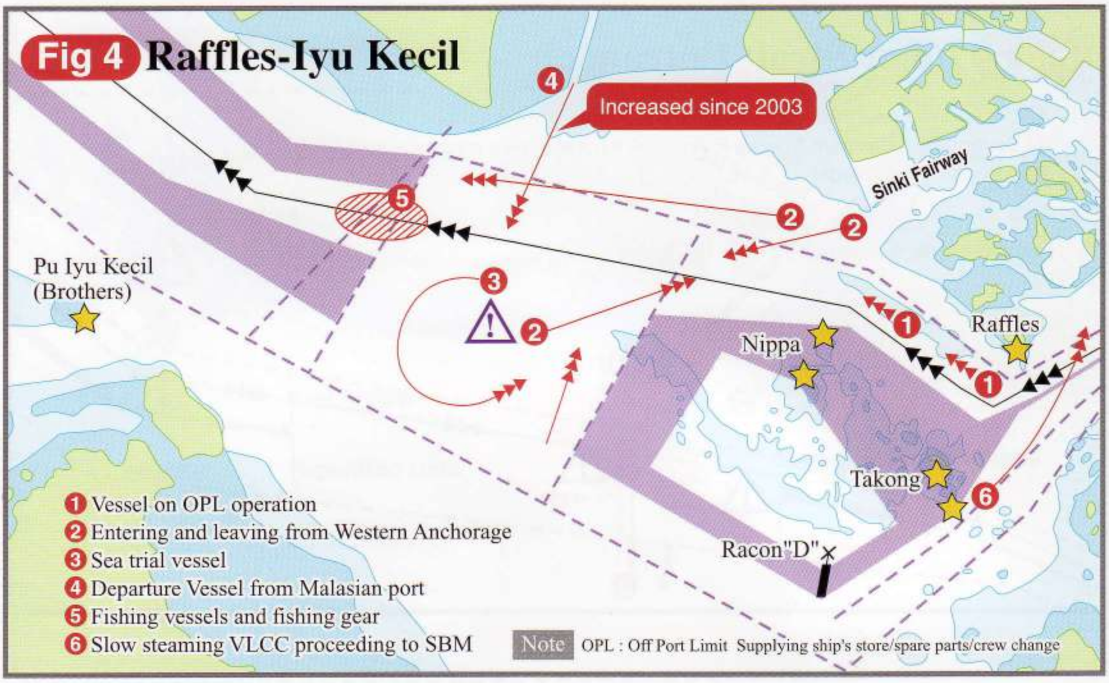


Fig 4 Raffles-Iyu Kecil

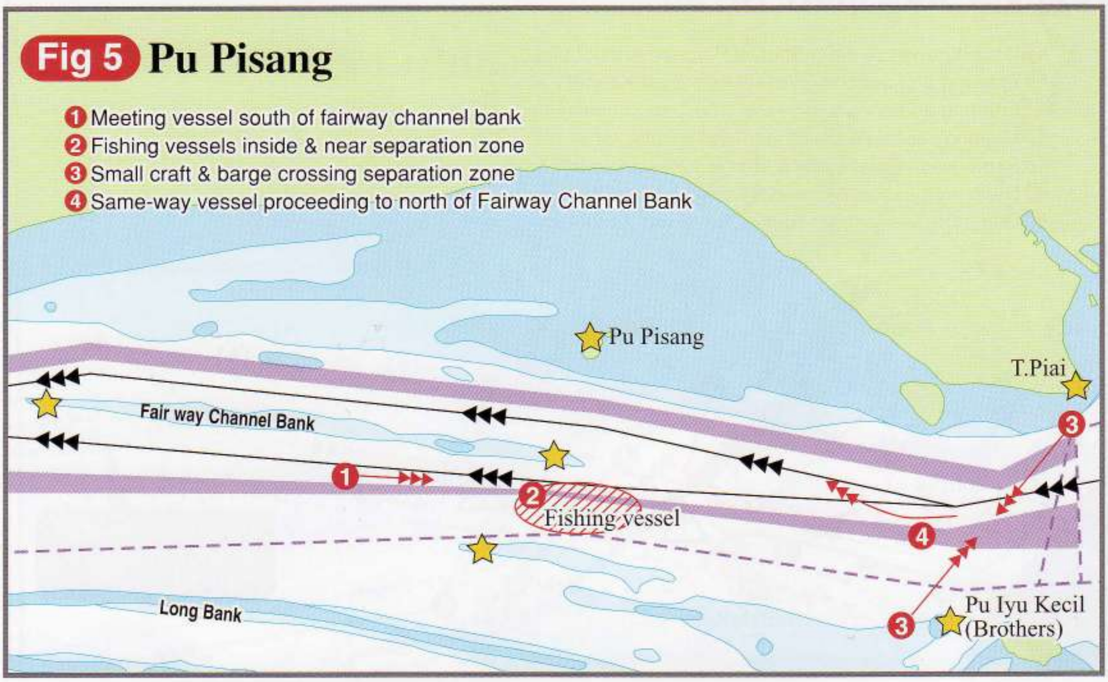
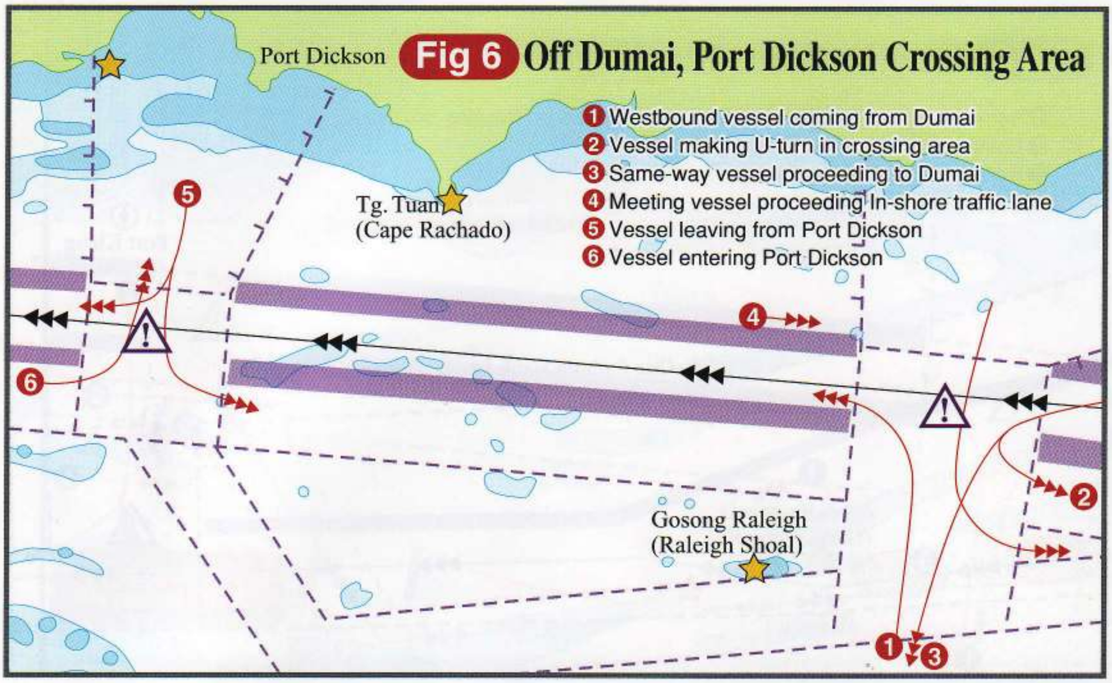


Fig 5 Pu Pisang


Port Dickson
Fig 6 Off Dumai, Port Dickson Crossing Area
1 Westbound vessel coming from Dumai
2 Vessel making U-turn in crossing area
3 Same-way vessel proceeding to Dumai
4 Meeting vessel proceeding In-shore traffic lane
5 Vessel leaving from Port Dickson
6 Vessel entering Port Dickson
Tg. Tuan
(Cape Rachado)
Gosong Raleigh
(Raleigh Shoal)

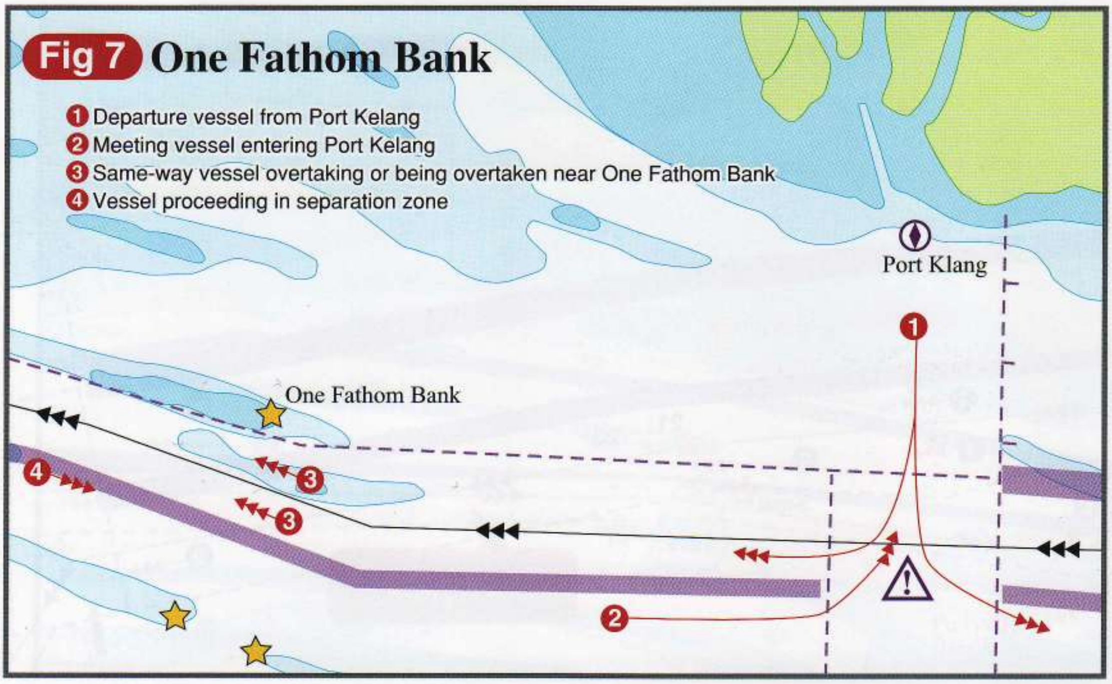


Fig 7 One Fathom Bank
1 Departure vessel from Port Kelang
2 Meeting vessel entering Port Kelang
3 Same-way vessel overtaking or being overtaken near One Fathom Bank
4 Vessel proceeding in separation zone
Port Klang
One Fathom Bank

Eastbound

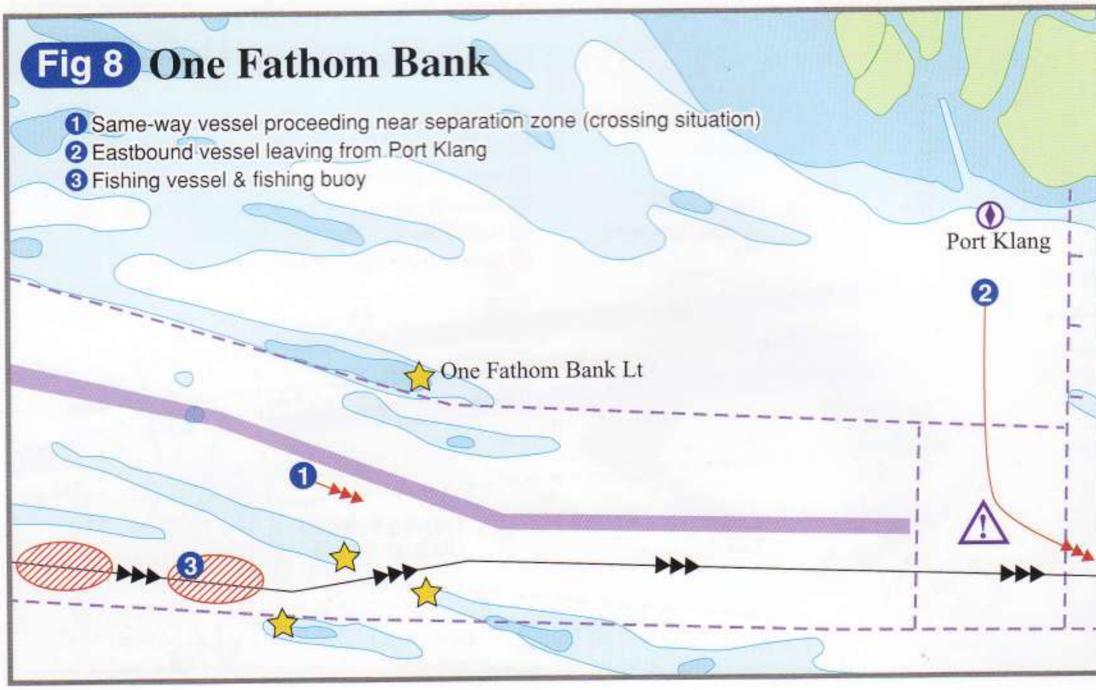


Fig 8 One Fathom Bank

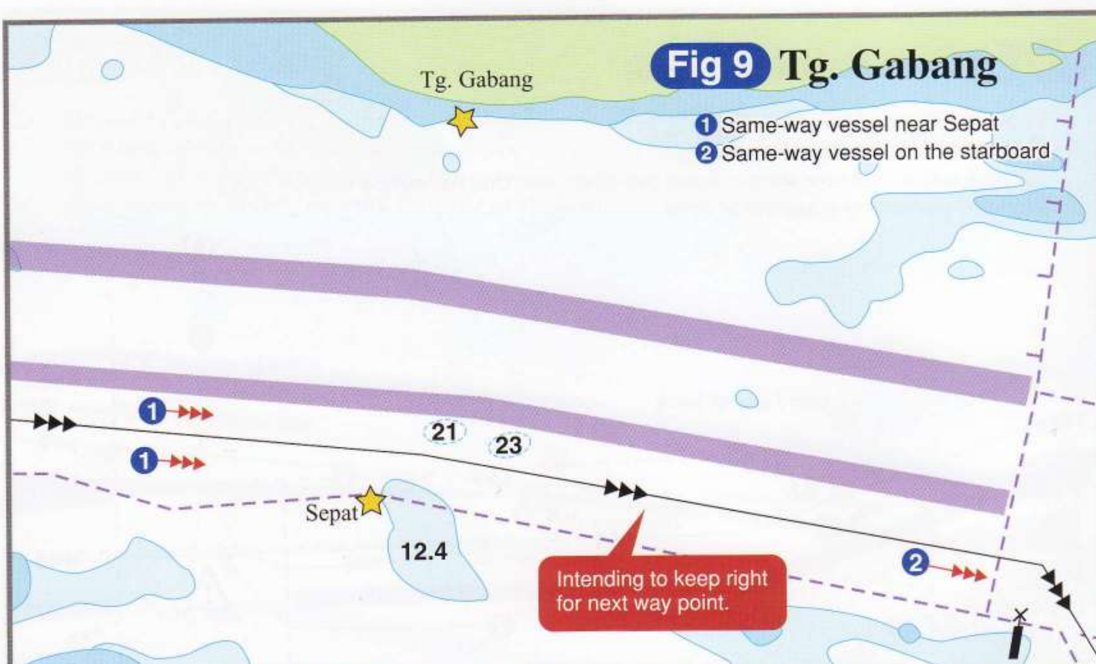


Fig 9 Tg. Gabang

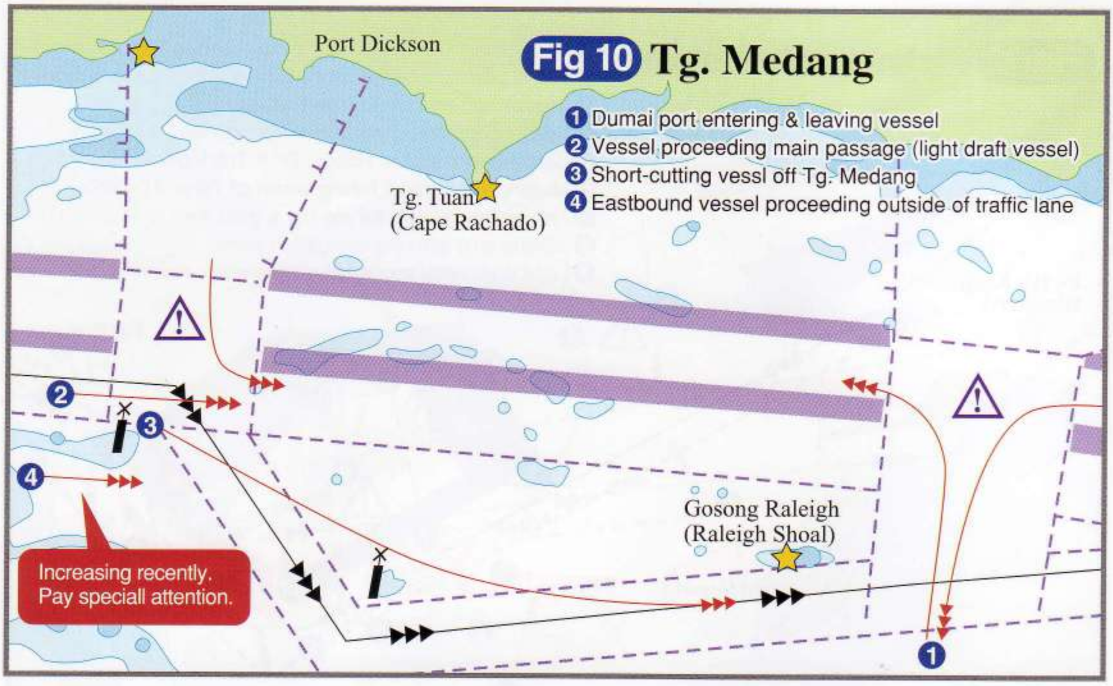


Fig 10 Tg. Medang
1 Dumai port entering & leaving vessel
2 Vessel proceeding main passage (light draft vessel)
3 Short-cutting vessl off Tg. Medang
4 Eastbound vessel proceeding outside of traffic lane
Port Dickson
Tg. Tuan
(Cape Rachado)
Gosong Raleigh
(Raleigh Shoal)
Increasing recently.
Pay speciall attention.

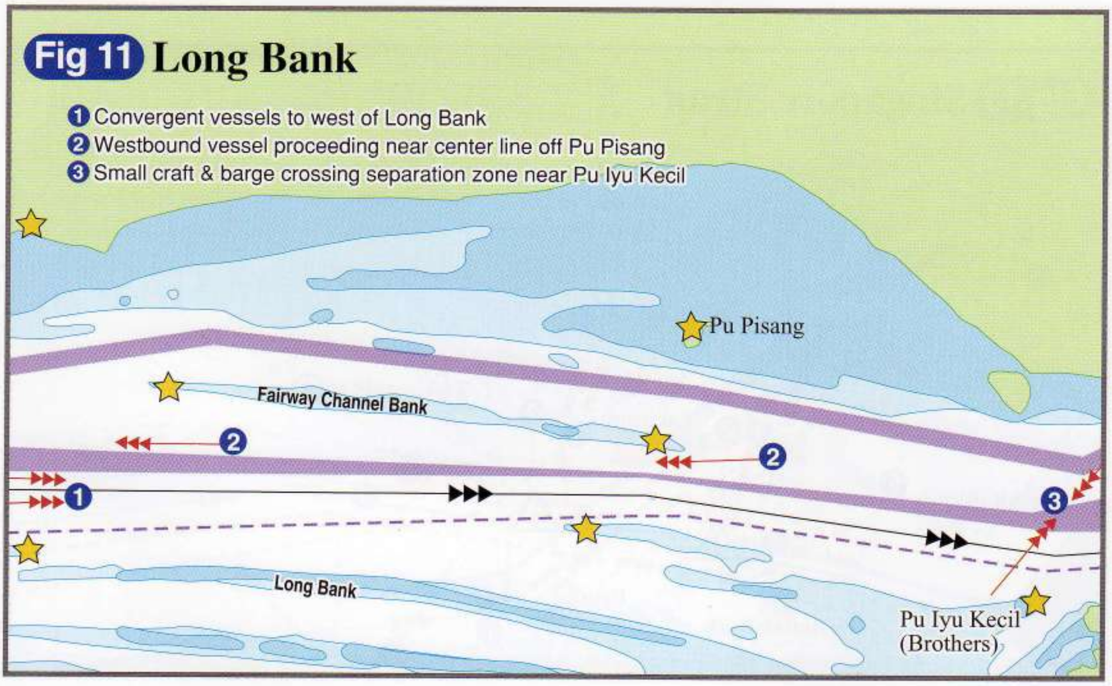


Fig 11 Long Bank
1 Convergent vessels to west of Long Bank
2 Westbound vessel proceeding near center line off Pu Pisang
3 Small craft & barge crossing separation zone near Pu Iyu Kecil
Pu Pisang
Fairway Channel Bank
Long Bank
Pu Iyu Kecil
(Brothers)

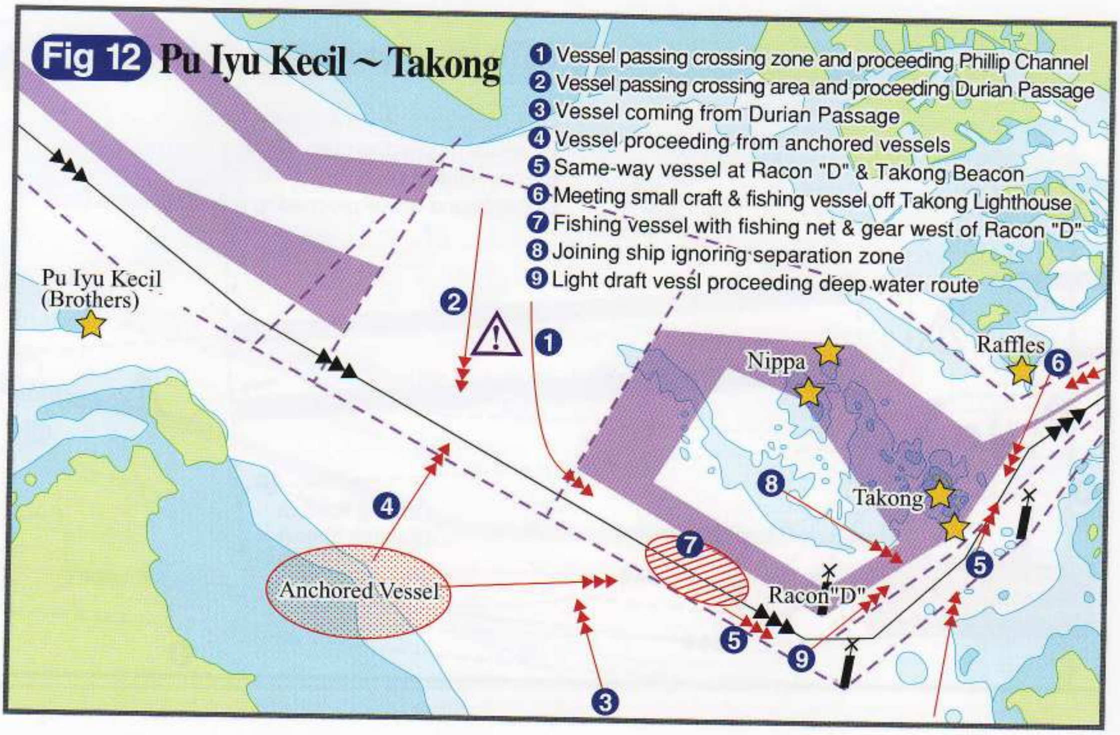


Fig 12 Pu Iyu Kecil ~ Takong

Fig 13 Singapore Strait

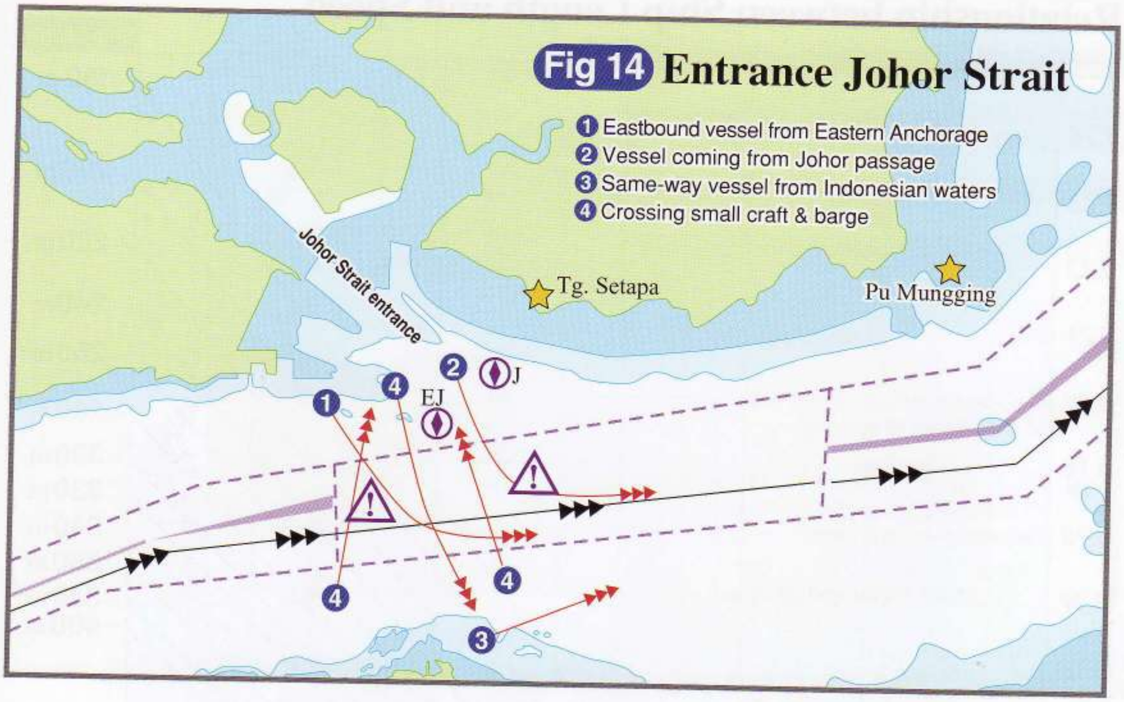


Fig 14 Entrance Johor Strait

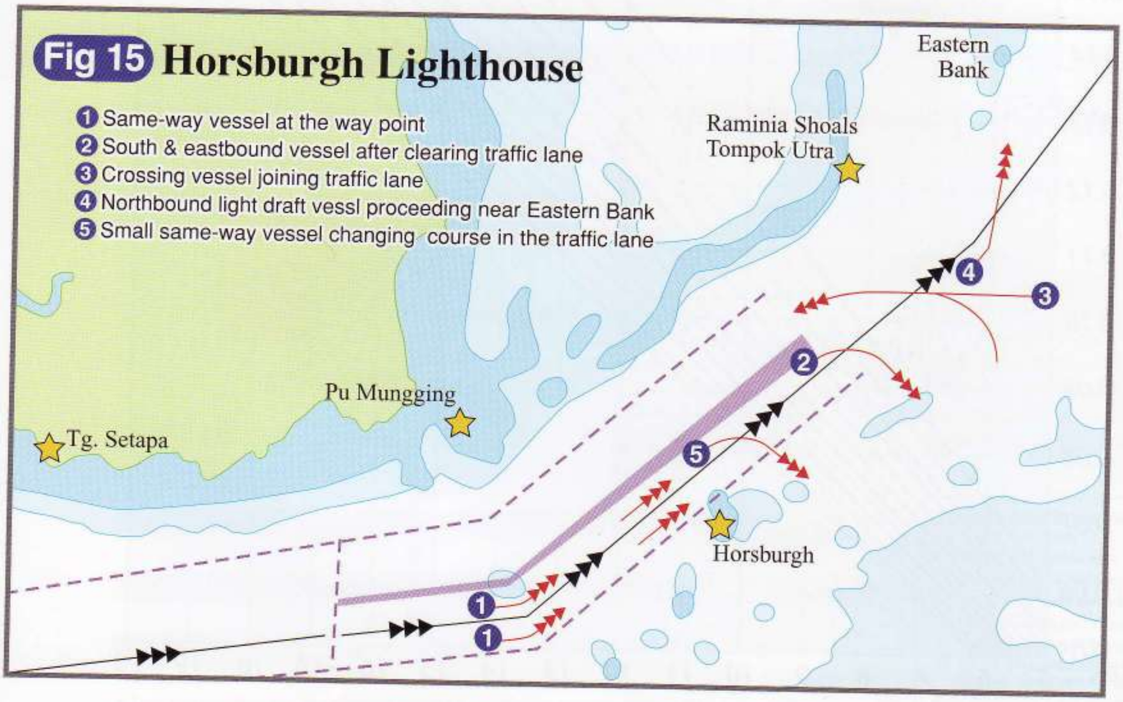
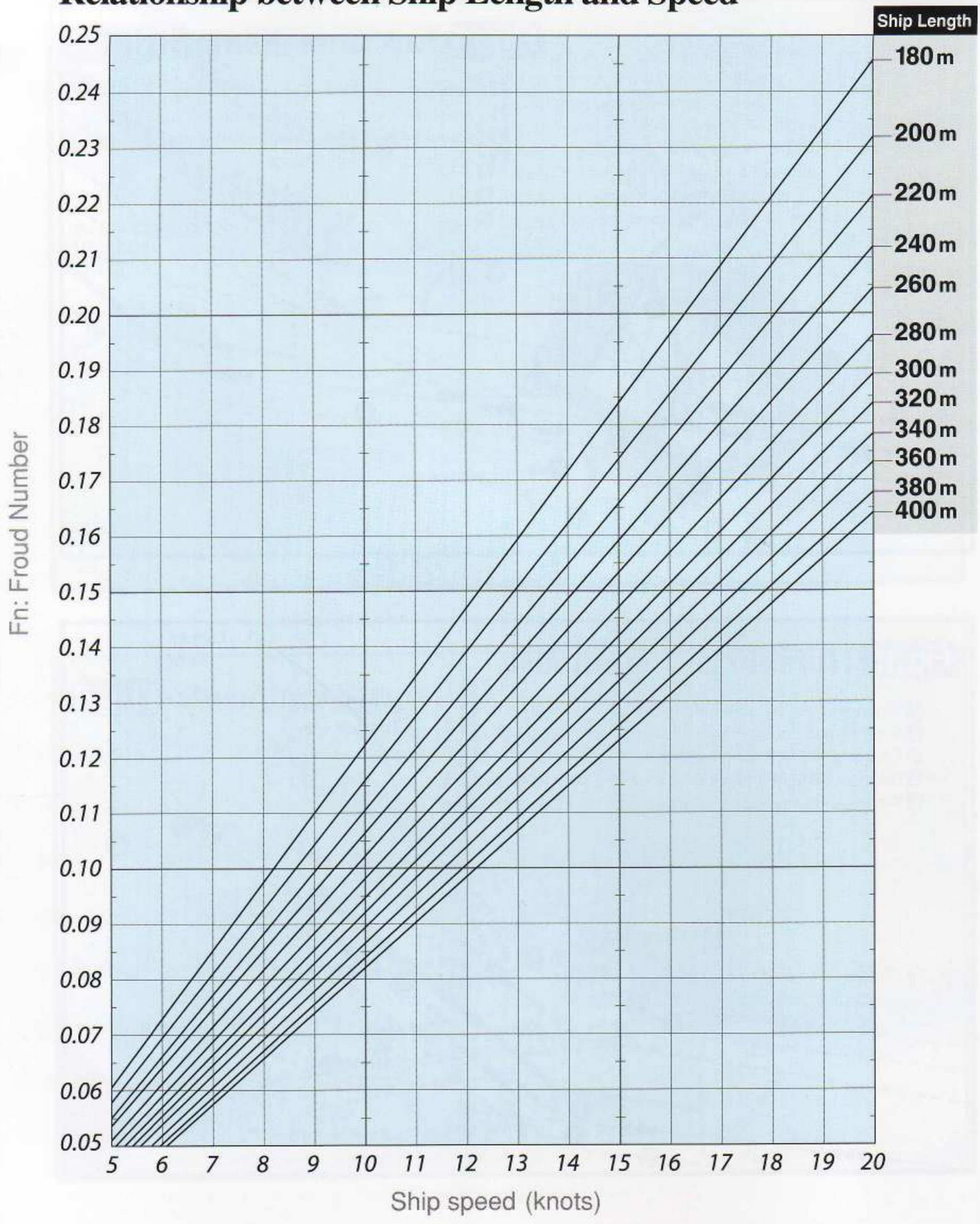


Fig 15 Horsburgh Lighthouse

Froud Number
Relationship between Ship Length and Speed



APPENDIX Operation Diagram for the Master

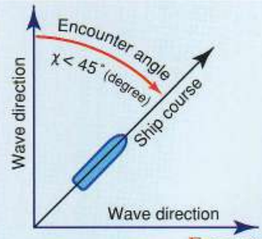


Fig.1
Encounter angle χ

Ship: Satisfaction to IMO stability criteria or equivalent

▼

Wave: Wavelength > 0.8 × ship length, $H_{1/3}$ > 0.04 × ship length
Estimate λ, T, and χ, where $T = 0.8\sqrt{\lambda}$

▼

Ship course: Wave direction is 0° to 45° from the stern.

▼

Encounter wave period, T_E (sec)

▼

If ship's speed is:

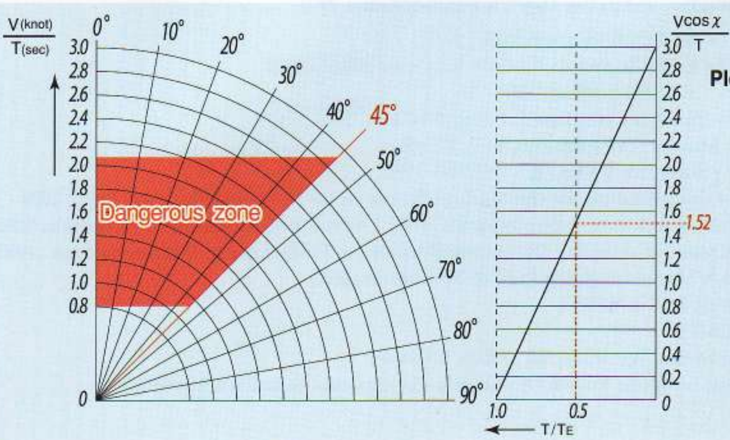
- (1) in Surf-riding zone
  Reduce to speed zone (2).
- (2) in marginal zone
  Reduce to speed zone (3)
  when large surging is felt.
- (3) beyond the zones

Fig.2
Diagram indicating dangerous zone due to surf-riding

▼

Next step

▼



Plot V (knot)/T (sec) versus χ on Figure 3

Fig.3
Diagram indicating dangerous zone of encountering to high wave group and relation between mean wave period and encounter wave period in following and quartering seas

▼

If V/T (χ) is in the dangerous zone, reduce the speed to come out of the zone.

▼

If V/T (χ) is beyond the dangerous zone, keep speed and course.

▼

If T_E is nearly equal to T_R or $T_R/2$, reduce the speed further.*

Judge T_E

* Take into consideration the minimum speed for maintaining course control of ship.

- L: length between perpendiculars of the ship (meter)
- V: actual ship speed (knot)
- T: mean wave period (second)
- T_E: encounter wave period (second)
- T_R: natural rolling period (second)
- λ: average length of the wave (meter)
- χ: ship's encounter angle to wave (degree), as shown in Figure 1
- $H_{1/3}$: significant wave height (meter)

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