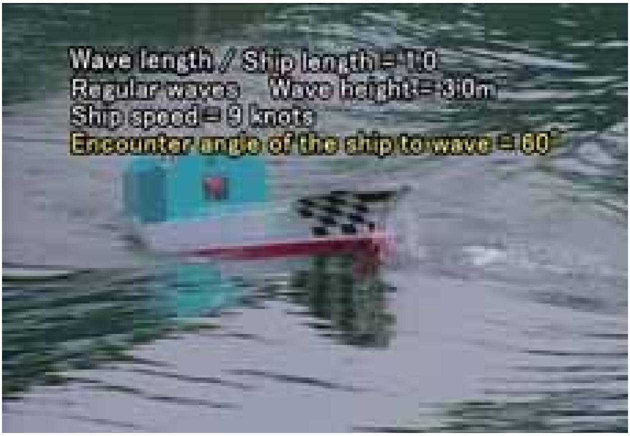
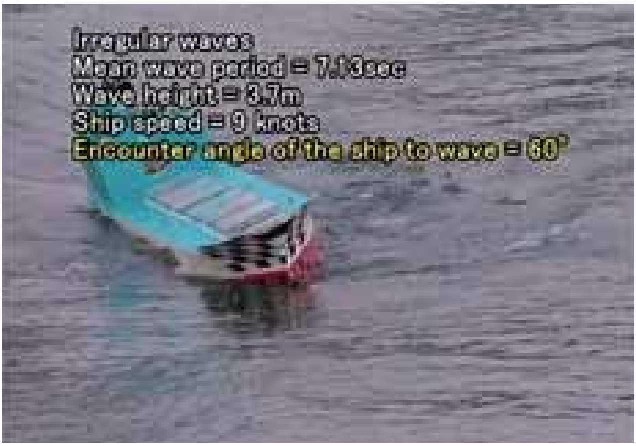
increased in excess of 60 degrees, the frequency of shipping seas dramatically decreased. On the other hand, when the angle of encounter of ship to the waves was increased to 60 degrees, there was increased rolling motion (Photographs 75 and 76).



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.

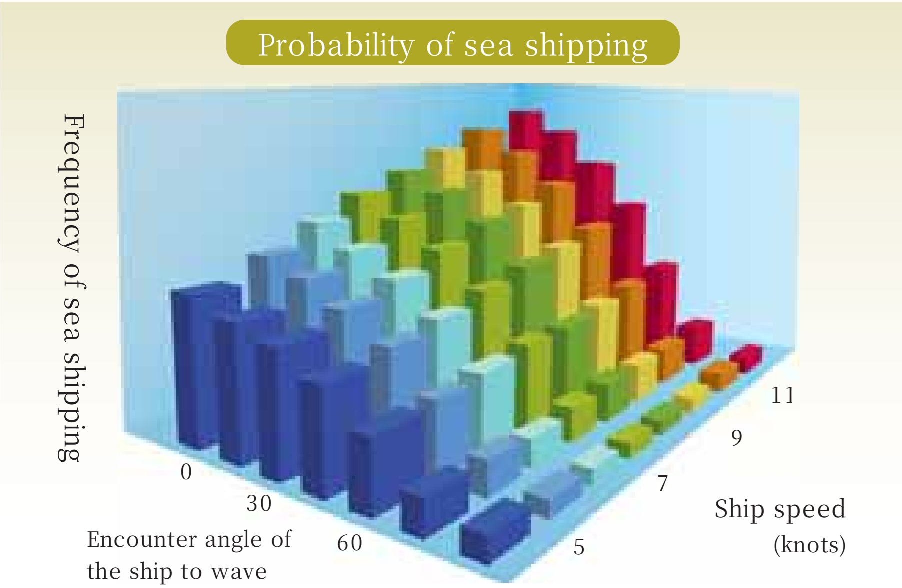


Fig. 77 Japan Captains' Association, DVD

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.

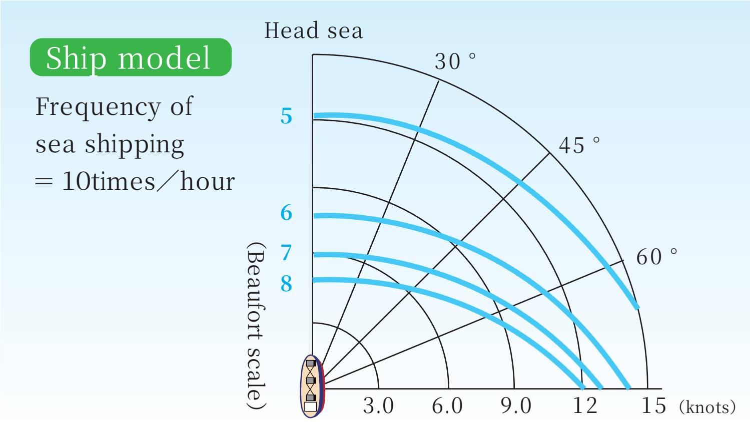


Fig. 78 Japan Captains' Association, DVD

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).

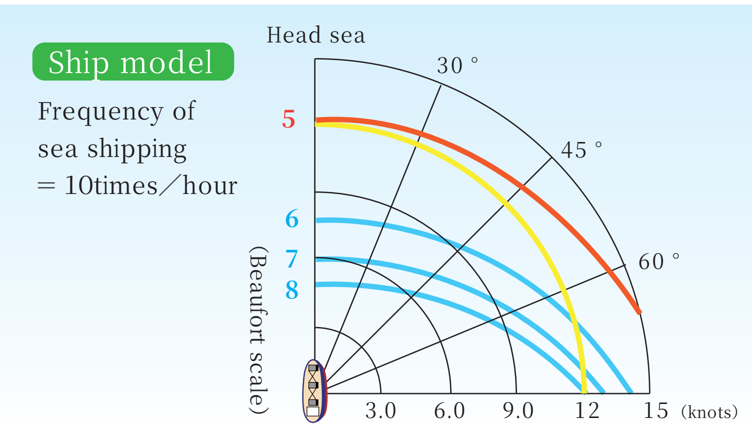


Fig. 80 Japan Captains' Association, DVD

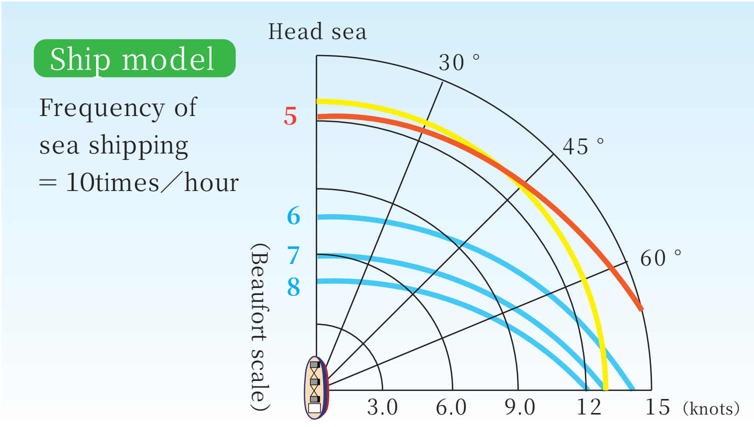


Fig. 81 Japan Captains' Association, DVD

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.

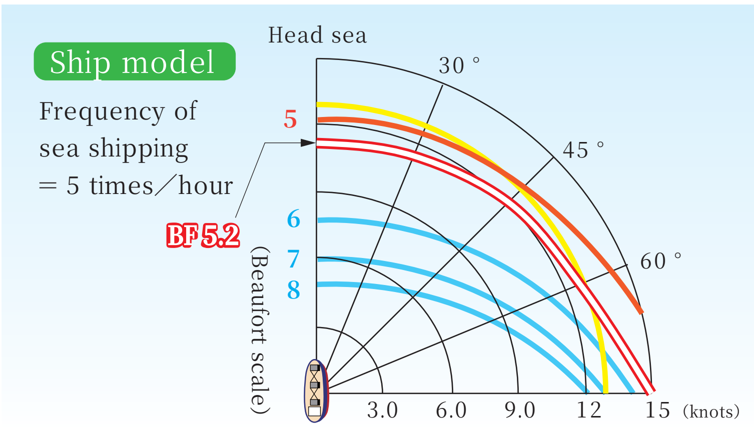


Fig. 82 Japan Captains' Association, DVD

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).

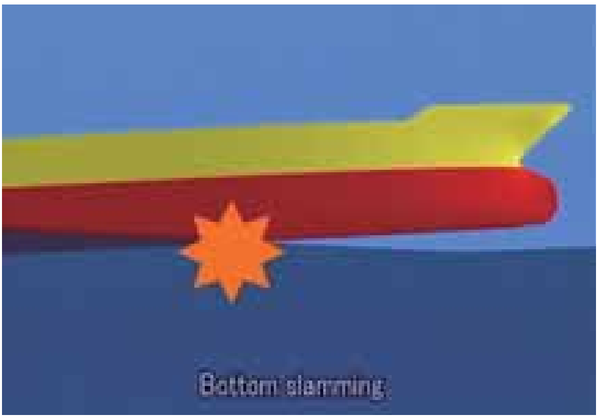


Fig. 84 Japan Captains' Association, DVD

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.

The author also has been aboard six large-sized container ships in total as a Master. As the author later learned, as a result of such phenomena known as springing or whipping, bow flare slamming occurred due to wind and waves and undulations (swells) diagonally in front, which caused the containers on the foremast and No.1 hold deck to slide from side to side. Although I knew that tankers and bulker hulls can be curved longitudinally, I was very concerned as to whether or not the shell plating would crack, on account of the fact that I had never seen containers slide from side to side in such a way before. At the dock inspection, I remember that there were small, but not severe, cracks on the floor of the under deck passage and handrails in the hold. I believe that new guidelines on the effects of vibrations while operating a ship in rough seas will be necessary.

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

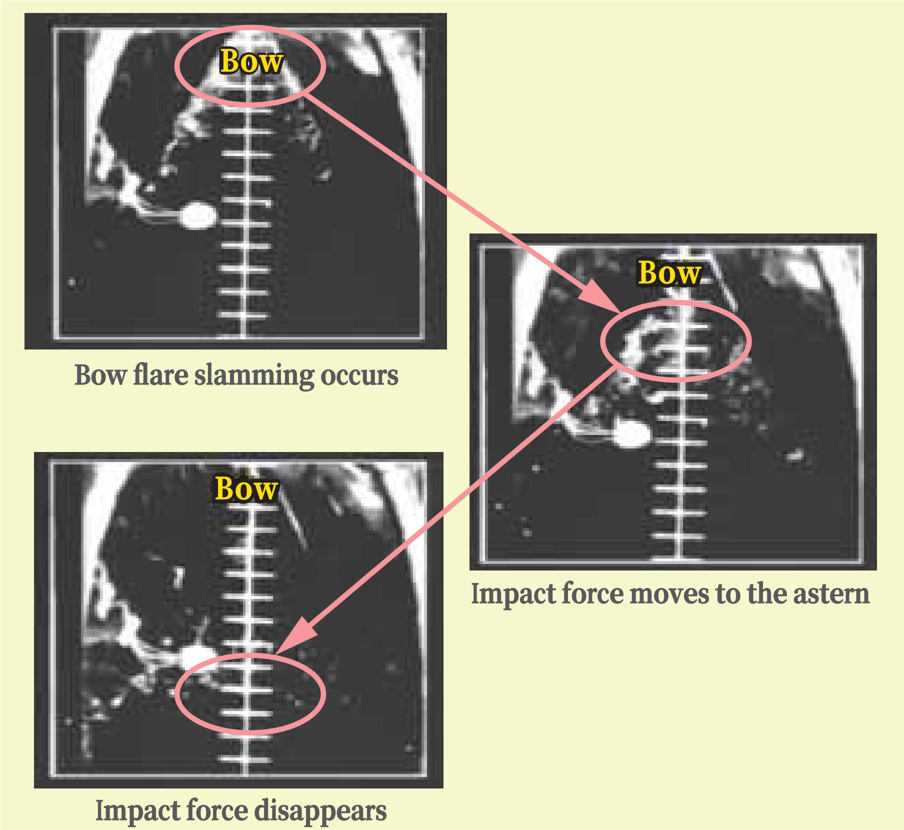


Fig. 90 Japan Captains' Association, DVD

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).

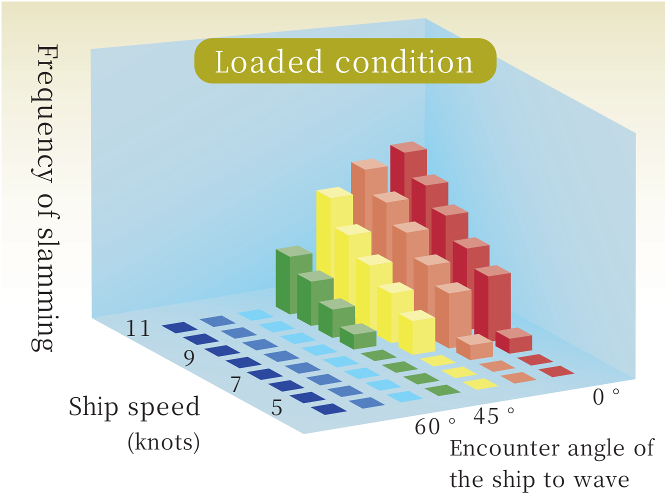


Fig. 91 Japan Captains' Association, DVD

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 increase 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

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

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

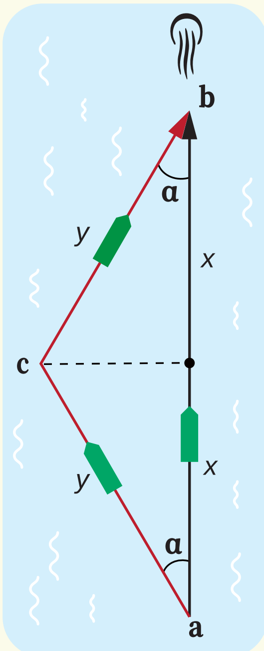


Fig. 93

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.64) and 92(P.69), 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.

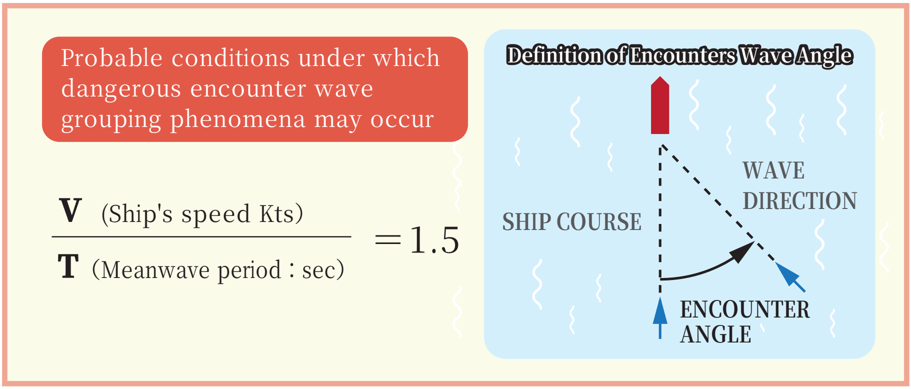


Fig. 95　Japan Captains' Association, DVD

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.

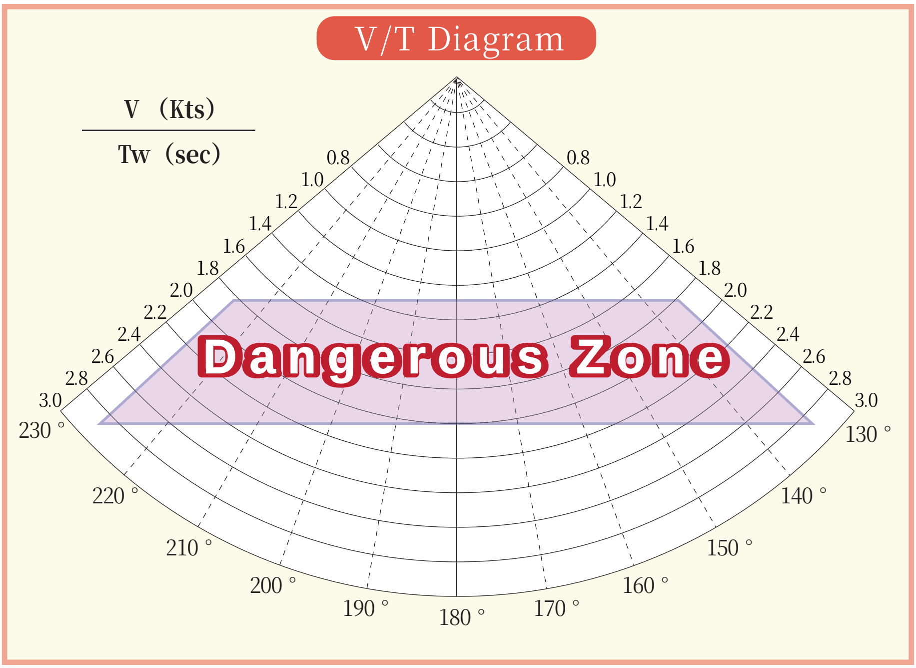


Fig. 96　IMO MSC.1/Circ.1228

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)　(See Note 4)

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

Note4: According to the"Safety measure for ferries and RORO vessels" in Ministry of Land, Infrastructure, Transport and Tourism." (28 April 2011), the average wave length is recommended to be larger than 0.6 L

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).

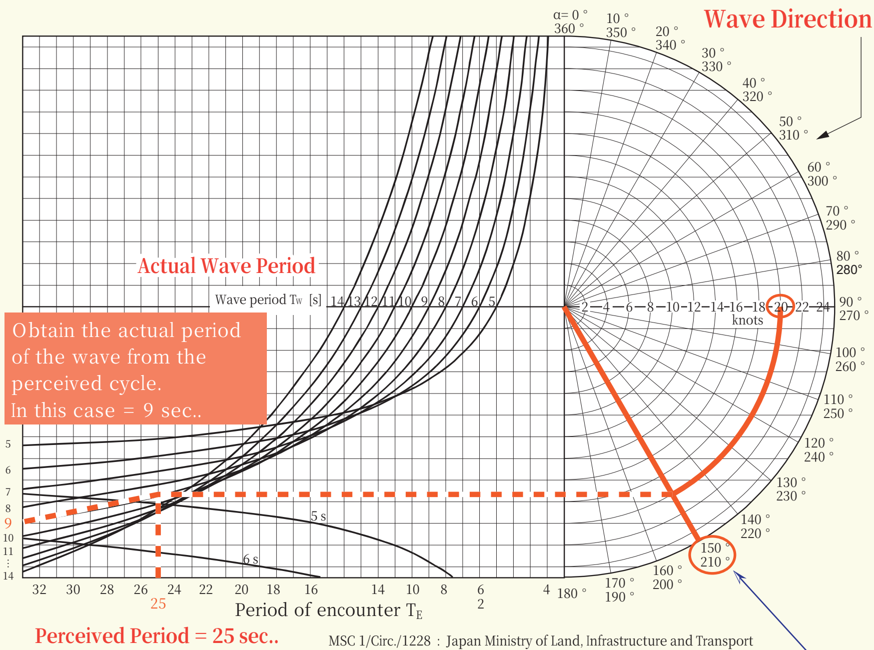
$$① \Rightarrow 120\,\mathrm{m} \times 0.8 = 96\,\mathrm{m} \leqq 126\,\mathrm{m}$$

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

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.

How to determine the actual wave period and wave length when experiencing a wave period on board a ship



Locate the point where angle of encounter of ship to waves at 150 degrees intersects with a ship speed of 20 knots

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).

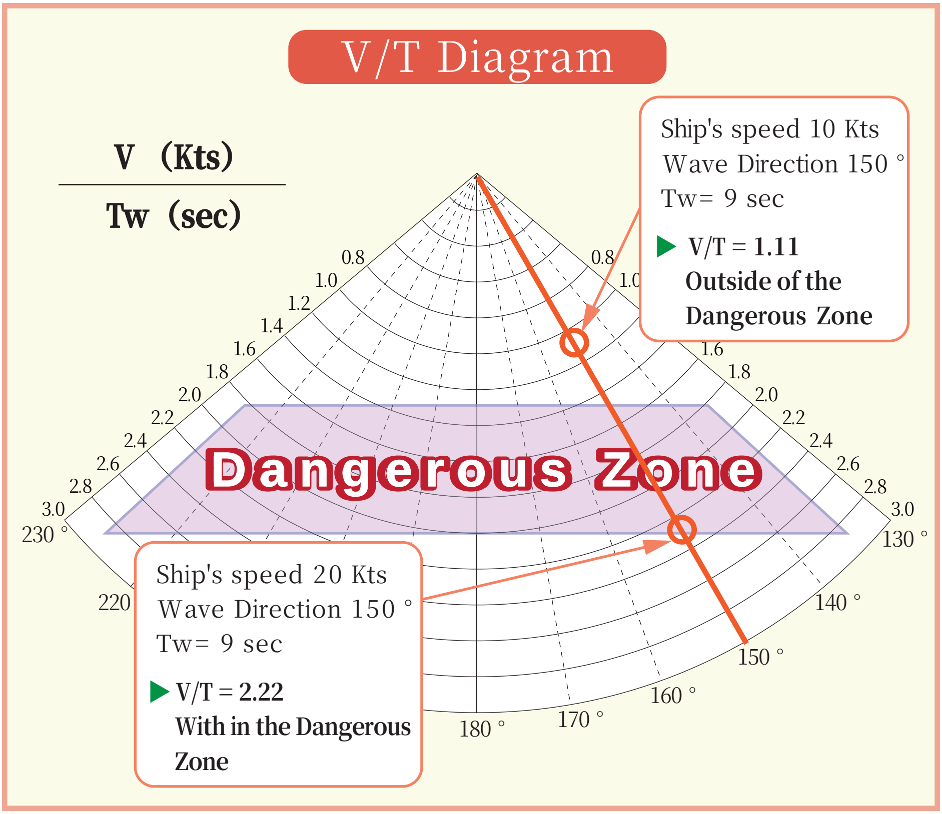


Fig. 100 IMO MSC.1/Circ.1228 and "Safety measure for ferries and RORO vessels" in Ministry of Land, Infrastructure, Transport and Tourism."

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).

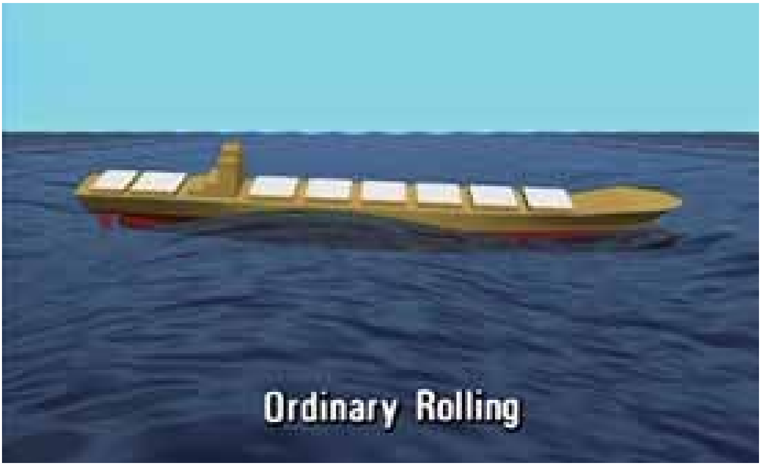


Fig. 101 Japan Captains' Association, DVD

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).

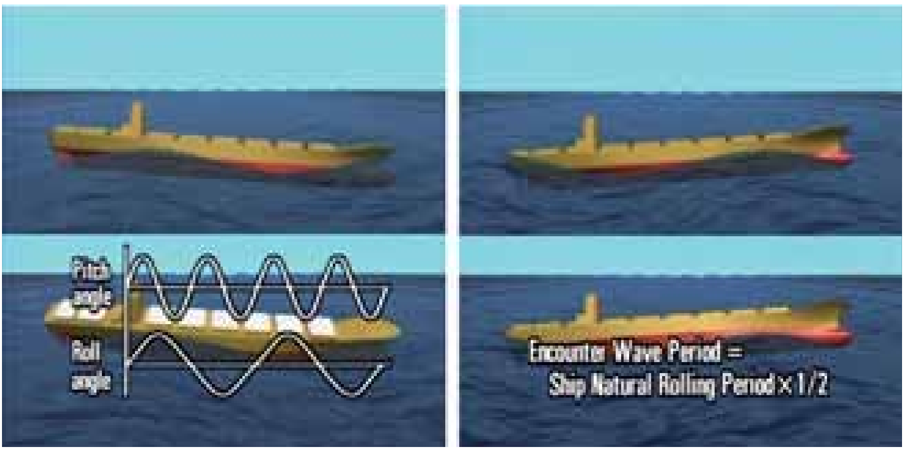


Fig. 102 Japan Captains' Association, DVD

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.

When the author operated a pure car carrier in the Indian Ocean, the carrier was exposed to wind from 30 degrees on the starboard under wind force 2 and a huge swell from a quarter stern also on the starboard side. The author experienced only a small tolling to begin with, however this gradually developed into a rolling motion and, suddenly, the carrier was on a 15 to 20 degree inclination to the port side.

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).

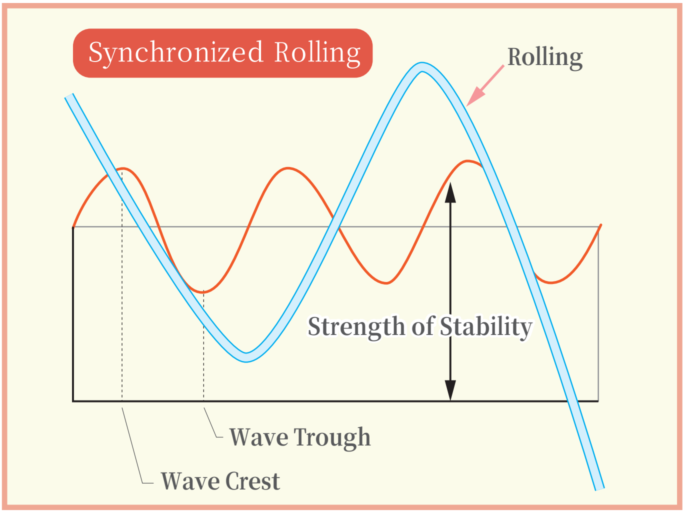


Fig. 103

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).

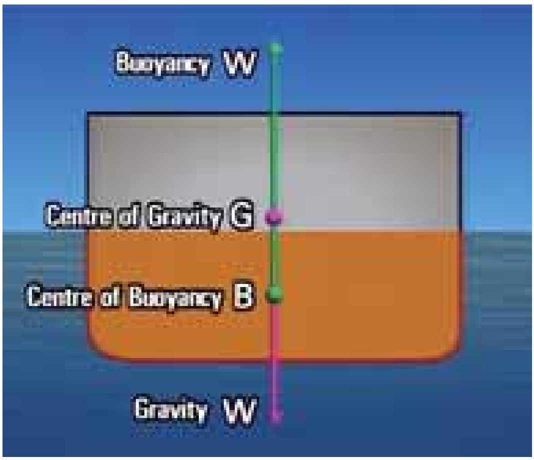


Fig. 104 Japan Captains' Association, DVD

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).

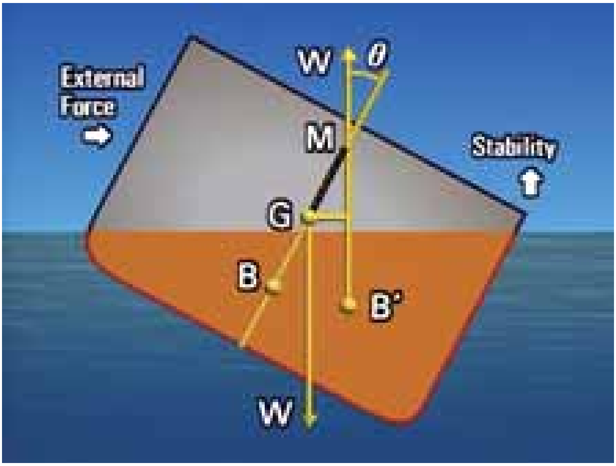


Fig. 105 Japan Captains' Association, DVD

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:

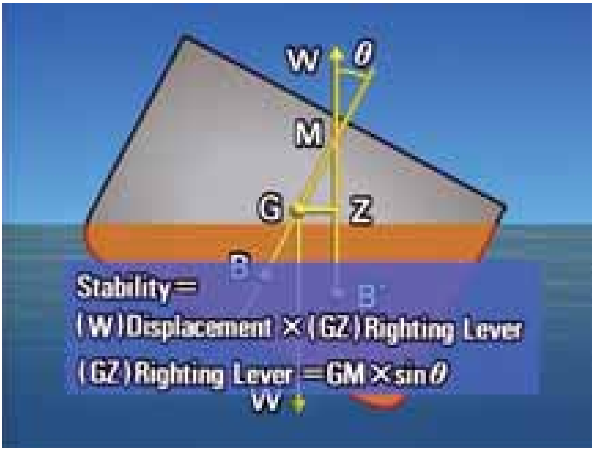


Fig. 106 Japan Captains' Association, DVD

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.

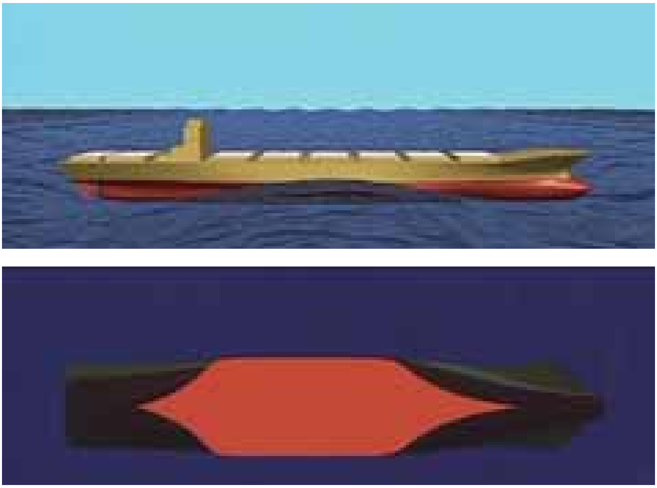
The author has also been aboard an 8,000 TEU type container carrier. The author experienced several occasions whereby the calculated draft on departure was less than the actual draft - by more than 30cm. At the time of loading 1,000 containers, as the Ton per Centimeter (TPC) was 100 tons (this is the amount of weight necessary to submerge the ship's hull at 1 cm), it means that containers which were heavier than the declared weight (by 3,000 tons at gross weight) were loaded (each container was on average 3 tons heavy). Thus, calculated GM and actual GM are different (on occasion there may be a significant difference, for example, the actual measured GM may be around 30cm smaller than that of the calculated GM).

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 =

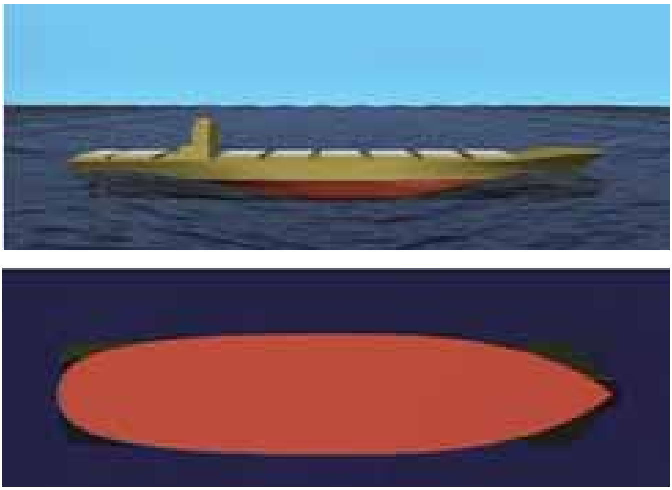
The degree of stability is determined generally by the area of the water plane as previously shown in the chart. For instance, if a ship rides on a crest equal in length to the ship's length at midships, stability is reduced as the water planes at her bow and stern decrease due to the lower water lines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

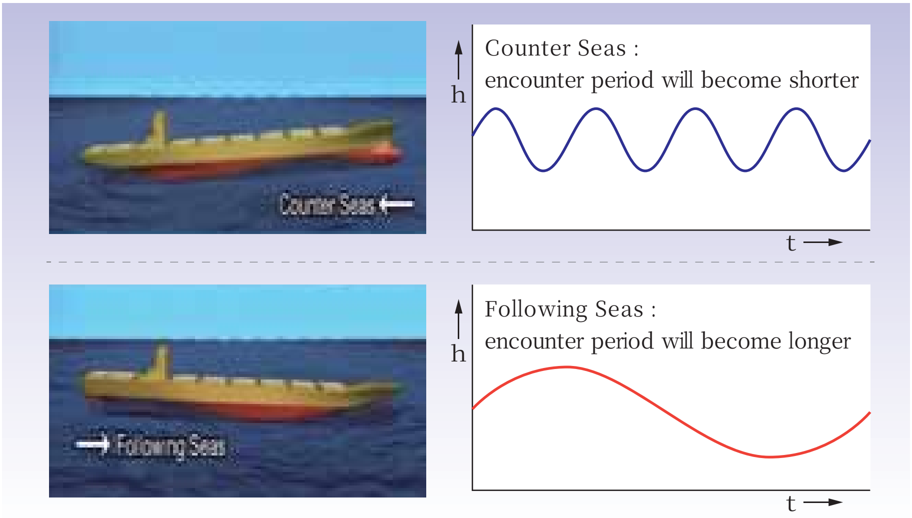


Fig. 110 Japan Captains' Association, DVD

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.

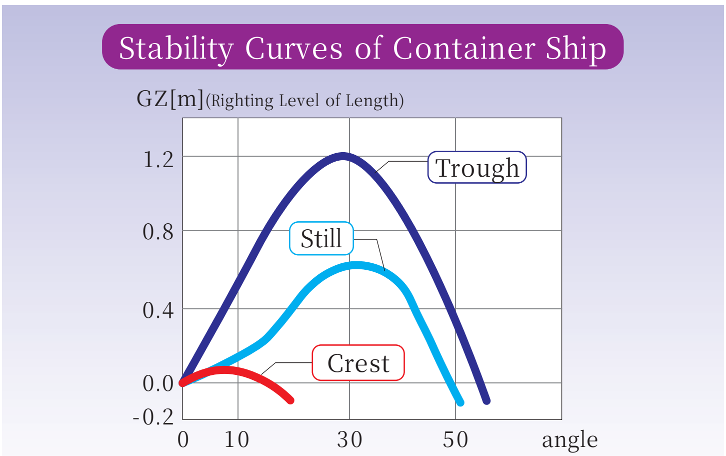


Fig. 111 Japan Captains' Association, DVD

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).

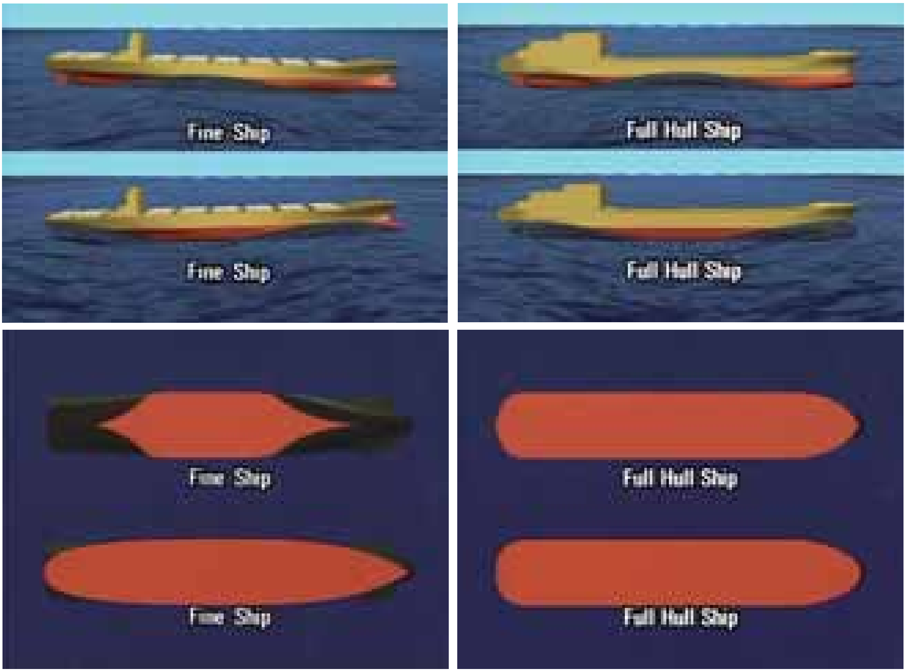


Fig. 112 Japan Captains' Association, DVD

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

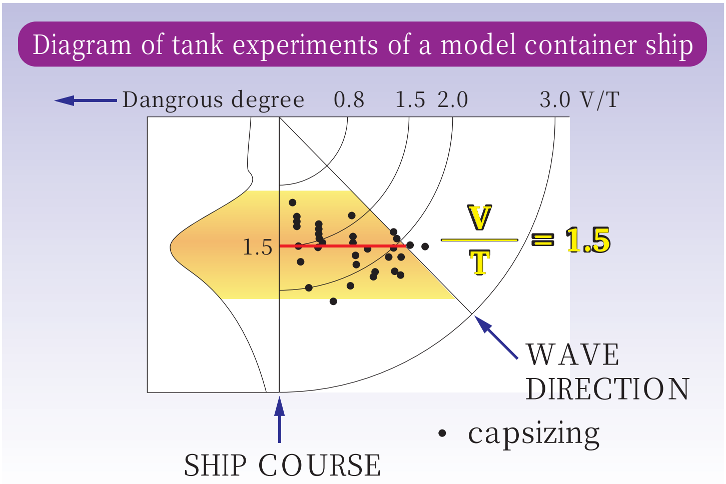


Fig. 113 Japan Captains' Association, DVD

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.

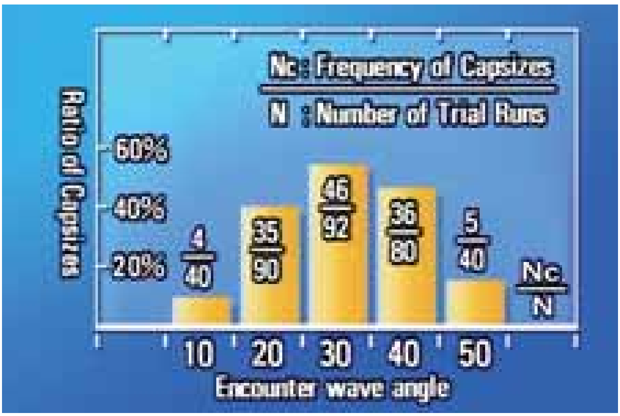


Fig. 114 Japan Captains' Association, DVD

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).

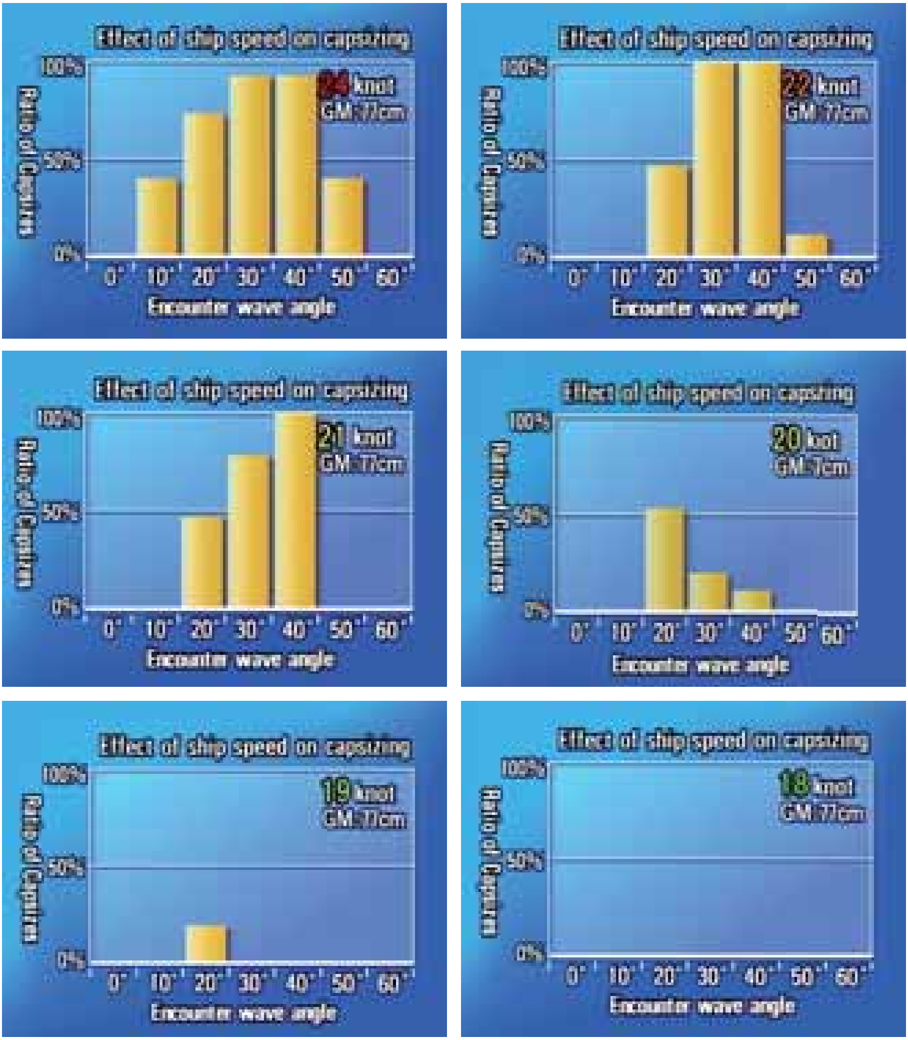


Fig. 115 Japan Captains' Association, DVD

= 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.