The Safe Manoeuvring of a Ship in Following and Quartering Seas

高 玉 德*

〈목 차〉

Abstract

when a ship is running in following and quartering seas and on a crest with the ship's length being nearly the same as the wave length, ship's stability will be lost most; "T" shape crests with highly concentrated energy will appear during the process of transformation from irregular waves to regular ones, and the ship may be under continuous impact of large waves for a long period of time; Synchronism will also appear when the ship's natural period of rolling and period of encounter are close to each other. For safe navigation, proper stability should be well ensured, proper speed and course chosen with speed under 1.8L1/2 kn (L is the ship's length), initial listing avoided, special attention paid to steering.

Key words : ship manoeuvring following seas and quarterly seas countermeasures

1. Introduction

A ship sailing at sea is always at the mercy of the elements, the impact of sea waves is one of them. Due to the influence of waves upon the ship's hull, the shape and volume of the ship's submerged part are changing constantly, causing stability and the hydrodynamic force upon the hull to change accordingly, which is the cause of the ship's various movements in heavy seas. The movements of the ship in following seas and quarterly seas can be superimposed upon each other causing more complicated movements, which sometimes lead to unmanoeuvrability and capsizing [1]. The navigating officers have long been aware of the danger of beam-on seas which can make ships capsize, and the measures that should be taken to avoid them. But it's not

* Gao yude Qingdao Ocean Shipping Mariners' College China P.R.

the case with the following seas and quarterly seas. From the points of stability variation and wave impact, this paper is to analyse the dangerous situations anticipated in following seas and quarterly seas and to provide the necessary measures to ensure safe navigation.

2. The variation of stability

For a vessel in still water with a list angle of θ degrees, its righting lever can be expressed with the components shown in Fig. 1 as:

$$GZ = BR - BG\sin\theta \quad \cdots\cdots (1)$$

where, R is the intersection of the horizontal line through the centre of buoyancy B in the upright condition and the vertical line through the centre of buoyancy B′ when listing.

Suppose the change of the shape of the submerged part of the ship in a wave causes the centre of buoyancy in the upright condition to shift from B to B*, then the righting lever of the ship in a longitudinal wave can be expressed as:

$$GZ^* = B^*R^* - B^*G\sin\theta \quad \cdots\cdots (2)$$

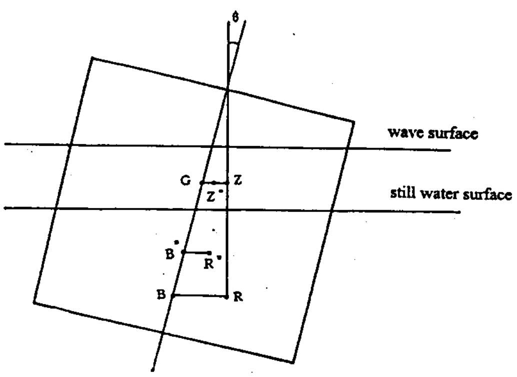

Fig. 1. ship's righting levers in waves

The difference between (1) and (2) is the variation △GZ, which is:

$$\triangle GZ = (B^*R^* - BR) - BB^*\sin\theta \quad \cdots\cdots (3)$$

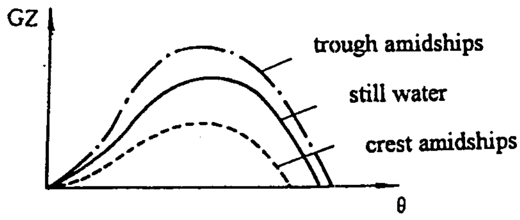

Fig. 2. GZ curves

Therefore, it can be concluded that the ship's stability variation is due to the variation of the form stability and the shift of the centre of buoyancy[2]. Fig. 2 illustrates the changes of the ship's static stability curves when the ship speed V_S approaching the wave speed V_W of following seas, and the wave length of following seas approaching the ship's length. The stability will be decreased when a crest is amidships, but increased when crests at her both ends.

3. The analyses of the danger of capsizing in heavy seas

3.1 Coordinate System

Set up a coordinate system as shown in Fig. 3, $O_1\xi\eta\zeta$ being the absolute coordinates, OXYZ the ship borne coordinates. This coordinate system shows the relationship between waves and their encounters with a ship.

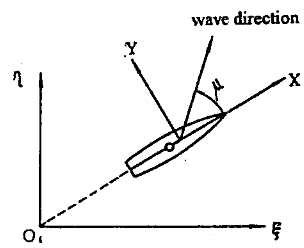

Fig. 3. coordinate system

When $\mu=0$, the directions of the waves and the ship are the same, following seas appear; when $\mu=\pi$, the directions are opposite, head seas; when $\mu=\pi/2$ or $3\pi/2$, beams seas; when $4\pi/6\leq\mu\leq5\pi/6$ and $7\pi/6\leq\mu\leq8\pi/6$, bow quarterly seas; when $\pi/6\leq\mu\leq2\pi/6$ and $10\pi/6\leq\mu\leq11\pi/6$, (stern) quarterly seas.

3.2 The Dangerous Situations of a Ship in Following Seas

When a ship is running before following seas, capsizing can be found in the following three situations:

(1) capsizing caused exclusively by the lost of stability when riding on a crest. Under such a circumstance, the ship's speed is almost the same as that of the wave advance, the ship's length as that of the waves, the crest can be over the middle of the bulwark, causing the ship to ship a lot of water on to the deck, which increases the danger of capsizing[3];

(2) capsizing caused by synchronism when the period of encounter and the period of rolling are the same. In this situation, the ship's righting moment fluctuates periodically and the ship rolls violently and continuously. If the stability is not enough or measures are not taken timely, the ship is likely to capsize;

(3) when the ship is travelling at about the same speed as the waves and is on the down slopes, she will be accelerated to start surfing. It is very likely for the vessel at this time to broach abruptly and, as a result, to capsize. Under such circumstances, the ship's heading is swayed into the beam-on mode, causing severe heeling. If rudder is being applied for a course change or there is initial listing, then the effect of rudder and the initial listing angle will coincide and enlarge the heeling moment.

3.3 The Dangerous situations of a Ship in quarterly seas

When sailing in quarterly seas, the ship is likely, under certain navigation circumstances, to be under continuous impact by the wave train resulting in capsizing, even if the waves are not so heavy, or just moderate. From the experiment of sailing in quarterly seas, it is observed that capsizing is caused by the joint action of the factors concerning the ship's behaviour in heavy seas. Under such circumstances, the ship when overtaken by one or several steep waves will be caused to heel seriously with a lot of water shipped on deck. She can be capsized if the subsequent waves are large enough[4].

The navigation dangers of a ship found in the quarterly seas experiment can be explained with the encounter characteristics. According to the wave theory, "T" shape wave spectrum will appear when irregular wave spectrum $Sw(\omega_o)$ are being transformed into $Sw(\omega_e)$, i.e.:

$$S_w(\omega_e)=S_w(\omega_o)\frac{d\omega_o}{d\omega_e}=S_w(\omega_o)\cdot\frac{1}{|1-2\omega_o V\cos\mu/g|} \quad \cdots\cdots (4)$$

in which:

$$\begin{cases} \omega_e=\omega_o(1-\omega_o V\cos\mu/g) \\ \dfrac{d\omega_e}{d\omega_o}=1-2\omega_o V\cos\mu/g \end{cases} \quad \cdots\cdots (5)$$

Where, V is ship speed, is the angle between ship's heading and the direction of the waves, g is the acceleration of gravity.

If ω_o, V and μ can satisfy the following formula:

$$1-2\omega_o V\cos\mu/g=0 \quad \cdots\cdots (6)$$

then the encounter wave spectrum $Sw(\omega_e)$ will be infinite outside the critical encounter frequency ω_{ec}, and the following formulae hold:

$$\begin{cases} \omega_{e_\xi} = \omega_{o_\xi}/2 \\ \omega_{e_\xi} V\cos\mu / g = \dfrac{1}{4} \end{cases} \quad \cdots\cdots (7)$$

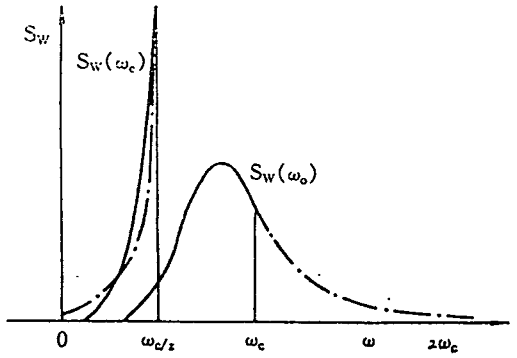

Fig. 4. irregular wave spectrum transformed into encounter wave frequency ω_e

The relationship between the two spectra Sw(ω_o) and Sw(ω_e) is illustrated in Fig. 4. When $\omega_{o\xi}$ is approaching the frequency of the main waves or the spectrum summit frequency, the transformation spectrum of the encounter waves is narrow but high in its value.

The waves we can see at sea are often irregular, their behaviour is illustrated in Fig. 5, while Fig. 4 illustrates their behaviour after transformed into encounter wave spectrum. The above analysis shows that a ship sailing in irregular following seas and quarterly seas can be accompanied by high waves according to the probability of these high waves appearing in irregular waves. Occasionally, this may happen for a long period of time. Therefore, continuous impact of the high waves will make the ship roll violently and ship a lot of water. When the rolling period and other responding periods coincide to heel the ship, she will be in the most dangerous situation.

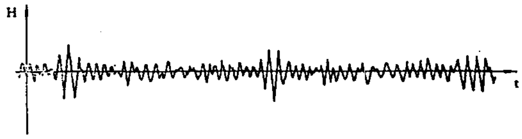

Fig. 5. the behaviour of irregular wave surfaces

4. The Safe Manoeuvring of a Ship in Following Seas and Quarterly Seas

The above analyses tell us that two types of dangerous conditions for a ship sailing in following seas and quarterly seas have been found: one is when the component of the ship's speed in the direction of the wave propagation approaches the speed of the main wave train. The ship will be pounded continuously by a series of large waves that can be anticipated in such a sea state, it is very likely for the ship to lose much of her stability with a crest amidships and, due to periodical variation of the stability, to be in unstable rolling motion and synchronous rolling. All of the above will coincide to cause cargo shifting and shipping water, and even capsizing; the other condition is when the component of the ship's speed in the direction of the wave propagation approaches the phrase velocity of the waves, the ship is accelerated to start surfing and is very likely to broach, during which capsizing is very possible[4].

The following measures should be taken to keep a ship sailing in following seas and quarterly sea from the dangers of capsizing:

(1) the initial transverse metacentric height determined in the actual stowage plan should not

be less than the critical transverse metacentric height under this condition, and the rolling period should be in the proper range. The variation of the wave surfaces causes the stability to vary accordingly when the ship is sailing in heavy seas. If the value of the metacentric height is too small, it might become negative with a crest amidships, resulting in the ship's capsizing;

(2) strengthen the lashing and securing of cargo to prevent it from shifting and to prevent the ship from listing in heavy seas;

(3) choose proper course and heading to avoid the dangerous range, i.e. adjust the period of encounter. The period of encounter Te , in relation to the waves as shown in Fig. 6, can be calculated with the following formula:

$$Te = \frac{\lambda}{C + V\cos\mu} \quad \cdots\cdots (8)$$

where, is the wave length, C is the wave speed, V is the ship's speed, is the angle between ship's heading and wave propagation direction.

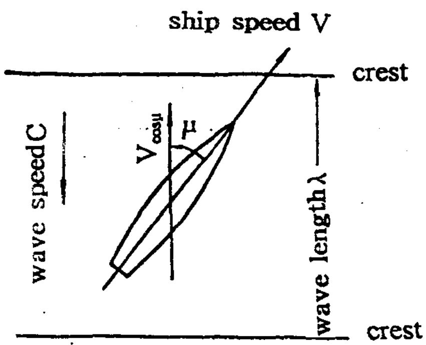

Fig. 6.

Formula (8) shows that to change ship speed V or angle, or both at the same time can change the period of encounter to avoid synchronism[5].

Care should be taken if $\mu = 90°$ or $270°$, i.e. seas abeam, $\cos\mu = 0$, when changing speed is useless for adjusting the period of encounter. The only way out to reduce rolling is to change the ship's course. Furthermore, changing course, more often than not, is accompanied by some adverse factors. Therefore, reducing speed first is always appreciated. As for the dangerous condition of surfing, ship's speed should be controlled within $1.8L^{1/2}$ kn (L is the ship's length);

(4) for a ship sailing in heavy seas the initial listing angle and the abrupt applying of rudder can obviously cause the ship to heel. Therefore, when the rudder is to be applied in heavy seas, care should be taken and the timing determined carefully as well.

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