§ 6

Wind and Waves and Undulations (swells)

When operating in rough seas, waves will be caused by winds and swell from several different directions, which will cause the vessels to undergo a number of complicated oscillations. In this situation, it is important to have a precise grasp of the lengths of waves and their undulations, their cycle and wave heights in order to operate safely. Wind and waves and undulations (swells) will be described below.

6－1 Basic Form of a Wave

As can be seen in Figure 55, a single wave has a sine curve movement and the relationship between the wave length, wave speed and cycle can be shown in the following formula.

$$\text{Wave speed [v] } \mathbf{m/sec} = \frac{\text{Wave length } \lambda \text{ [m]}}{\text{Wave cycle period } \mathbf{T} \text{ [sec]}}$$

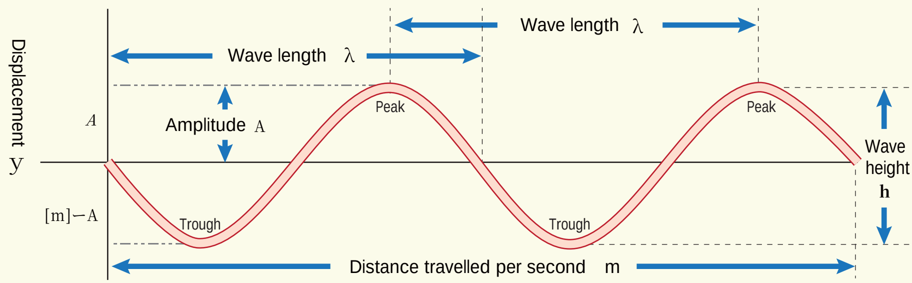


Fig. 55

In reality, there is rarely one wave or swell, but rather, the ship is tossed in several different waves, winds and swells, all of which differ in wavelength, speed, number of cycles and come from different directions. An example of synthetic waves is shown in Figure 56.

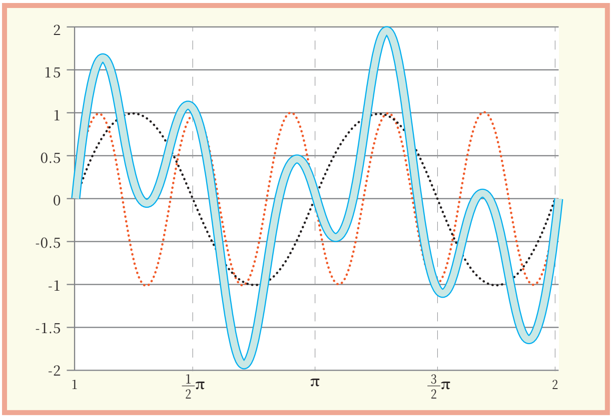


Fig. 56

Wave height [Hc], when some waves mix, can be determined when using the following; by taking the root mean square surface of each wave height.

$$Hc = \sqrt{H_w^2 + H_a^2 + H_b^2 + \cdots\cdots\cdots\cdots}$$

For instance, if the wave height is 1m and the height of the swell is 2m, the wave height of the synthetic wave shall be 2.236m.

$$\sqrt{1^2 + 2^2} = \sqrt{5} = 2.236\text{m}$$

6 — 2 Differences between Wind and Waves and Undulations (swells)

As can be seen in Figure 57 below, when wind blows on the sea, the sea surface starts to move and riffled waves propagate in the direction of the blowing wind. If the wind speed is greater than the wave speed, the wave will continue to develop as it is pushed by the wind. Waves that are produced by the wind blowing on the sea are referred to as “wind and waves”. Moreover, when wind and waves continue on to an area of sea where no wind is blowing, when the sea wind weakens, or when the direction of the wind suddenly changes, the type of wave that is no longer driven by the wind is referred to as an undulation (swell). An undulation (swell) is a propagating wave that attenuates. Compared with other wind and waves of the same height, its shape is regular and rounded, and the peak of the wave is also horizontally wide.

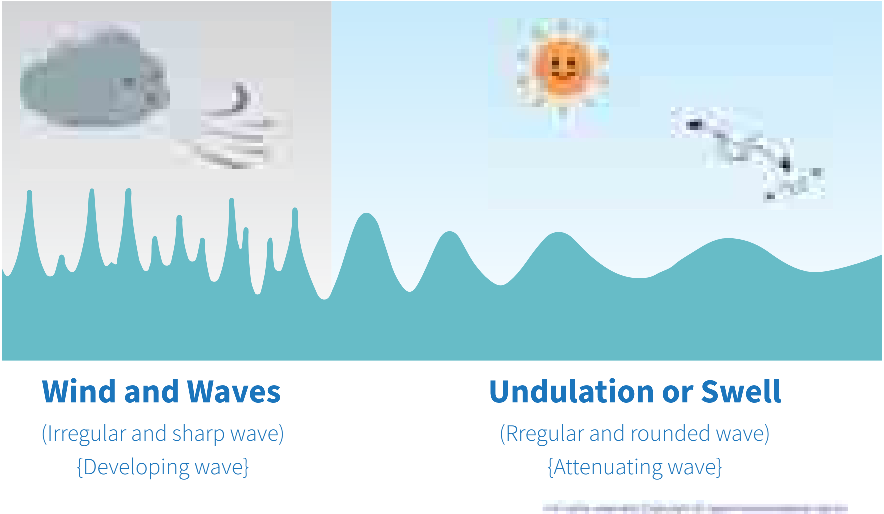


Fig. 57 From the Japan Meteorological Agency website

§ 7 Ship Handling in Rough Sea: Head and Countering / Following Seas

In this chapter, Ship Handling in Rough Sea, I would like to explain how dangerous it is when a ship is pitching and rolling in the event of it being exposed to head and countering or following seas.

7－1 Ship Handling in Head and Countering Seas

When a ship navigates in head seas, its hull is subjected to severe shocks which induce violent ship motions. Well trained and experienced navigators are able to respond to this by altering the ship's course and speed as required. However, to accomplish safe navigation in head seas, it is necessary to have more reliable ship-handling techniques backed by theoretical knowledge as to why these phenomena are created and how to avoid the generation of these critical effects, in addition to possessing sea-going experience.

When there are wind and waves and huge undulations (swells) coming from several different directions, a ship at the mercy of wave forces, heaves, pitches and rolls repeatedly. Also, depending on the ship's relative position in waves and, whether it is being lifted up to the top of a crest or falling into a trough, hogging, sagging and twisting forces generate great deflections in the entire hull structure (Fig. 58). In addition, the ship's speed is usually decreased by wind and wave resistance. This phenomenon is particularly augmented in head seas.

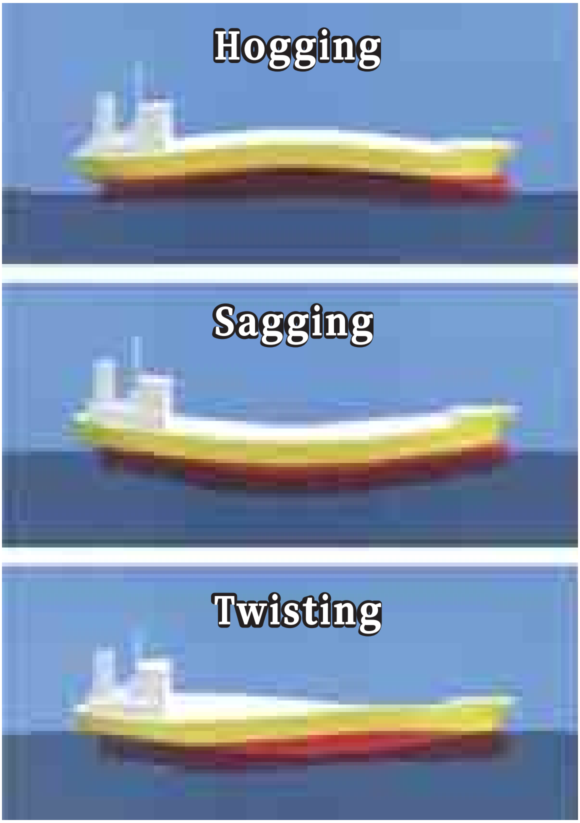


Fig. 58 Japan Captains' Association, DVD

Pitching intensified motion in head and countering seas of rough weather has the greatest influence on the safety of a ship. In particular attention is to be paid to the following relationship between the length of a wave and the length of a ship (Lpp):

① When wave length is shorter than ship length(Lpp)

Because the ship motions are insignificant as the influence of waves is weak, the bottom of the bow neither rises enough to be exposed dangerously nor dips enough for the fore deck to take on water (Fig. 59).

Fig. 59 Japan Captains' Association, DVD

② When wave length is longer than ship length (Lpp)

A ship pitches and heaves slowly at the front and rear surface of waves that will affect its form. However, this does not cause significant movement (Fig. 60).

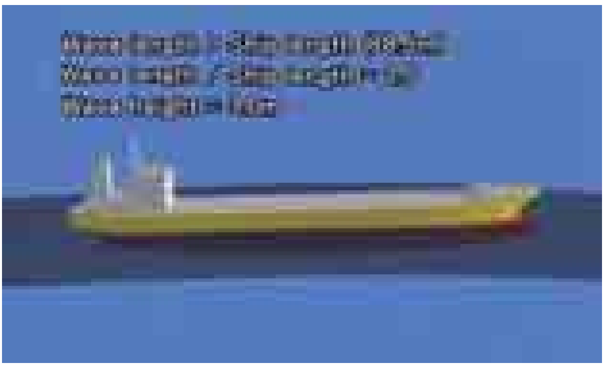


Fig. 60 Japan Captains' Association, DVD

③ When wave length is almost equal to ship length (Lpp)

When wave length is almost equal to ship length, ship motion will be most intense. The heaving of the bow on a crest and the plunging of it into the succeeding wave will be accelerated (Fig. 61).

Fig. 61 Japan Captains' Association, DVD

In such cases, changes in water level both forward and aft become particularly great in regular wave conditions (See Fig. 62) and relative water level at the bow is greatest when wave length is equal to ship length, and seas are likely to be shipped when the relative water level exceeds the freeboard at the bow (highlighted in orange colour), while in contrast, slamming may occur when the relative water level drops far enough below the forward draft to the extent that the bottom plates at the bow are exposed (highlighted in red).

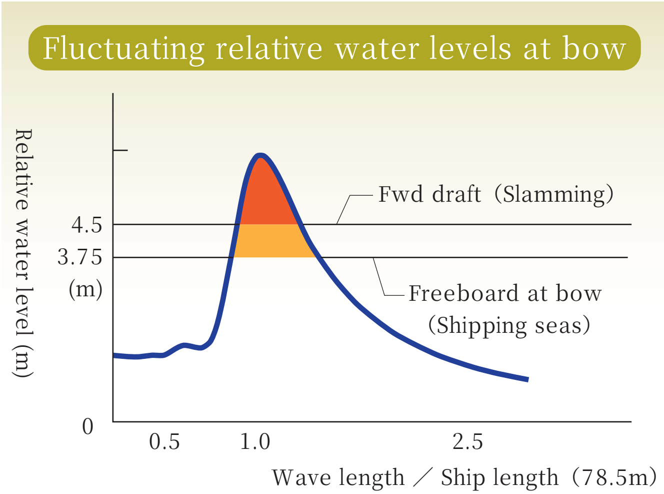


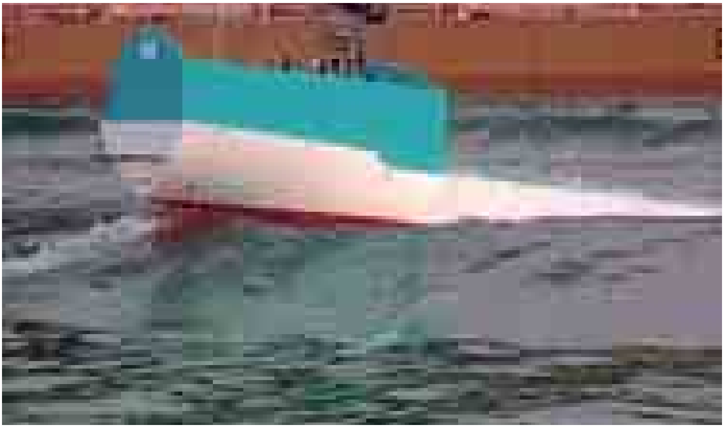
Fig. 62 Japan Captains' Association, DVD

These head and countering seas cause the following phenomena:

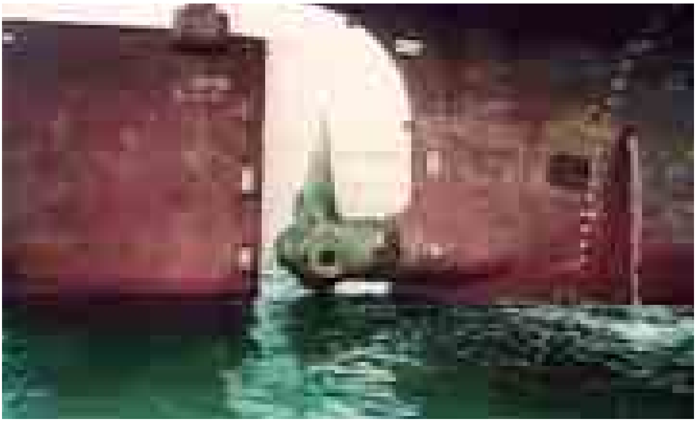
1	Propeller Racing
2	Speed Reduction and a Torque Rich Effect on the Engine
3	Shipping Seas
4	Slamming Phenomenon

7−1−1 Propeller Racing

Whenever a ship pitches and heaves heavily at the bow, an equivalent heaving motion is generated at the stern. Due to these motions, the stern lifts out of the sea at intervals exposing part of the propeller and causing instant increases of propeller revolutions accompanied by intense vibrations due to the abrupt reduction of propeller load. This phenomenon is called propeller racing and can have adverse effects not only on the propeller itself, but also on the propeller shaft and engine (Photographs 63 and 64).



Photograph 63 Japan Captains' Association, DVD



Photograph 64 Japan Captains' Association, DVD

Therefore, it is recommended to make the stern draft as deep as possible so that propeller immersion is kept at more than 20 percent of the diameter of the propeller when navigating in rough seas. However, when trimming excessively for a ballast passage, forward draft will be reduced. As the possibility of slamming phenomenon increases (mentioned below), it is essential that the hull's condition be properly maintained in light of this (Fig. 65).

Fig. 65 Japan Captains' Association, DVD

7–1–2 Speed Reduction and the Torque Rich Effect on the Engine

When the vessel receives waves and undulation (swells) from the front, the resistance of these combined with additional wind pressure, the ship's speed will decrease, and the engine will undergo a torque rich effect. Figure 66 illustrates speed reduction characteristics in irregular waves. For instance, in the case of a container ship with a length of 250m, the ratio of speed reduction becomes markedly larger at approximately 30%, when wave height is greater than 6m.

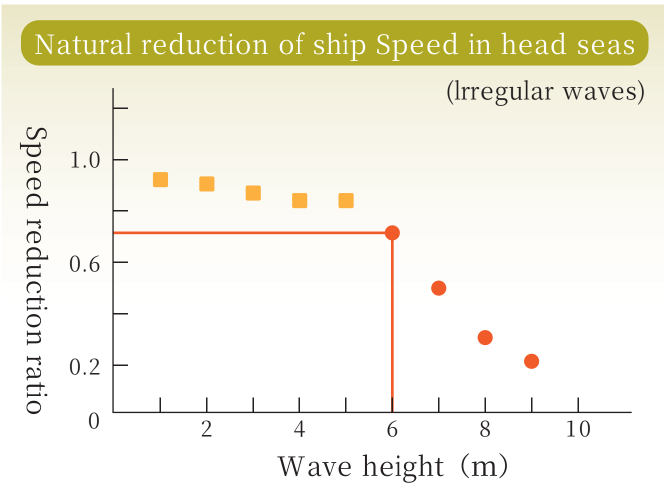


Fig. 66 Japan Captains' Association, DVD

As resistance to the hull increases, the engine requires more fuel in order to maintain the same number of revolutions as set under normal conditions, forcing the ship to plough through the water under excess engine load. This causes what is known as a torque rich effect and may often result in engine trouble due to overheating, or in a great waste of fuel. In such conditions, it is essential to reduce ship speed, because the engine might be damaged as a result of over-heating or it may consume a huge amount of fuel unnecessarily.

Photograph 67 Japan Captains' Association, DVD

If I compare the torque rich effect to driving a car, I am sure that many of our Club members may be able to relate to the following scenario. When a car being driven on a level road comes across a very steep upward slope, its speed falls. In an effort to maintain the same speed, the driver often reacts, by pressing the accelerator down hard. However, the engine output is limited and the speed does not increase. If the effort is continued, the engine will overheat. This is referred to as the torque rich effect.

Fig. 68 Japan Captains' Association, DVD

As with the car, it is essential for a ship to reduce engine revolutions, while the Master and Chief Engineer have in-depth meetings regarding the load status of the engine, whenever there are signs that the engine is becoming torque rich.

7−1−3 Shipping Seas

A ship may sometimes sustain severe damage from the impacting green seas. Deck machinery, deck cargo and hatch covers are often damaged as a result of shipping seas which may cause water to enter into the holds. Damage sustained from shipping seas is two-fold: damage caused to the bow from green sea pounding, and damage inflicted on deck machinery and appliances from the subsequent incursion of sea water.


Photograph 69 Japan Captains' Association, DVD


Photograph 70 Japan Captains' Association, DVD


Photograph 71 Japan Captains' Association, DVD


Photograph 72 Japan Captains' Association, DVD

The dynamic pressure of green sea pounding on the deck vertically from above may reach around twice that of seas being shipped. For example, if a 100 ton mass of sea water fell from 4m above deck, the stress would be equivalent to what 20 fully grown elephants each weighing 5 tons would generate by jumping one after another at intervals of no more than three seconds onto a deck area of 40 m^2 from a height of 4m above the deck. It is easy to imagine the scale of such huge dynamic pressure. Furthermore, the dynamic stress of a sweeping mass of launched and shipped seas over decks, proportional to the square of the ship's speed, becomes almost as great as that from vertical pounding. Deck machinery such as sounding pipes and so on can be damaged as a result.

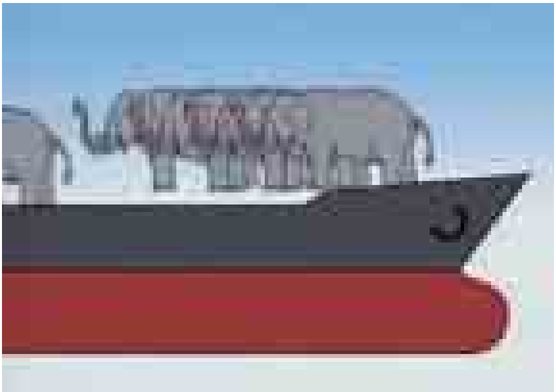


Fig. 73 Japan Captains' Association, DVD

The following are the results obtained from ship model trials of shipping seas: the simulation was carried out under the following conditions:

Gross tonnage	Length	Breadth	Depth	Design draft	Beaufort scale	Wave hight	Mean wave period	Ship speed
699 G/T	78.5m (Lpp)	12.8m	7.8m	4.52m Even Keel	6	3m	7.13secs	9knots

① When changing the wave length and encounter angle of ship to wave

Results of trials which were conducted using varying wave length to ship length (Lpp) ratios of 0.5 (wave length: 39m), 2.5 (196m) and 1.0 (79m), and by changing the encounter angle of ship to wave from zero to 90 degrees by 15 degrees per each wave length, are indicated in the Figure 74 (three dimensional).

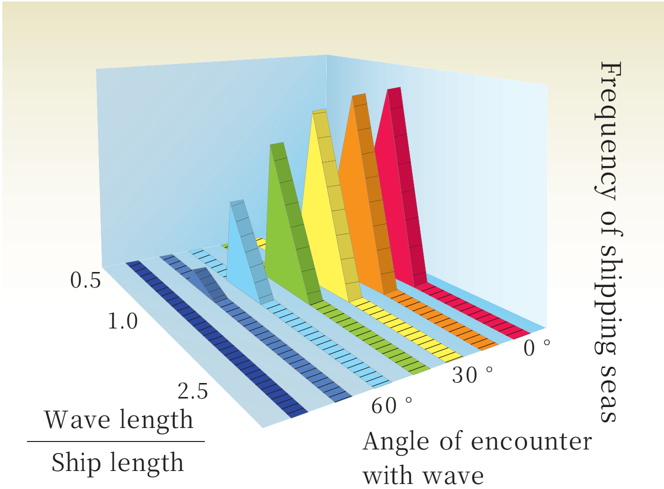


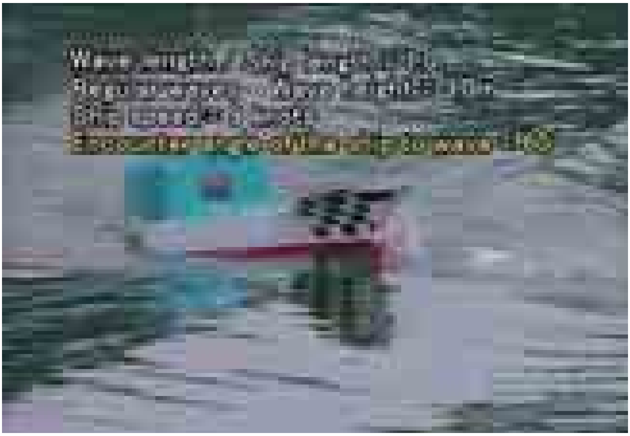
Fig. 74 Japan Captains' Association, DVD

Because the effect of the wave was minimal when applying a wave length to ship length (Lpp) ratio of 0.5 (wave length: 39m), ship motion was insignificant, and no seas were shipped. Also, when wave length was increased to 196m, equivalent to 2.5 times the ship length (Lpp), the ship only pitched and heaved slowly along the surfaces of the waves and, again, no seas were shipped.

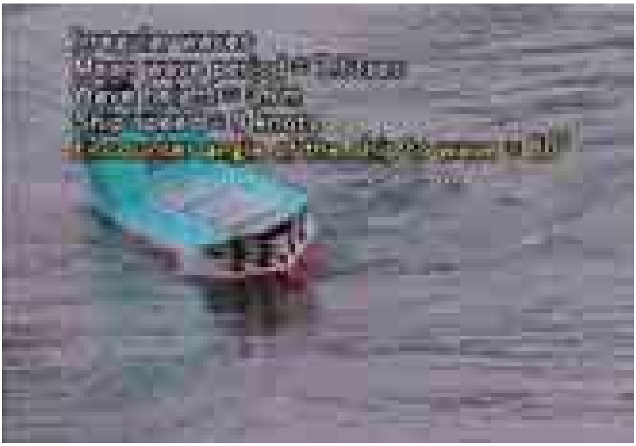
When a wave length of 79 m, which is equal to the ship's length, was applied, the pitching motion was intensified, and the phenomena associated with shipping seas constantly occurred.

Meanwhile, when the encounter angle of ship to wave was anywhere between zero to 90 degrees, and wave length was equal to the ship's length, there was almost no change in frequency of shipping seas compared with the encounter angle of ship to wave set between zero to 45 degrees.

When the angle of encounter of ship to the waves was increased to more than 45 degrees, the frequency of seas being shipped started to decrease. Moreover, when the same angle was increased in excess of 60 degrees, the frequency of shipping seas dramatically decreased. On the other hand, when the angle of encounter of ship to the waves was increased to 60 degrees, there was increased rolling motion (Photographs 75 and 76).



Photograph 75 Japan Captains' Association, DVD



Photograph 76 Japan Captains' Association, DVD

② When reducing speed

Next, results of trials to test for the probability of shipping seas were conducted using a ship model to simulate a wave length of 79 m, which would be equal to the ship's length, with a reduction in speed from 11 to 3 knots, with a much greater ship to wave encounter angle between the range of zero to 90 degrees. See Figure 77.

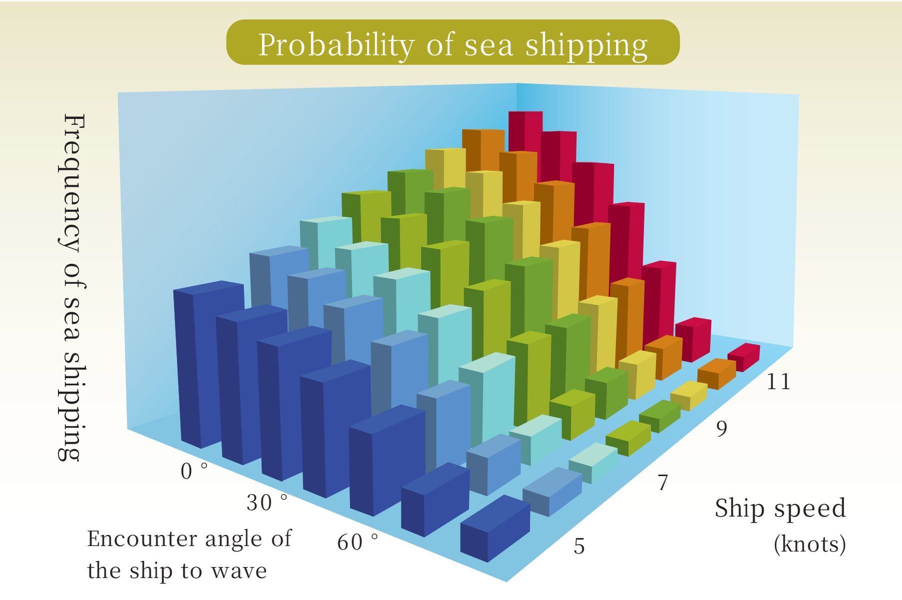


Fig. 77 Japan Captains' Association, DVD

Regarding the frequency of seas being shipped with an angle of encounter at zero degrees, when the speed is reduced from 11 knots to 6 knots, shipping seas can be reduced significantly. Further, no seas were shipped at a speed of 3 knots. Also, when the angle of encounter was altered to 60 degrees, the frequency of seas being shipped was decreased greatly.

In summing up the results of these trials, it is clear that the frequency of seas being shipped increased in proportion to ship speed, and that until the angle of encounter was increased to more than 60 degrees, changing the angle of encounter had limited affect. Figure 78 indicates ship speed and angle of wave encounter and shows wave heights represented by wind forces on the Beaufort scale corresponding to the frequency of shipping seas (10 times/hour) which are shown as blue lines. The relationship between wind forces on the Beaufort scale and wave height, as trial conditions, can been seen in the Table 79.

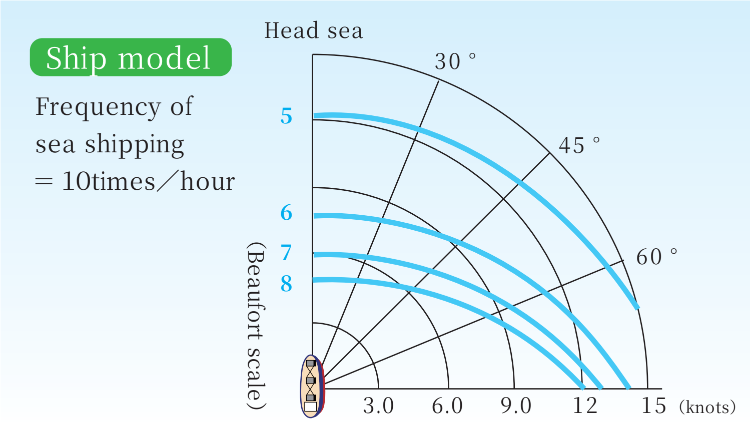


Fig. 78 Japan Captains' Association, DVD

Beaufort scale	5	6	7	8	9	10	11
Wave Height (m)	2.0	3.0	4.5	6.5	7.5	9.0	11.5

Fig. 79 Japan Captains' Association, DVD

According to the results obtained from ship model trials, if the allowable frequency of shipping seas is 10 times per hour in head seas under wind force 5, ship speed is 12 knots (Fig. 80). If the angle of encounter is altered to 45 degrees, a ship speed of up to 13 knots is permissible (Fig. 81).

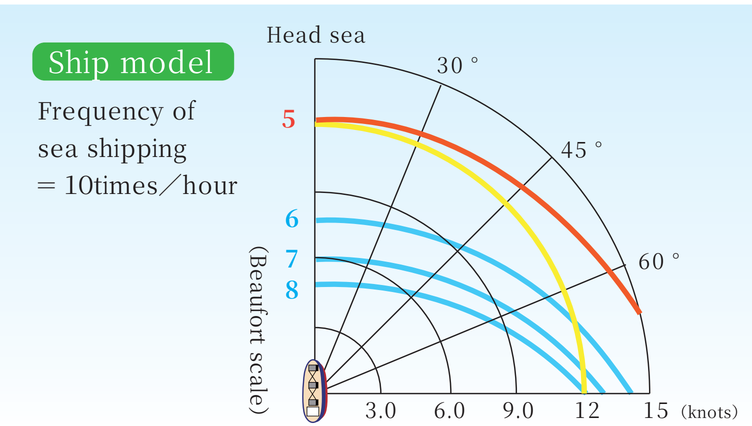


Fig. 80 Japan Captains' Association, DVD

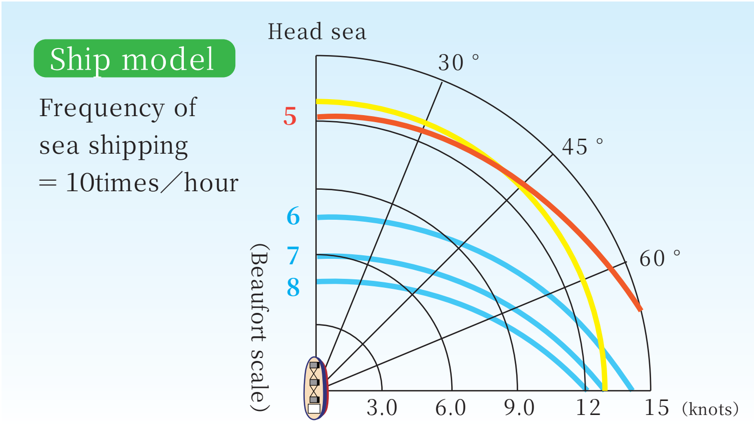


Fig. 81 Japan Captains' Association, DVD

If the allowable frequency of shipping seas is 5 times per hour in head seas, ship speed should be 11 knots (Fig. 82). That is to say, when wind force is increased up to approximately 5.2, the frequency of shipping seas can be decreased from 10 times per hour to 5 times per hour if speed is reduced to 11 knots from 12 knots.

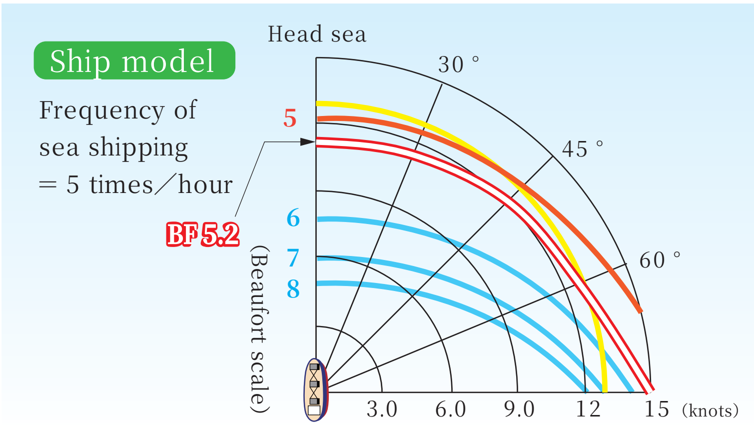


Fig. 82 Japan Captains' Association, DVD

Likewise, in the case of a fully laden container ship with a gross tonnage of 40,000 tons sailing in head seas under wind force 10, the frequency of seas being shipped can be reduced by half, from 10 times per hour to 5 times per hour if ship speed is reduced from 19 knots to 17 knots. In the case of a fully laden ore carrier with a gross tonnage of 110,000 tons in head seas under wind force 5, the frequency of seas being shipped can be reduced by half, from 10 times per hour to 5 times per hour if ship speed is reduced from 13 knots to 12 knots.

To summarize these results, it is clear from Figure 83 that the frequency of seas being shipped can be reduced by half by reducing speed only to around 1 ～ 2 knots.

Frequency reduction of shipping sea by speed reduction

	Coaster	Container	Bulker
GT	699 G/T	40,000 G/T	110,000 G/T
Lpp	78.5 m	250m	280m
Frequency of shipping sea	Beaufort 5	Beaufort 10	Beaufort 5
10 times/hour	12 Kts	19 Kts	13 Kts
5 times/hour	11 Kts	17 Kts	12 Kts
Speed difference	1 Kts	2 Kts	1 Kts

Table 83 Japan Captains' Association, DVD

7−1−4 Slamming Phenomenon

When a ship sails at a relatively high speed in head seas, slamming may occur. Slamming can be broken down into the following categories.

① Bottom slamming

Bottom slamming is caused by the interaction of a ship's bottom and the sea surface when a raised hull plunges into the sea (Fig. 84).

Fig. 84 Japan Captains' Association, DVD

② Bow flare slamming

This phenomenon is caused by collision impact with the sea surface at a relatively high speed. This phenomenon often occurs on a ship with a large bow flare such as a relatively fine container ship, PCC and fishing boats (Fig. 85).

Fig. 85 Japan Captains' Association, DVD

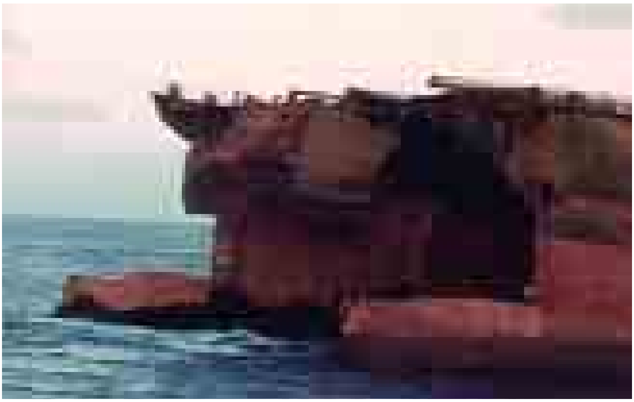
③ Bow breaking wave impact

When a vessel sails on a calm sea surface, she propulsers pushing the seawater forward. At that point, seawater is lifted at the bows (built-up waves) . This phenomenon often occurs when full-hull type ships such as tankers and bulkers are fully loaded, by breaking wave impact which is caused by breaking waves superimposed on built-up waves (Fig. 86).

Fig. 86 Japan Captains' Association, DVD

These forms of slamming phenomena often not only cause structural damage to the bow, bottom or bow flare, but also lead to major cargo damage. Occasionally, such impact and consequent hull damage may result in the ship sinking (Photographs 87 and 88).

Photograph 87 Japan Captains' Association, DVD



Photograph 88 Japan Captains' Association, DVD

Particularly relevant for large-sized container ships, springing and whipping will occur simultaneously: the former can be defined as stationary oscillations of the hull due to a continuous vibration between the hull construction and cyclic wave external force which can occur in relatively calm oceanographic conditions, and the latter can be defined as momentary oscillations of the hull induced by external impacts such as shock load associated with slamming in rough weather.

Just as with the trials that were conducted to analyse the frequency of seas being shipped using a ship model above, trial results of the bottom slamming phenomenon are as follows: The following conditions were applied: Ratio of wave length to ship length (Lpp): 1.0.

Gross tonnage	Length	Breadth	Depth	Design draft	Beaufort scale	Wave hight	Mean wave period	Wave length	Ship speed
699 G/T	78.5m (Lpp)	12.8 m	7.8m	4.52m Even Keel	6	3m	7.13 secs	79m	11knots

Whenever bottom slamming occurs, great pressure is instantaneously exerted on the bottom of the bow by the sea surface. The maximum force created during this impact acts to bend the ship's bow structure upward (Fig. 89).

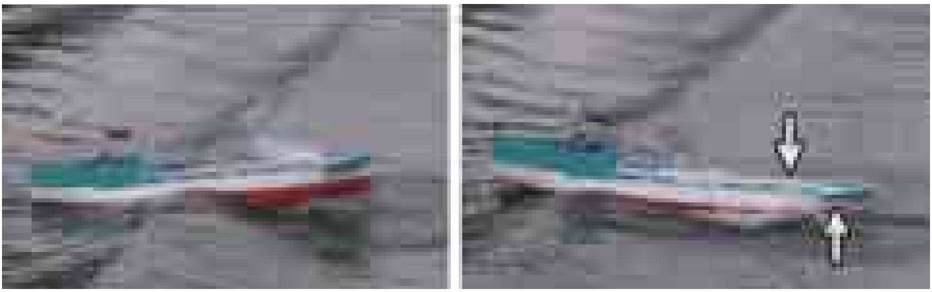


Fig. 89 Japan Captains' Association, DVD

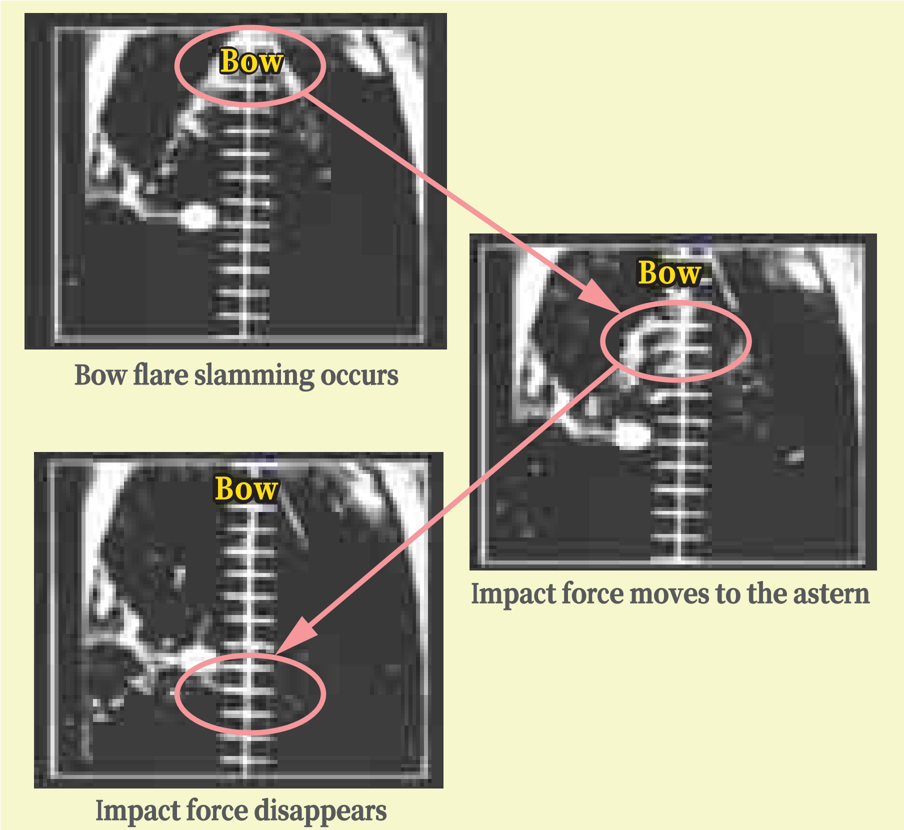


Fig. 90 Japan Captains' Association, DVD

Figure 90 is a scene which was photographed using a ship model with a transparent bottom so as to observe the process by which the phenomena associated with slamming occur and the influences of such phenomena. The photograph shows that water pressure due to slamming runs toward the bow from the stern. Here, in a ship model trial, researchers studied what conditions cause slamming to be generated.

Trial results of the frequency of bottom slamming are indicated in Figure 91 (three dimensional).

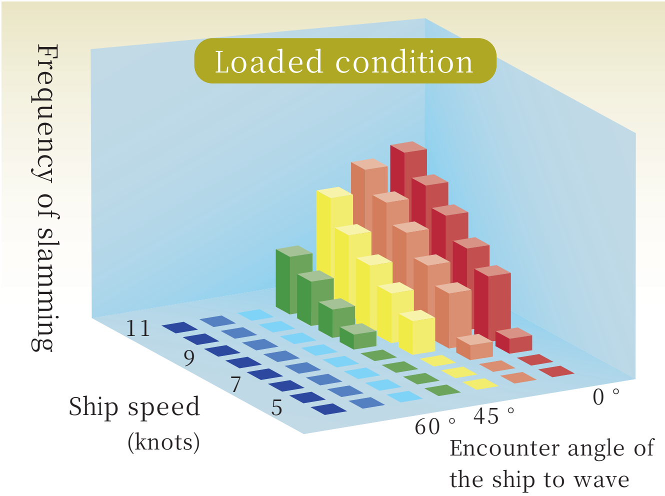


Fig. 91 Japan Captains' Association, DVD

Bow flare slamming becomes more frequent when wave length is equal to ship length in head and countering seas, but the frequency of it considerably decreased when ship speed was decreased to 6 knots. On the other hand, when ship speed was maintained at 11 knots and the encounter angle to the waves was changed (altered angle), the frequency of bow flare slamming did not decrease so significantly when the heading was changed to a course of less than 45 degrees. When the angle of encounter of ship to waves was increased to 60 degrees, there was increased rolling motion, but the frequency of bow flare slamming decreased somewhat. In the same way as we studied the frequencies of shipping seas, trials were conducted using model ships of a container ship and a bulker. A summary of the trials are shown in Table 92. Decreasing the speed may reduce the frequency of slamming dramatically.

Frequency reduction of slamming by speed reduction

	Coaster	Container	Bulker
GT	699 G/T	40,000 G/T	110,000 G/T
Lpp	78.5 m	250m	280m
Frequency of slamming	Beaufort 6	Beaufort 10	Beaufort 11
5 times/hour	5 Kts	17 Kts	8 Kts
2 times/hour	4 Kts	13 Kts	5 Kts
Speed difference	1 Kts	4 Kts	3 Kts

Table 92 Japan Captains' Association, DVD

7−1−5 Rough Weather Head and Countering Sea Countermeasures

The most effective countermeasure in head and countering seas of rough weather is to reduce speed. Namely, as the above model ship trials have proved, if the angle of encounter is not altered to more than 60 degrees, significant results cannot be expected. Although changing heading course can reduce the four different phenomena for head and countering seas, in this case, a new problem will occur: increased rolling motion. Particularly, please pay extra attention to parametric roll resonance.

The two different situations are shown in Figure 93: The first (with no deviation course from a to b) in the event of directly heading for the destination following the original course with slow steaming and the second (with deviation course **a** ⇒ **c** ⇒ **b**) in the event of navigating to the destination with deviation by keeping the speed before deceleration. Each relationship is as follows:

Initial Speed(Kts) : S

Deceleration(Kts) : R

Change-over Angle(degree) : α

Time required for decelerating and proceeding directly (a ⇒ b)

$$\frac{2 \times x}{(S-R)} \text{ hour}$$

Time required, keeping Initial Speed, for detouring (a ⇒ c ⇒ b)

$$\frac{2 \times y}{S} \text{ hour}$$

Change-over angle, in case of same number of required times, between deceleration and detouring

$$\frac{2 \times x}{(S-R)} = \frac{2 \times y}{S}$$

$$\text{Cos } \alpha^\circ = \frac{x}{y} = \frac{(S-R)}{S} = 1 - \frac{R}{S}$$

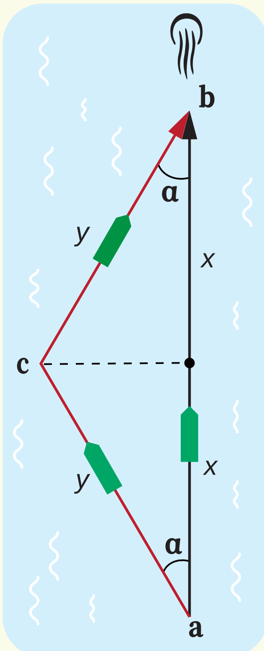


Fig. 93

Table 94 shows the angle needed for a direct heading and detour heading of vessels under the same time constraints that set sail at an initial speed of 20 knots or 15 knots.

Change-over angle when the required time in the case of direct deceleration and detour is the same

Deceleration (Kts)	Initial Speed 20 Kts		Initial Speed 15 Kts	
	Speed after Reducing(Kts)	Change-over Angle(degree)	Speed after Reducing(Kts)	Change-over Angle(degree)
2 Kts	18 Kts	26 degree	13 Kts	30 degree
3 Kts	17 Kts	32 degree	12 Kts	37 degree
4 Kts	16 Kts	37 degree	11 Kts	42 degree
5 Kts	15 Kts	41 degree	10 Kts	48 degree
6 Kts	14 Kts	45 degree	9 Kts	53 degree
7 Kts	13 Kts	49 degree	8 Kts	57 degree
8 Kts	12 Kts	53 degree	7 Kts	62 degree
9 Kts	11 Kts	56 degree	6 Kts	66 degree
10 Kts	10 Kts	60 degree	5 Kts	70 degree

Table 94

As can be seen in Tables 83(P.62) and 92(P.67), if speed is reduced by 2 to 3 knots, the frequency of seas being shipped and bottom slamming due to head and countering seas will be reduced by half.

On the other hand, when calculating the altered angle of the heading needed for a course, requiring the same amount of time to reach the destination, in the event of slow steaming with deviation and without reducing speed by 3 knots, when ship speed is at 20 knots, the altered angle necessary will be 32 degrees. For a ship sailing at 15 knots, the angle will be less than 37 degrees. Namely, if course heading angle is increased to 60 degrees in order avoid shipping seas or bottom slamming, even if the initial speed can be maintained, the time of arrival will still be delayed because of the deviated course taken.

On the contrary, in order to not be affected by such phenomenon on an altered course heading of 60 degrees, if a vessel sailing at 20 knots is reduced to 10 knots, and a vessel sailing at 15 knots is reduced to 7 knots (a speed reduction of approximately one-half), the time of arrival will be the same.

Compared with taking a detour, if speed is reduced by adjusting engine output, the amount of fuel consumption will be reduced. In addition, as described above, because there are wind and waves and huge undulations (swells) coming from several different directions, a ship cannot maintain her initial speed even if she can alter her heading course.

From the above, regarding rough weather head and countering sea countermeasures, if a specific ETA is to be realised, having the nerve to reduce speed so as not to expose the engine to the torque rich effect until out of the rough weather, only then is it recommendable to increase speed in order to make up for the delay, resulting in a safe voyage.

7－2 Ship Handling in Following Seas of Rough Weather

Commonly, it may have been thought that ship handling in head and countering seas, whereby the vessel heads towards the waves and wind, was considerably more challenging than handling a ship in following seas. However, from a ship operational point of view, the Master and Navigation Officers, for example, consider it to be easier because a ship in head and countering rough weather seas is easier to control as the ship's bow can be positioned towards wind and waves, paying extra attention to the ensuing influences (see previous chapter) the hull may undergo. On the contrary, when being exposed to following seas, more prudent ship operation will be necessary in rough weather, because there is a situation whereby the ship will be unmaneuverable.

When operating in following seas, attention must be paid to the four phenomena below:

1	**"Encounter Wave Grouping Phenomena"** occur when a ship is sailing in rough seas that involve irregular waves with sudden serial high waves attacking the ship regularly from the aft
2	**"Parametric Rolling Phenomena"** occurs when the amplitude of the ship's roll is gradually magnified
3	**"Reduction of Stability"** is a phenomena that occurs when a ship rides on a crest equal in length to the ship's length at midships, thus making the vessel unstable
4	**"Broaching-to Phenomena"** often resulting from surf-riding in which a ship loses steerage

7—2—1 Encounter Wave Grouping Phenomena

Ocean waves are an integration of irregular waves comprising those of diverse lengths, heights and directions. Specifically, when a ship is sailing at the same speed as a high wave group or navigating whereby the speed of the waves are faster than the speed of the ship speed at the aft, the ship is continuously being hit repeatedly and severely by a series of high waves that cause its manoeuvrability to be uncontrollable. Also, similar to head and countering seas, damage to the hull and steering can be caused by seas being shipped from the astern (poop down). This is a dangerous encounter group wave phenomenon. According to a number of experiment results, the most probable conditions under which a ship might be caught in a dangerous encounter wave grouping phenomena can be seen in Figure 95. Shown are the combination of encounter angles of the ship to the wave coming from aft, the ship's speed and the wave period.

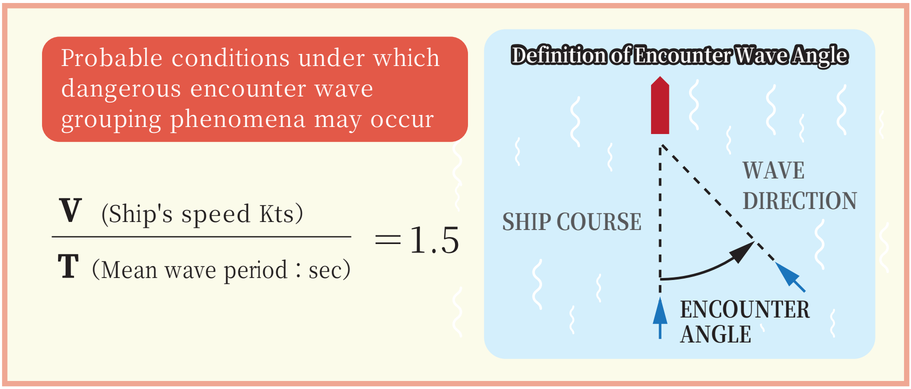


Fig. 95 Japan Captains' Association, DVD

According to 4.2.2. for successive high-wave attack of the IMO's Ship Handling Guidlines (MSC.1/Circ.1228: 11 January 2007), in the event of a ship being exposed to following seas directly from the aft, the dangerous zone is defined to be within a range of 1.3 to 2.0, as can be seen in Figure 96.

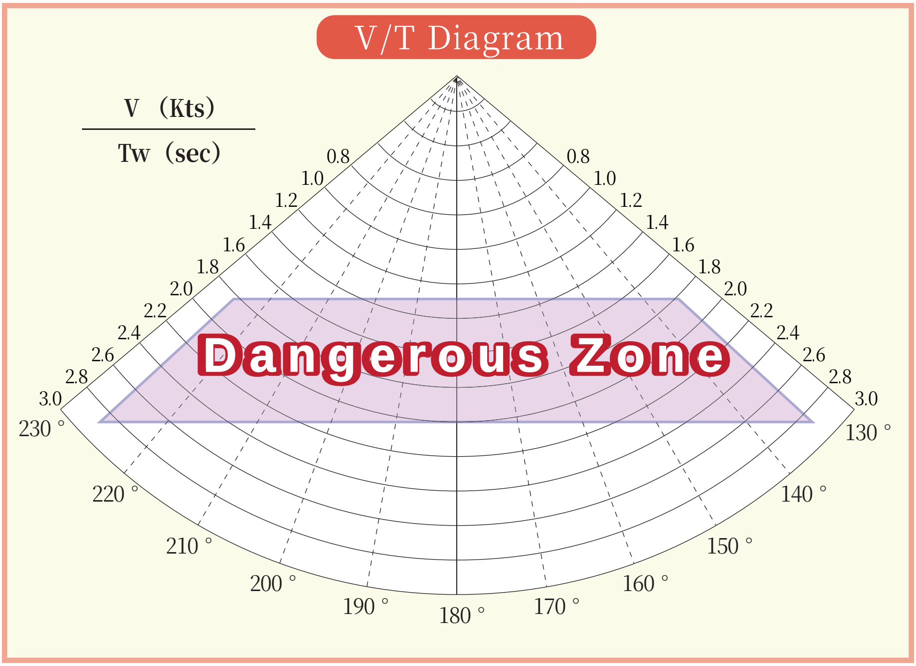


Fig. 96 IMO MSC.1/Circ.1228

Also, in 4.2.2.1 the guidelines define how to evaluate whether a ship is being successively attacked by high waves:

① The average wave length is larger than 0.8 L（Lpp：Length between Perpendicular）(MSC/Circ.1228)

② The significant wave height is larger than 0.04 L (Lpp: Length between Perpendicular)

Method of evaluation to assess whether a ship is being successively attacked by high waves

For instance, if a ship's Lpp is 120m, wave length is 126m and the significant wave height is 5m, it is possible to ascertain that the ship is being successively attacked by high waves (Calculating formula 97).

$$① \Rightarrow 120\,\text{m} \times 0.8 = 96\,\text{m} \leqq 126\,\text{m}$$

$$② \Rightarrow 120\,\text{m} \times 0.04 = 4.8\,\text{m} \leqq 5\,\text{m}$$

Calculating formula 97

When evaluating, the actual values of wave length and wave height shall be applied. However, because a ship obtains speed ahead while navigating, the actual wave period and length will be different from that experienced by the sway motion of a ship. A graph (Fig. 98) for determining the actual wave period from the wave period as experienced onboard is introduced both in the MSC.1/Circ.1228 and in "Safety measure for ferries and RORO vessels" by the Ministry of Land, Infrastructure, Transport and Tourism.

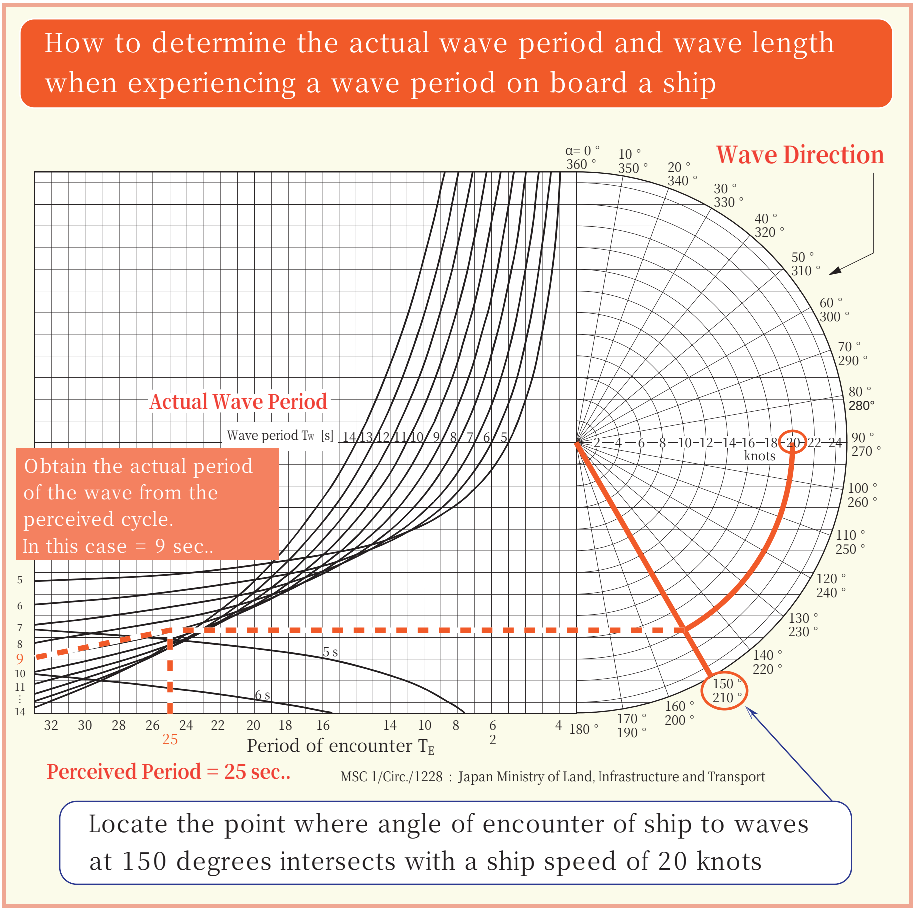


Fig. 98 IMO MSC.1/Circ.1228 and "Safety measure for ferries and RORO vessels" in Ministry of Land, Infrastructure, Transport and Tourism."

For instance, if a ship is sailing with its angle of encounter to waves at 30 °, its speed at 20 knots and feeling as though the period of waves are around 25 seconds, the actual wave period can be calculated using the following formula (The red lines in Fig. 98).

1	In the protractor to the right in the chart above, locate the point where the 30 degree angle represents waves coming from the aft (angle of encounter of ship to waves at 150 degrees) intersects with a ship speed of 20 knots.

▼

2	Trace along the dotted line to the left side of the graph to find the point at which the wave period is experienced onboard the ship (25 seconds in this case).

▼

3	The actual wave period will be the curve that is closest to the intersection at 25 seconds (9 seconds in this case).

The approximate values of wave length can be calculated using the formula below (see Calculating formula 99).

Wave length (m) = 1.56 × the square of wave period

Calculating formula 99

In the above formula, 1.56 × 9 × 9 = 126m (wave length). Also, the wave height can be observed by the naked eye.

Then, the Master will determine if the ship is within the dangerous zone using Figure 95. Namely, if the actual wave period and calculated wave length can be determined from the wave period experienced onboard, it will be possible to confirm whether the ship is within the dangerous zone using the actual wave period and ship speed (Fig. 100).

In this example, when sailing at 20 knots, the wave period and ship speed ratio show 2.22, thus it is possible to judge whether the ship is within the dangerous zone. By keeping the encounter angle to the waves unchanged and by reducing speed down to 10 knots, the ratio becomes 1.11, which means that it is possible to escape from the dangerous zone (Fig. 100).

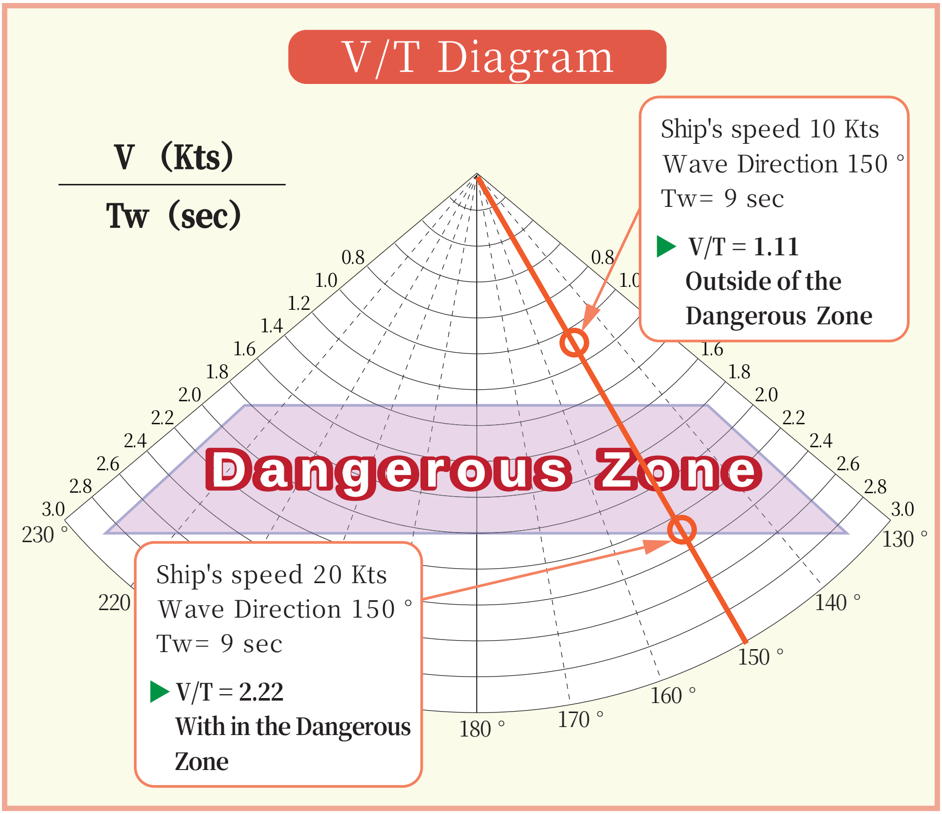


Fig. 100 IMO MSC.1/Circ.1228 and "Safety measure for ferries and RORO vessels" in Ministry of Land, Infrastructure, Transport and Tourism."

In reality, if your ship does end up within the dangerous zone as a result of the Encounter Wave Grouping Phenomenon, it is required that you navigate using a combination of speed reduction and alter course in order to escape from the zone.

7−2−2 Parametric Rolling Phenomena

When a ship proceeds through regular longitudinal waves, the ship rolls repeatedly, for instance, to the starboard side on the first crest and to the port side on the following trough (Fig. 101).

Fig. 101 Japan Captains' Association, DVD

However, when parametric rolling occurs, a ship rolls to the starboard side on the first crest and to port side on the following crest, which means that one rolling cycle is completed for every two wave cycles. Consequently, the amplitude of the ship's roll is gradually magnified. The ship rolls only once for every two cycles of passing waves, while the ship pitches once synchronous to the cycle of passing waves. This type of rolling is magnified when the encounter wave period reaches half of the ship's natural rolling period (Fig. 102).

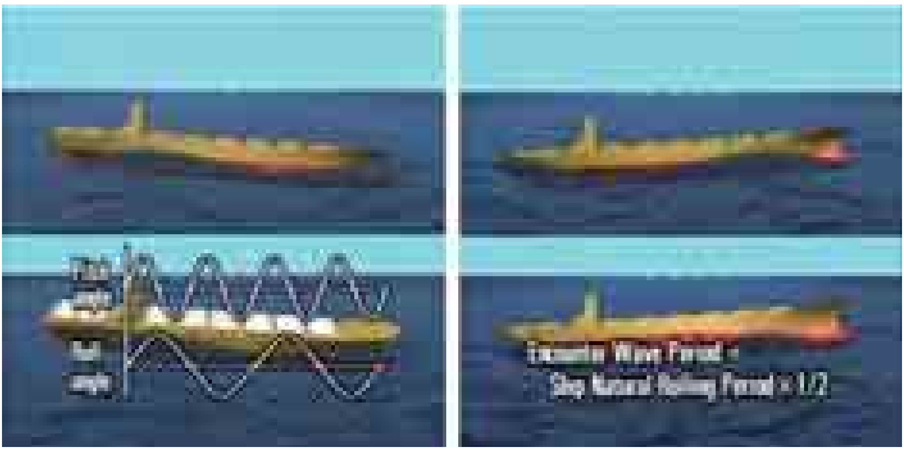


Fig. 102 Japan Captains' Association, DVD

Regarding this parametric rolling phenomena, the above conditions can occur not only in rough weather, but also in calm oceanographic conditions, when a ship may be approached by a huge swell from a quarter stern.

Even if your ship is exposed to a weak wind during her voyage, it is essential to keep sailing, while paying extra attention to the swells. Also, please remember that this is more likely to occur on ships with smaller GM. Countermeasures to avoid parametric rolling are as below:

Countermeasures for parametric rolling

- The encounter wave period shall not coincide with one half of the natural rolling period of ship.
- When the ship rolls once while pitching twice, and you believe that the ship is parametrically rolling, you should reduce the ship's speed as much as possible in order to maintain course. Or, in the case that there are several huge swells, you should observe which swells are causing parametric rolling and alter course by a wide margin if necessary.
- In addition, care must be taken regarding the synchronous rolling motion which might occur when the encounter wave period is equal to the natural rolling period of the ship.

= Synchronous rolling motions =

These phenomena might occur when the encounter wave period is equal to the natural rolling period of the ship. This synchronous rolling motion means that there is greater probability of ship rolling motion intensifying dramatically to cause a large angle inclination, and that control of the ship may be lost (Fig. 103).

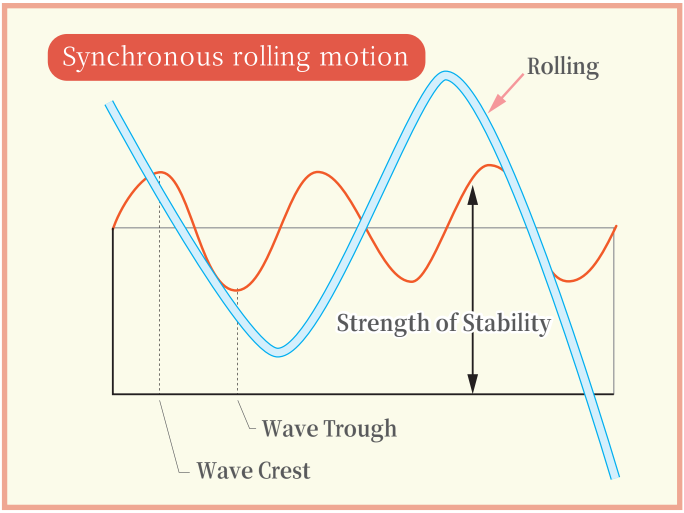


Fig. 103

7−2−3 Reduction of Stability

Firstly, stability will be reviewed.

＝ Stability ＝

When a ship floats under stable conditions, both the downward gravitational force, acting on the centre of gravity G, and the upward buoyant force, acting on the centre of buoyancy B, act on the same vertical line in equilibrium (Fig. 104).

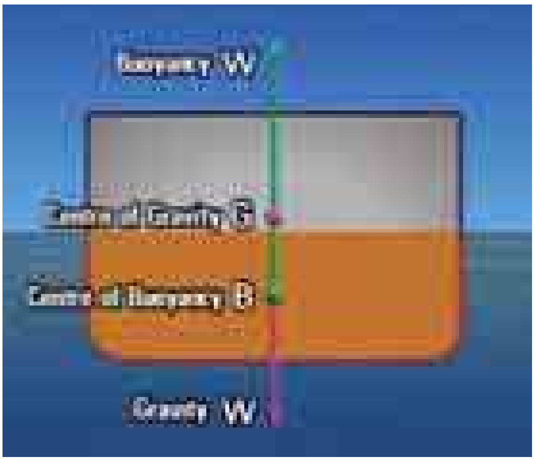


Fig. 104 Japan Captains' Association, DVD

If a ship heels due to an external force, the centre of buoyancy shifts from the initial vertical line due to the relocation of the immersed section, although the centre of gravity remains at the initial position. This creates an imbalance between the gravitational force and the buoyant force, which had previously been in line (Fig. 105).

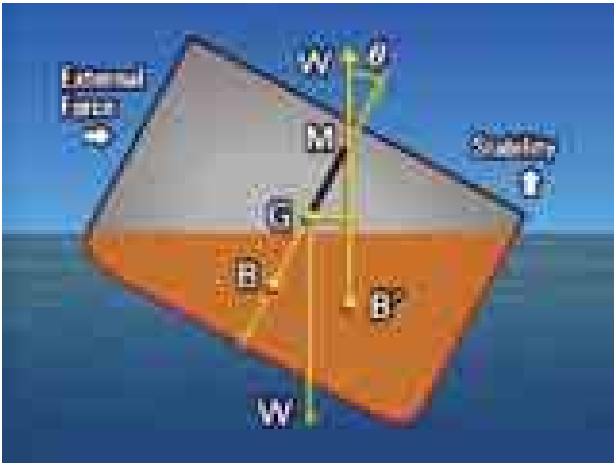


Fig. 105 Japan Captains' Association, DVD

The intersection point M of the vertical line passing the centre of buoyancy and the vertical centreline of the ship is called the metacentre, and the span between G centre of gravity and M metacentre is called GM. This GM governs a ship's stability and its dynamic characteristics.

The scope of a ship's stability is defined primarily by the length of the lever between the centre of buoyancy and the centre of gravity GZ, which is obtained by the formula whereby GM is multiplied by sinθ (Fig. 106).
Stability can be calculated with the following calculation formula:

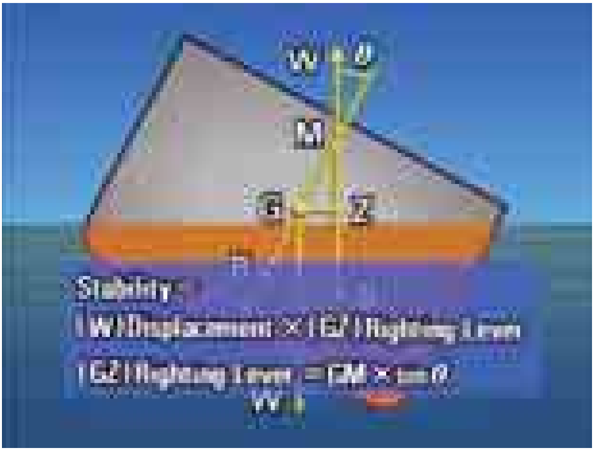


Fig. 106 Japan Captains' Association, DVD

Stability =
Displacement tonnage (W) × righting arm (righting lever) (GZ)

In addition, there is the following relationship between the natural rolling period of a ship (T) and GM which is closely related to stability (Calculating formula 107).

$$GM = \frac{4\pi^2 \times K^2}{g \times T^2}$$

$$0.64 \times \frac{B^2}{T^2}$$

$$T \quad \frac{0.8 \times B}{\sqrt{GM}}$$

T : Rolling period (sec)

K : Radius of gyration
(Large vessel 0.4×B) m

B : Breadth (m)

g : Gravitational acceleration
($9.8m/sec^2$)

Calculating formula 107

In the case of loaded dry bulk cargo or a ship loaded with liquid cargo such as a tanker, there is not a significant difference between the actual GM and the GM that was calculated by cargo stowage calculation software.

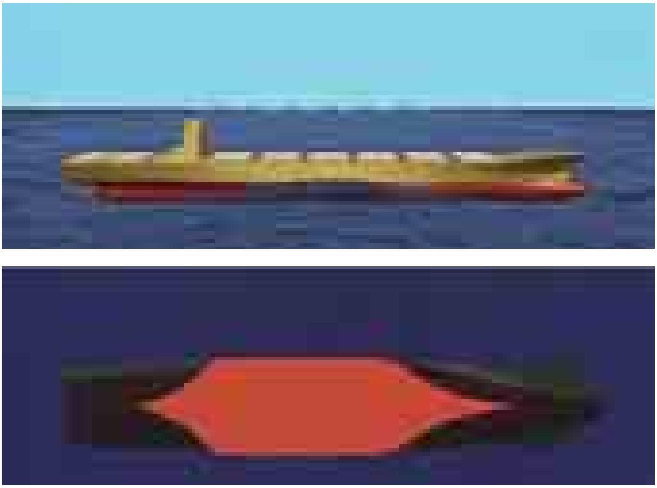
However, in the case of actual cargo weight being different from the declared weight, i.e. a container ship, there is a large difference between the actual GM and the calculated GM that uses cargo information provided from the terminal.

Regarding container ships with a large number of ports of call, stability is calculated (including each calculation of estimated departure draft, strength and GM) by reading the declared weights and differences compared to the actual weight from the drafts of each port, based on accumulated data and past records. In order to take the differences into consideration, firstly a calculation is carried out using the cargo information provided by the terminal. Then, the value, which multiplies the difference per one container which is calculated using the empirical value multiplied by the quantity of containers, is to be purposefully input into the 1st tier of the cargo on deck most closely located to the centre of hull gravity G - we calculated the estimated departure draft and GM using a wide margin to be on the safe side.

After having departed port, each duty officer gauges the natural rolling period of the ship, the Master checks actual GoM (values added that account for the reduction of GM due to liquid with free surface in the tank) against a reference list of GM and natural rolling period, the final drawing of which is provided by the shipyard.

= Reduction of stability in following seas =

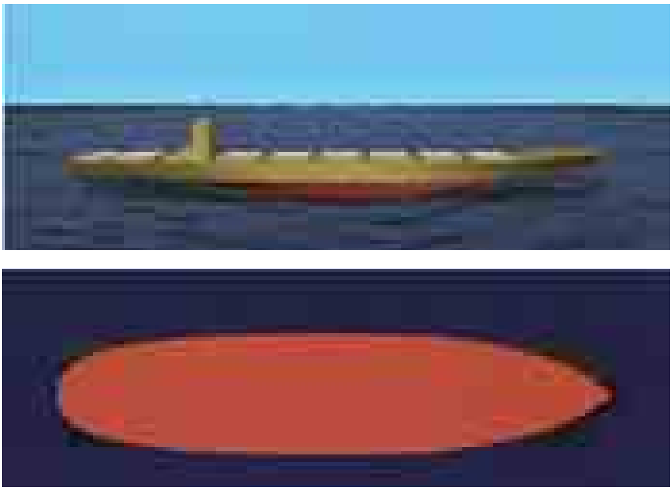
The degree of stability is determined generally by the area of the water plane as previously shown in the chart. For instance, if a ship rides on a crest equal in length to the ship's length at midships, stability is reduced as the water planes at her bow and stern decrease due to the lower water lines at both ends (Fig. 108).



Wave crest at midships water planes ▶ small ▶ reduction of stability

Fig. 108 Japan Captains' Association, DVD

On the other hand, when a trough of the same wave passes the midships, stability is increased as the water planes at her bow and stern increase due to higher water lines (Fig. 109).



Wave trough at midships water planes ▶ large ▶ increase of stability

Fig. 109 Japan Captains' Association, DVD

Even if a ship is in a situation with reduced stability, the time span the ship might endure this will be shorter when sailing in counter seas. Conversely, the possibility of risk is increased in following and quartering seas, as the time span is greatly increased (Fig. 110).

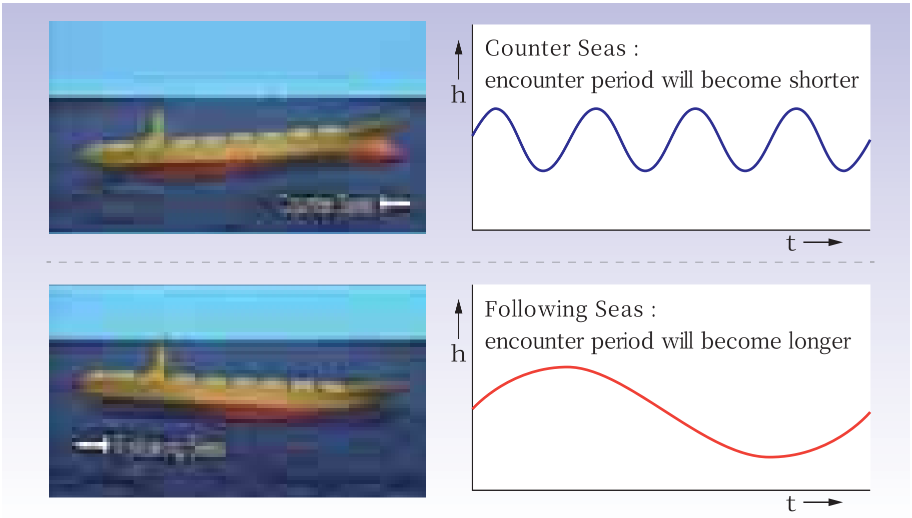


Fig. 110 Japan Captains' Association, DVD

Figure 111 shows the increase or decrease of a container ship's stability. The curves show that stability drastically decreases at the crest of the wave.

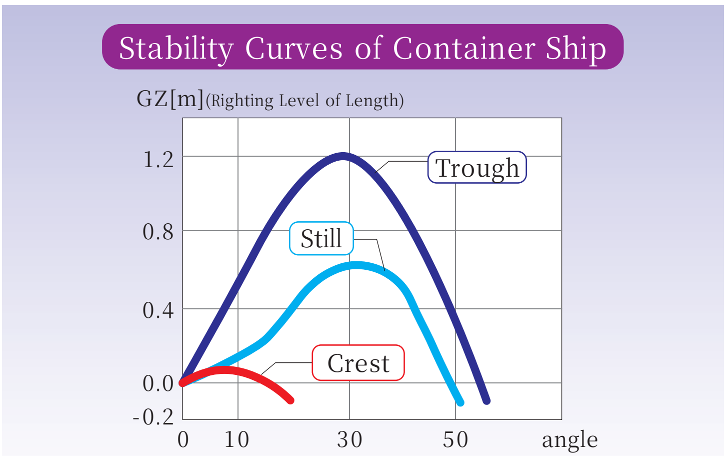


Fig. 111 Japan Captains' Association, DVD

The reduction of stability tends to be more significant in fine ships with a large flare, such as: container ships, fishing vessels and pleasure boats; and least significant in full-hull ships, such as: tankers and bulkers (Fig. 112).

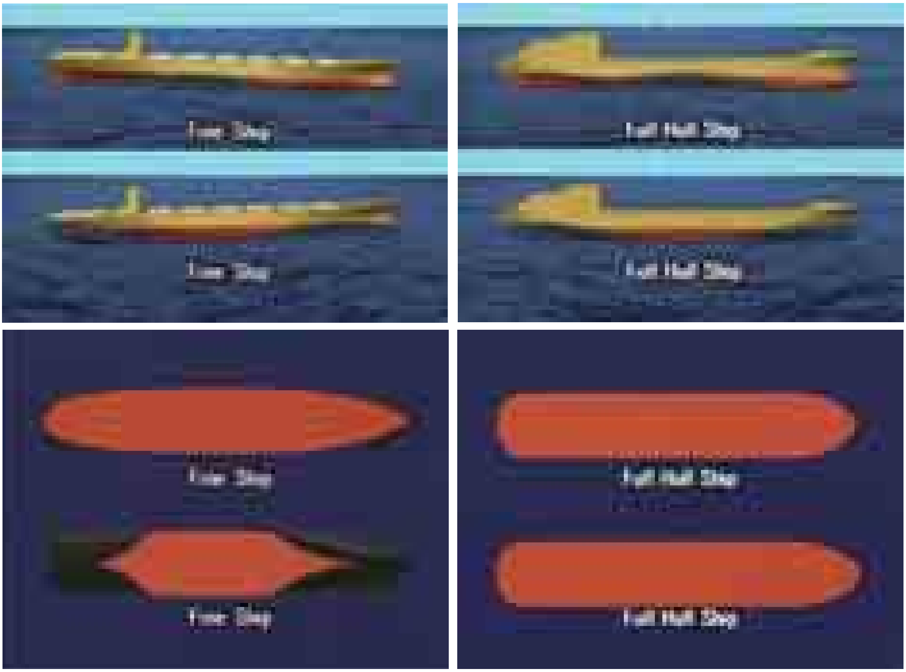


Fig. 112 Japan Captains' Association, DVD

Reduction of stability like this occurs when the ship speed is the same as the speed of the waves. When the crest of a wave stays under the metacentre, the risk can be increased. Figure 113 shows a diagram of tank experiments of a model container ship, and at which angle the ship capsizes. It is possible to observe that capsizing occurred at around 1.5, when dangerous encounter wave grouping phenomena are more frequent.

(Dimensions of the model ship)

Length	Breadth	Depth	Draft
150.0m	27.2m	13.5m	8.5m

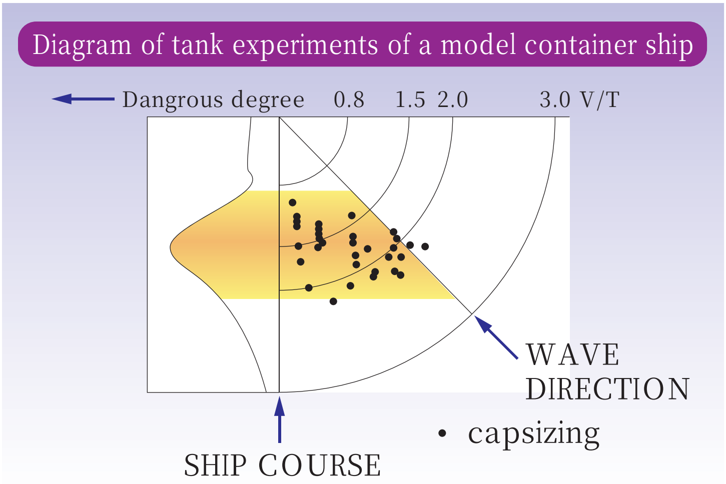


Fig. 113 Japan Captains' Association, DVD

Using the same model ship sailing at 22 knots, Figure 114 indicates the frequency of capsizes due to a reduction of stability by changing the angles of encounter in following seas. One can see that the frequency of capsizes increases when sailing in following seas that approach the aft from 10 to 50 degrees. In particular, 20 to 40 degrees aft is conspicuously the most dangerous area.

Fig. 114 Japan Captains' Association, DVD

From data obtained by past experiments, we can see how the frequency of capsizes due to a reduction of stability changes depending on the ship's speed. The data indicate that the faster the ship sails in those sea states, the greater the risk of capsizing is due to the reduction of stability, and in contrast, the risk decreases at reduced speeds (Fig. 115).

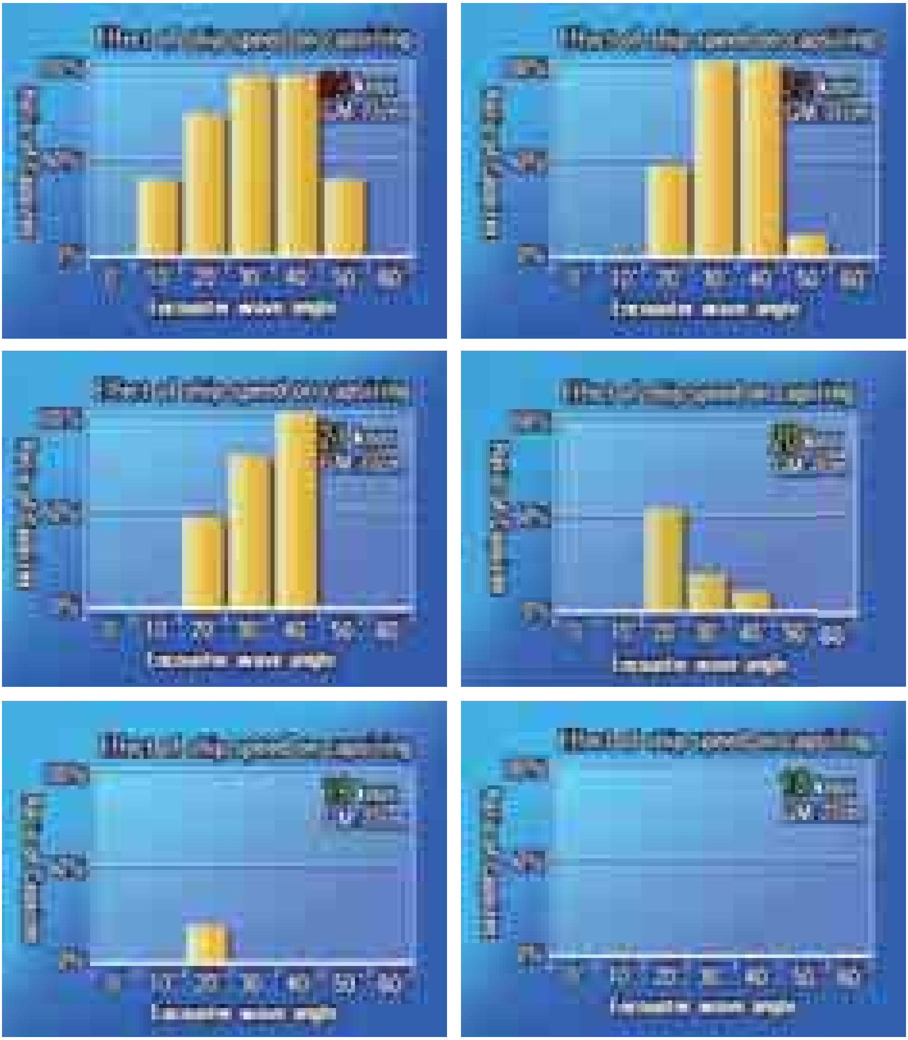


Fig. 115 Japan Captains' Association, DVD

= Countermeasures for the reduction of stability in following seas =

If the angle of encounter is not altered to 20-40 degrees, the frequency of capsizes will decrease. However, the most effective countermeasure is to reduce speed so that the crest of a wave does not stay under the metacentre as described above.

7－2－4 Surf-riding (Broaching-to) Phenomena

Broaching-to phenomena occurs when operating in following seas and when the speed of the waves is the same or faster than the ship's speed. It often results in a ship losing steerage when it is being accelerated forwards on the steep forefront of a high wave, which is then followed by surf-riding. This is an extremely dangerous phenomenon as the ship will lose steerage and turn abruptly with great centrifugal inertia exposing her broadside to beam seas, often resulting in instantaneous capsizing.

In the diagram (Fig. 116), the abscissa represents propeller revolutions and the ordinate represents the speed of the model ship. In calm seas, the ship's speed changes, as propeller revolutions (r.p.m.) increase. R.P.M. and ship speed are proportional, however it becomes a loose curve due to propeller slip.

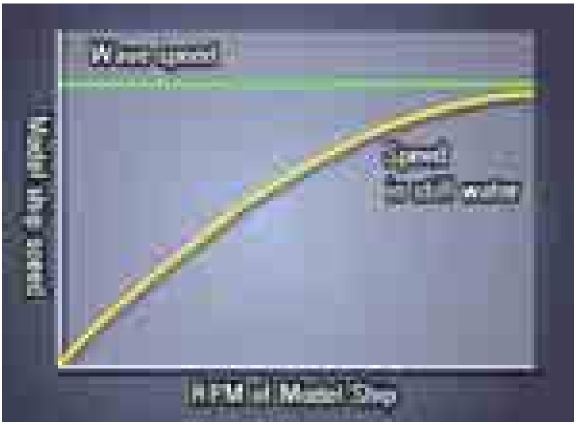


Fig. 116 Japan Captains' Association, DVD

In contrast, in following seas, even if propeller revolutions are increased, the actual speed of the model ship varies between up and down slopes of a wave, because ascending is impeded every up slope of a wave and descending accelerated at each down slop of a wave under the influence of the sea (blue coloured area). The difference between these ascending and descending speeds tends to increase as propeller revolutions increase (Fig. 117).

Fig. 117 Japan Captains' Association, DVD

However, if propeller revolutions are increased, this regular repetition of speed change suddenly collapses at a specific number of revolutions, and the ship's speed sharply increases discontinuously (orange coloured area). In other words, the surf-riding phenomenon is created when the maximum speed of these repeating motions of the model ship reaches the same speed as the waves (Fig. 118).

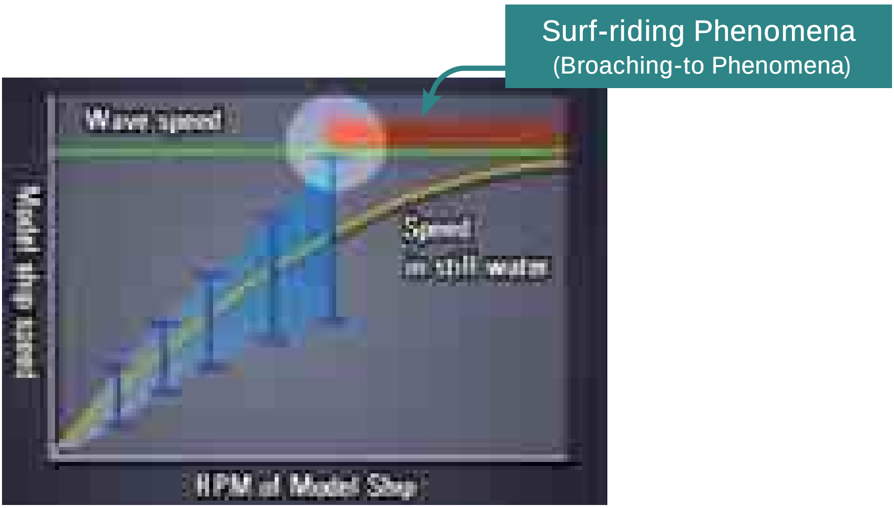


Fig. 118 Japan Captains' Association, DVD

As can be seen in Figs. 119, 120 and 121, the graphs show the patterns of speed changes when a model ship sails while being exposed to following seas at a constant rotation of propeller revolutions. The horizontal axis represents time (seconds) and the vertical axis represents ship speed. The ship speed is accelerated at the down slope of a wave with a resultant greater ratio of period of proceeding with the waves and the ship speed is decelerated at the up slope of wave with a resultant smaller ratio of period. Figure 119 indicates the speed changes that occur when propeller revolutions and speed are low. Speed variations almost draw sinusoidal waves with a resultant smaller ratio of period.

When propeller revolution and speed are low

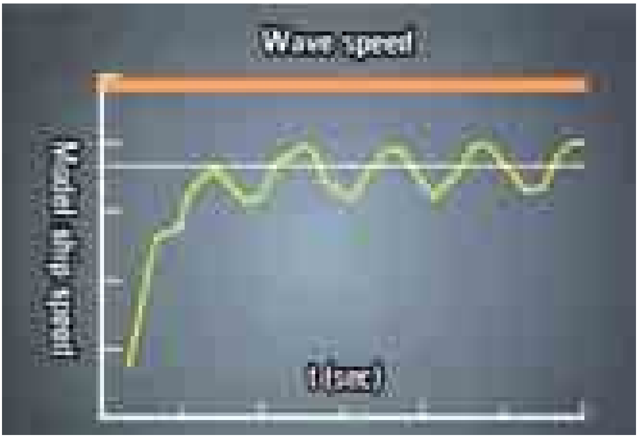


Fig. 119 Japan Captains' Association, DVD

While the ship speed accelerates it closer matches the speed of the wave, the number of the speed variations decrease (Figs. 120 and 121).

When the ship's speed increases a little

Fig. 120 Japan Captains' Association, DVD

When the ship's speed is increased further

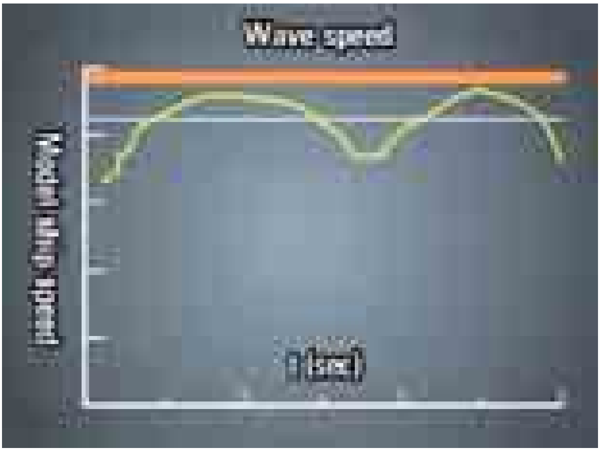


Fig. 121 Japan Captains' Association, DVD

As can be seen in Figure 122, the ship speed is accelerated at the down slope of a wave with a resultant greater ratio of period of proceeding with the waves and the ship speed is decelerated at the up slope of wave with a resultant smaller ratio of period.

Fig. 122 Japan Captains' Association, DVD

Even if propeller revolutions are further increased, ship speed does not fluctuate any more when the ship comes under the grip of surf-riding (Fig. 123).

Transfer to Surf-riding (Broaching-to)

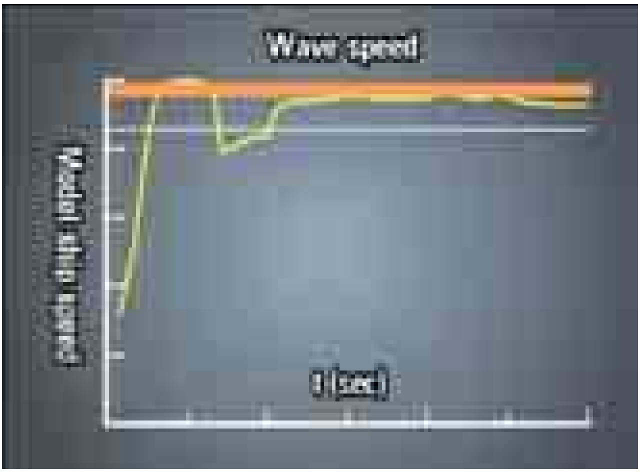


Fig. 123 Japan Captains' Association, DVD

To avoid surf-riding (broaching-to), one should be aware of the ship's critical speed that causes this phenomenon. The critical speed varies according to wave length and wave height. According to 4.2.1 of the Guidlines (MSC.1/Circ.1228), the following formula (Calculation formula 124) for a ship's critical speed is set forth.

Broaching Occurence **Critical Ship's speed (kts)** =

$$1.8 \times \sqrt{\text{Ship's Length (Lpp)}} \div \cos(180 - \alpha)$$

Range of α : 135° < α < 225°

Calculating formula 124

Therefore, the ship's speed should be reduced to less than 1.8 multiplied by root L. (length of ship) in order to avoid surf-riding.

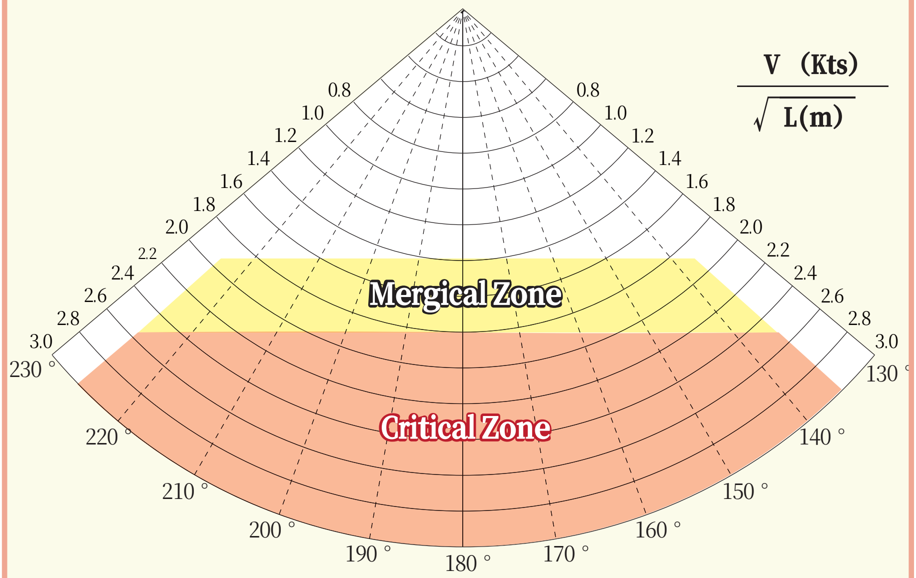
Although this cannot be found in the MSC.1/Circ 1228, in the previous MSC.1/Circ .707(19 October 1995), the following formula (Calculating formula 125) is shown as "Surf-Riding (Broaching-to) marginal zone" in order to avoid huge speed changes. This speed change runs the risk of causing broaching-to, although it does not reach the "Surf-Riding (Broaching-to) dangerous zone" and surf-riding. To be on the safe side, it is necessary not to enter this zone.

Broaching Occurence **Merginal Ship's speed (kts)** =

$$1.4 \times \sqrt{\text{Ship's Length (Lpp)}} \div \cos(180 - \alpha)$$

Calculating formula 125

Figure 126 shows the "Surf-Riding Dangerous Zone" (area in pink colour) which is introduced in the Guidlines (MSC.1/Circ.1228). In addition, "Surf-Riding (Broaching-to) marginal zone (area in yellow colour)" shown in MSC.1/Circ .707(19 October 1995) has been added.



Broaching Occurence **Critical Ship's speed (kts)** =

$$1.8 \times \sqrt{\text{Ship's Length (Lpp)}} \div \cos(180 - \alpha)$$

Broaching Occurence **Merginal Ship's speed (kts)** =

$$1.4 \times \sqrt{\text{Ship's Length (Lpp)}} \div \cos(180 - \alpha)$$

In Fig. 126 "Surf-Riding (Broaching-to) marginal zone speed" has been added to MSC.1/1228 4.2.1

Table 127 shows the ship's Critical speed at which broaching-to phenomena will occur. When deciding on the optimum speed, you should take the extra speed added by acceleration at the down slope of a wave into consideration. Even for a vessel whose Lpp is longer than 200m, it is important to be aware of this phenomenon that may more commonly be associated with high speed crafts.

Broaching Occurences Critical Speed								
Ship's Length (Lpp)	10 m	20 m	50 m	70 m	100 m	150 m	200 m	300 m
$1.8 \times \sqrt{Lpp}$	6 Kts	8 Kts	13 Kts	15 Kts	18 Kts	22 Kts	25 Kts	31 Kts
Broaching Occurences Mergical Speed								
$1.4 \times \sqrt{Lpp}$	4 Kts	6 Kts	10 Kts	12 Kts	14 Kts	17 Kts	20 Kts	24 Kts

Table 127

When a ship is sailing in shallow waters, the surf-riding phenomenon can occur even when a ship is sailing at a comparatively low speed. This is because the propagation of waves is deterred in shallow waters, so the critical point may be comparatively attainable even when a ship is sailing at a low speed. This should be borne in mind in particular by seafarers operating high-speed pleasure boats and fishing vessels.

7－2－5 Countermeasures for Rough Weather Following Seas

The most effective countermeasure in head and countering seas in rough weather is to reduce speed, however, in following seas, the combination of dynamically changing heading course and ship speed reduction are required in order to avoid the aforementioned phenomena from occurring. In addition, a great deal of ship operating skill will be needed because of the decreased steerage ability experienced when attempting to change heading course.

In particular, when there are wind and waves and several huge swells from a quarter stern, the countermeasures should be taken while at the same time appropriately judging which wind and waves or which direction of swell are causing the ship’s pitching and rolling. The length, height, period and speed of the waves must also be precisely grasped. Prior to all of this, it should be noted that, prompt maneuvering in order to avoid even coming into contact with such phenomena should be taken at the earliest possible moment.

§ 8 Conclusion

In anticipation of operating a ship in areas of rough weather, such as head and countering or following seas, the Master is duty-bound to: obtain as much information as possible on weather and sea conditions, select the most suitable sea route while taking into account the ETA, be aware of the amount of fuel being consumed and possible cargo damage that can occur as a result of rough weather. The charterer will demand that a tight schedule and minimized amount of fuel usage be adhered to in order to improve profitability of the vessel.

Needless to say, the final choice of route lies with the Master and the safety of his vessel. With this in mind, all information between the charterer, the shipowner, the ship management company and the WRS (Weather Routing Service) provider must be shared. However, first and foremost, it is necessary to set the course with the agreement of those concerned and the Master - who stands on the front line of ship handling, whose opinions and intentions are to be well valued - before departing the port and before the ship is exposed to rough sea.

Although the precise prediction of weather and sea conditions has improved over the recent years, it is still not 100% guaranteed. Naturally, although one may choose a route with a detour, there may be a situation whereby a shorter voyage was not taken due to a misinformed rough sea forecast. However, this came about as a result of weather and sea conditions which are difficult to forecast in advance correctly. Therefore, through the cooperation and understanding of all concerned parties including the charterers/operators, shipowners and ship management companies it should be understood that external and unpredictable phenomena that are beyond the control of the seafarer are existent and that those seafarers should not be held singularly accountable as an afterthought.

Attachment: MSC.1/Circ. 1228 (11 January 2007)

References

- MSC.1/Circ. 1228 (11 January 2007) : Attachments
  imo.udhb.gov.tr/dosyam/EKLER/1228.pdf
- " Safety measure for ferries and RORO vessels " in Maritime Bureau of Ministry of Land, Infrastructure, Transport and Tourism. "(28April 2011)
  http://www.mlit.go.jp/common/000144432.pdf
- Japan Captains ' Association, DVD
  SHIP HANDLING IN FOLLOWING SEAS
  SHIP HANDLING IN HEAD AND COUNTERING SEAS
  Weather and Sea States around Japan and Characteristics of Major Ports and Bay in Japan
  Many of the figures and photographs are cited from the above DVD. We are deeply grateful for being allowed to use the above references.
- From the Japan Meteorological Agency website
  https://www.jma.go.jp/jma/index.html
  We would also like express our gratitude to the Japan Meteorological Agency for allowing us refer to their website for figures and explanations.
- Masanori Shiraki, 2007, Shin Hyakuman-nin no Tenki Kyōshitsu: Seizando
- From the Japan Weather Association website

Attachment: MSC.1/Circ. 1228 (11 January 2007)

INTERNATIONAL MARITIME ORGANIZATION
4 ALBERT EMBANKMENT
LONDON SE1 7SR

Telephone: 020 7735 7611
Fax: 020 7587 3210

IMO

E

Ref. T1/2.04

MSC.1/Circ.1228
11 January 2007

REVISED GUIDANCE TO THE MASTER FOR AVOIDING DANGEROUS SITUATIONS IN ADVERSE WEATHER AND SEA CONDITIONS

1 The Maritime Safety Committee, at its eighty-second session (29 November to 8 December 2006), approved the Revised Guidance to the master for avoiding dangerous situations in adverse weather and sea conditions, set out in the annex, with a view to providing masters with a basis for decision making on ship handling in adverse weather and sea conditions, thus assisting them to avoid dangerous phenomena that they may encounter in such circumstances.

2 Member Governments are invited to bring the annexed Revised Guidance to the attention of interested parties as they deem appropriate.

3 This Revised Guidance supersedes the Guidance to the master for avoiding dangerous situations in following and quartering seas (MSC/Circ.707).

***

I:\CIRC\MSC\01\1228.doc

ANNEX

REVISED GUIDANCE TO THE MASTER FOR AVOIDING DANGEROUS SITUATIONS IN ADVERSE WEATHER AND SEA CONDITIONS

1 GENERAL

1.1 Adverse weather conditions, for the purpose of the following guidelines, include wind induced waves or heavy swell. Some combinations of wave length and wave height under certain operation conditions may lead to dangerous situations for ships complying with the IS Code. However, description of adverse weather conditions below shall not preclude a ship master from taking reasonable action in less severe conditions if it appears necessary.

1.2 When sailing in adverse weather conditions, a ship is likely to encounter various kinds of dangerous phenomena, which may lead to capsizing or severe roll motions causing damage to cargo, equipment and persons on board. The sensitivity of a ship to dangerous phenomena will depend on the actual stability parameters, hull geometry, ship size and ship speed. This implies that the vulnerability to dangerous responses, including capsizing, and its probability of occurrence in a particular sea state may differ for each ship.

1.3 On ships which are equipped with an on-board computer for stability evaluations, and which use specially developed software which takes into account the main particulars, actual stability and dynamic characteristics of the individual ship in the real voyage conditions, such software should be approved by the Administration. Results derived from such calculations should only be regarded as a supporting tool during the decision making process.

1.4 Waves should be observed regularly. In particular, the wave period T_W should be measured by means of a stop watch as the time span between the generation of a foam patch by a breaking wave and its reappearance after passing the wave trough. The wave length λ is determined either by visual observation in comparison with the ship length or by reading the mean distance between successive wave crests on the radar images of waves.

1.5 The wave period and the wave length λ are related as follows:

$$\lambda = 1.56 \cdot T_W^2 \text{ [m] or } T_W = 0.8\sqrt{\lambda} \text{ [s]}$$

1.6 The period of encounter T_E could be either measured as the period of pitching by using stop watch or calculated by the formula:

$$T_E = \frac{3T_W^2}{3T_W + V\cos(\alpha)} \text{ [s]}$$

where V = ship's speed [knots]; and
α = angle between keel direction and wave direction (α = 0° means head sea)

1.7 The diagram in figure 1 may as well be used for the determination of the period of encounter.

1.8 The height of significant waves should also be estimated.

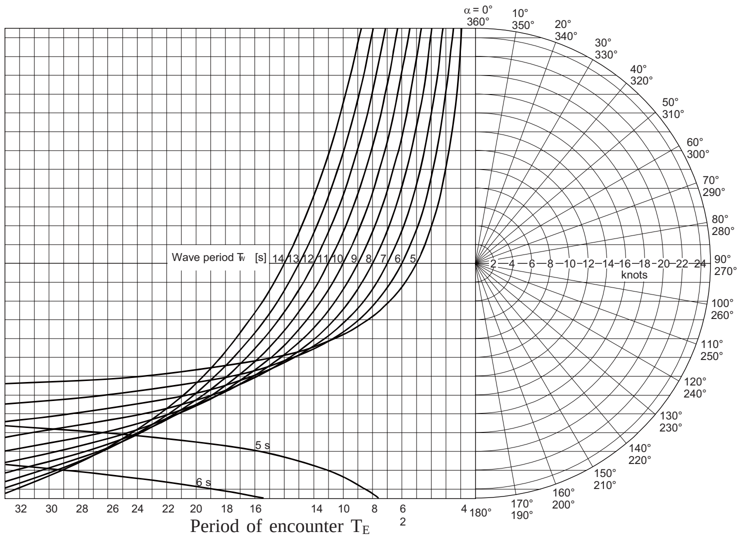


Figure 1: Determination of the period of encounter T_E

2 CAUTIONS

2.1 It should be noted that this guidance to the master has been designed to accommodate for all types of merchant ships. Therefore, being of a general nature, the guidance may be too restrictive for certain ships with more favourable dynamic properties, or too generous for certain other ships. A ship could be unsafe even outside the dangerous zones defined in this guidance if the stability of the ship is insufficient. Masters are requested to use this guidance with fair observation of the particular features of the ship and her behaviour in heavy weather.

2.2 It should further be noted that this guidance is restricted to hazards in adverse weather conditions that may cause capsizing of the vessel or heavy rolling with a risk of damage. Other hazards and risks in adverse weather conditions, like damage through slamming, longitudinal or torsional stresses, special effects of waves in shallow water or current, risk of collision or stranding, are not addressed in this guidance and must be additionally considered when deciding on an appropriate course and speed in adverse weather conditions.

2.3 The master should ascertain that his ship complies with the stability criteria specified in the IS Code or an equivalent thereto. Appropriate measures should be taken to assure the ship's watertight integrity. Securing of cargo and equipment should be re-checked. The ship's natural period of roll T_R should be estimated by observing roll motions in calm sea.

3 DANGEROUS PHENOMENA

3.1 Phenomena occurring in following and quartering seas

A ship sailing in following or stern quartering seas encounters the waves with a longer period than in beam, head or bow waves, and principal dangers caused in such situation are as follows:

3.1.1 Surf-riding and broaching-to

When a ship is situated on the steep forefront of a high wave in following or quartering sea conditions, the ship can be accelerated to ride on the wave. This is known as surf-riding. In this situation the so-called broaching-to phenomenon may occur, which endangers the ship to capsizing as a result of a sudden change of the ship's heading and unexpected large heeling.

3.1.2 Reduction of intact stability when riding a wave crest amidships

When a ship is riding on the wave crest, the intact stability can be decreased substantially according to changes of the submerged hull form. This stability reduction may become critical for wave lengths within the range of 0.6 L up to 2.3 L, where L is the ship's length in metres. Within this range the amount of stability reduction is nearly proportional to the wave height. This situation is particularly dangerous in following and quartering seas, because the duration of riding on the wave crest, which corresponds to the time interval of reduced stability, becomes longer.

3.2 Synchronous rolling motion

Large rolling motions may be excited when the natural rolling period of a ship coincides with the encounter wave period. In case of navigation in following and quartering seas this may happen when the transverse stability of the ship is marginal and therefore the natural roll period becomes longer.

3.3 Parametric roll motions

3.3.1 Parametric roll motions with large and dangerous roll amplitudes in waves are due to the variation of stability between the position on the wave crest and the position in the wave trough. Parametric rolling may occur in two different situations:

.1 The stability varies with an encounter period T_E that is about equal to the roll period T_R of the ship (encounter ratio 1:1). The stability attains a minimum once during each roll period. This situation is characterized by asymmetric rolling, i.e. the amplitude with the wave crest amidships is much greater than the amplitude to the other side. Due to the tendency of retarded up-righting from the large amplitude, the roll period T_R may adapt to the encounter period to a certain extent, so that this kind of parametric rolling may occur with a wide bandwidth of encounter periods. In quartering seas a transition to harmonic resonance may become noticeable.

.2 The stability varies with an encounter period T_E that is approximately equal to half the roll period T_R of the ship (encounter ratio 1:0.5). The stability attains a minimum twice during each roll period. In following or quartering seas, where the encounter period becomes larger than the wave period, this may only occur with very large roll periods T_R, indicating a marginal intact stability. The result is symmetric rolling with large amplitudes, again with the tendency of adapting the ship response to the period of encounter due to reduction of stability on the wave crest. Parametric rolling with encounter ratio 1:0.5 may also occur in head and bow seas.

3.3.2 Other than in following or quartering seas, where the variation of stability is solely effected by the waves passing along the vessel, the frequently heavy heaving and/or pitching in head or bow seas may contribute to the magnitude of the stability variation, in particular due to the periodical immersion and emersion of the flared stern frames and bow flare of modern ships. This may lead to severe parametric roll motions even with small wave induced stability variations.

3.3.3 The ship's pitching and heaving periods usually equals the encounter period with the waves. How much the pitching motion contributes to the parametric roll motion depends on the timing (coupling) between the pitching and rolling motion.

3.4 Combination of various dangerous phenomena

The dynamic behaviour of a ship in following and quartering seas is very complex. Ship motion is three-dimensional and various detrimental factors or dangerous phenomena like additional heeling moments due to deck-edge submerging, water shipping and trapping on deck or cargo shift due to large roll motions may occur in combination with the above mentioned phenomena, simultaneously or consecutively. This may create extremely dangerous combinations, which may cause ship capsize.

4 OPERATIONAL GUIDANCE

The shipmaster is recommended to take the following procedures of ship handling to avoid the dangerous situations when navigating in severe weather conditions.

4.1 Ship condition

This guidance is applicable to all types of conventional ships navigating in rough seas, provided the stability criteria specified in resolution A.749(18), as amended by resolution MSC.75(69), are satisfied.

4.2 How to avoid dangerous conditions

4.2.1 For surf-riding and broaching-to

Surf-riding and broaching-to may occur when the angle of encounter is in the range 135°<α<225° and the ship speed is higher than $\left(1.8\sqrt{L}\right)/\cos(180-\alpha)$ (knots). To avoid surf riding, and possible broaching the ship speed, the course or both should be taken outside the dangerous region reported in figure 2.

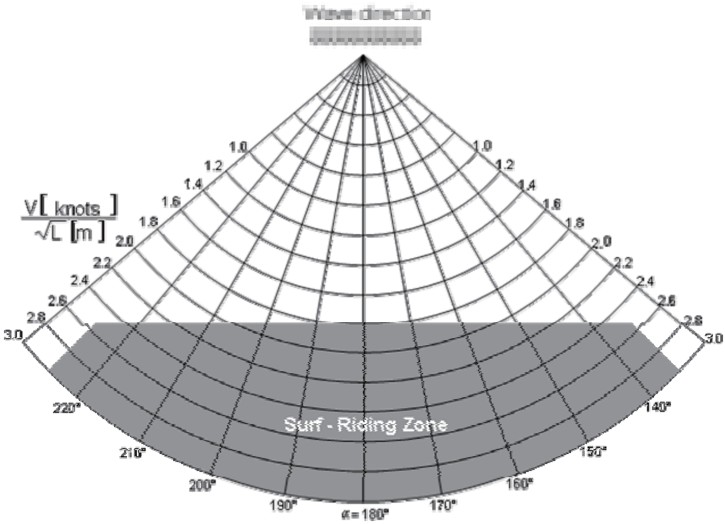


Figure 2: Risk of surf-riding in following or quartering seas

4.2.2 For successive high-wave attack

4.2.2.1 When the average wave length is larger than 0.8 L and the significant wave height is larger than 0.04 L, and at the same time some indices of dangerous behaviour of the ship can be clearly seen, the master should pay attention not to enter in the dangerous zone as indicated in figure 3. When the ship is situated in this dangerous zone, the ship speed should be reduced or the ship course should be changed to prevent successive attack of high waves, which could induce the danger due to the reduction of intact stability, synchronous rolling motions, parametric rolling motions or combination of various phenomena.

4.2.2.2 The dangerous zone indicated in figure 3 corresponds to such conditions for which the encounter wave period (T_E) is nearly equal to double (i.e., about 1.8-3.0 times) of the wave period (T_W) (according to figure 1 or paragraph 1.4).

4.2.3 For synchronous rolling and parametric rolling motions

4.2.3.1 The master should prevent a synchronous rolling motion which will occur when the encounter wave period T_E is nearly equal to the natural rolling period of ship T_R.

MSC.1/Circ.1228
ANNEX
Page 6

4.2.3.2 For avoiding parametric rolling in following, quartering, head, bow or beam seas the course and speed of the ship should be selected in a way to avoid conditions for which the encounter period is close to the ship roll period ($T_E \approx T_R$) or the encounter period is close to one half of the ship roll period ($T_E \approx 0.5 \cdot T_R$).

4.2.3.3 The period of encounter T_E may be determined from figure 1 by entering with the ship's speed in knots, the encounter angle α and the wave period T_W.

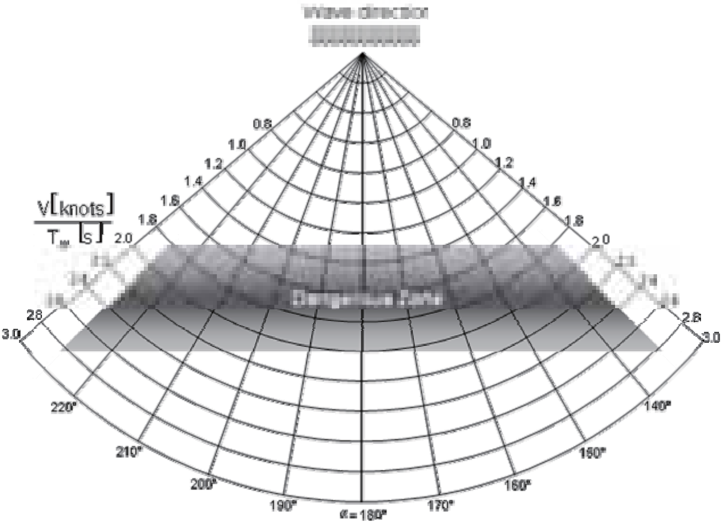


Figure 3: Risk of successive high wave attack in following and quartering seas

Abbreviations and symbols

Symbols	Explanation	Units
T_W	wave period	s
λ	wave length	m
T_E	encounter period with waves	s
α	angle of encounter (α = 0° in head sea, α = 90° for sea from starboard side)	degrees
V	ship's speed	knots
T_R	natural period of roll of ship	s
L	length of ship (between perpendiculars)	m

I:\CIRC\MSC\01\1228.doc

JAPAN P&I CLUB
日本船主責任相互保険組合

Website	www.piclub.or.jp/en/

Principal Office (Tokyo)	15th Floor, ARK Hills Front Tower, 2-23-1, Akasaka, Minato-ku, Tokyo 107-0052, JAPAN Phone: 81-3 6687 0505 Fax: 81-3 6871 0051
Kobe Branch	6th Floor Shosen-Mitsui Bldg. 5, Kaigandori Chuo-ku, Kobe, Hyogo 650-0024, Japan Phone: 81-78-321-6886 Fax: 81-78-332-6519
Fukuoka Branch	3rd Floor Hakata-Ekimae Center Bldg., 1-14-16 Hakata Ekimae, Hakata-ku, Fukuoka, Fukuoka 812-0011, Japan Phone: 81-92-260-8945 Fax: 81-92-482-2500
Imabari Branch	5th Floor, Central Bldg, 2-2-1, Kitahoraicho, Imabari, Ehime, 794-0028, Japan Phone: 81-898-33-1117 Fax: 81-898-33-1251
Singapore Branch	80 Robinson Road #14-01 Singapore 068898 Phone: 65-6224-6451 Fax: 65-6224-1476
Japan P&I Club (UK) Services Ltd	5th Floor, 38 Lombard Street, London, U.K., EC3V 9BS Phone: 44-20-7929-3633 Fax: 44-20-7929-7557

Edited by Loss Prevention and Ship Inspection Dept. Japan P&I Club