RELATION BETWEEN FREEBOARD AND CAPSIZING RISK FOR FISHING VESSELS

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Abstract

Almost Japanese purse seiners are designed with a small freeboard deck. This design is a weak point for stability.

The purposes of this study are to investigate the effects of freeboards on critical conditions of capsizing for Japanese purse seiners. Model experiments for Japanese purse seiners were conducted to clarify relation between freeboards and capsizing. The models used in the experiments are 80GT and 39GT Japanese purse seiners with changing freeboard sizes. Generally, the capsizing risk of a small freeboard ship is larger than that of a large freeboard ship. The model experiments demonstrate that the influence of difference freeboards on capsizing for 80GT Japanese purse seiners is small. On the other hand, the risk of capsizing for 39GT Japanese purse seiners with small freeboard is smaller than a large one. Moreover, surf-riding is harder with a 39GT Japanese purse seiner than with a 80GT purse seiner, and is harder with a 39GT Japanese purse seiner with a small freeboard than with a large one.

In this paper, the relationship between capsizing risk and freeboards for the Japanese purse seiner is discussed in roll motion in beam seas, pure loss of stability in following seas and surf-riding that induce broaching-to.

1. INTRODUCTION

The Japanese purse seiner is the most popular fishing vessel in Japan and a very small freeboard is characteristic of it. Purse seines occupy 30 ~ 50 % of Japanese catch quantity and play an important role for the demands of fishery resources and the fisheries economy. In recent years, serious sea disasters have frequently occurred among Japanese purse seiners. The cause of the accidents and the stability of purse seiners have been investigated experimentally. Some of the accidents were caused by stowage that did not satisfy the standard for load line and stability, and improper operation. However, there are few studies on the adequacy of existing standard for load line and stability for the Japanese purse seiner.

The purpose of this study is to investigate the effects of freeboards on critical conditions of capsizing for the Japanese purse seiner. Capsizing free running model experiments of Japanese purse seiners in following and quartering seas were conducted. The models used in the experiments are 80GT and 39GT Japanese purse seiners with changing freeboard sizes and the transverse metacentric height. The experimental results show that the risk of capsizing for the 39GT Japanese purse seiner with a small freeboard is smaller than a large one. It is well known that the risk of capsizing for a small freeboard ship is larger than that of large freeboard ship. Surf-riding is harder with a 39GT Japanese purse seiner than with a 80GT purse seiner. Moreover, surf-riding is harder with a 39GT Japanese purse seiner with a small freeboard than with a large one. In order to clarify these features, the relationship between the freeboard and capsizing risk for the Japanese purse seiner is discussed in roll motion in beam seas, pure loss of stability and surf-riding that induce broaching-to and capsizing. Firstly, ship motions with different freeboard sizes in waves are calculated, and roll amplitudes in beam seas for various freeboards are compared. Secondly, stability in following seas for the 39GT Japanese purse seiner with different freeboard sizes is calculated, and roll angles at maximum righting arms and vanishing points of stability for various freeboards in following seas are investigated. Lastly, the influence of the freeboard on the probabilities of surf-riding that induce broaching-to and capsizing is discussed. With the 39GT Japanese purse seiner with a small freeboard running in following and quartering seas, surf-riding is hard, because the stern submerges without being lifted on the wave crest. Moreover, forward wave force acting on the ship's body in following seas is calculated.

2. MODEL EXPERIMENTS OF SHIP CAPSIZE IN FOLLOWING AND QUARTERING SEAS

2.1. Outline of experiments

In order to investigate the relationship between freeboard, transverse metacentric height and capsizing risk, the experiments were conducted in the Marine Dynamics Basin (60m in length, 25m in width, 3.2m in depth) of the National Research Institute of Fisheries Engineering, in Japan. Two models used in the experiments are a 1/12.6 scale model of the 80GT purse seiner and a 1/10 scale model of the 39GT purse seiner. Figs. 1, 2 show side profile and Tables 1, 2 show principal particulars of the models. The

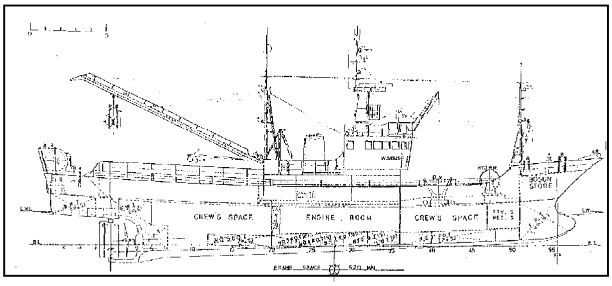

Fig. 1 Side profile of the 80GT purse seiner

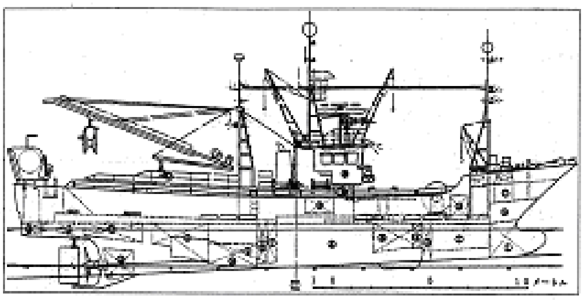

Fig. 2 Side profile of the 39GT purse seiner

Table 1 Principal particulars of the 80GT purse seiner

	Actual ship	Model ship
scale	1	1/12.6
L_{OA} [m]	36.50	2.900
L_{pp} [m]	29.00	2.300
B [m]	6.80	0.540
D [m]	2.60	0.206
d_m [m]	2.25	0.178
∇ [m^3]	271.47	0.136
C_b	0.612	0.612

Table 2 Principal particulars of the 39GT purse seiner

	Actual ship	Model ship
scale	1	1/10
L_{OA} [m]	29.22	2.922
L_{pp} [m]	23.00	2.300
B [m]	5.90	0.590
D [m]	2.15	0.215
d_m [m]	1.90	0.190
∇ [m^3]	151.95	0.152
C_b	0.606	0.606

forecastle, bilge keel, bulwark, deck scupper, exposed deck and deckhouse are geometrically scaled. The bridge is detached as a non-watertight structure. Tables 3, 4 show the ship's condition in these experiments. The circle marks show the ship conditions that satisfy the standard, and the cross marks show the ship conditions that do not satisfy the standard. Draft (*d*) and transverse metacentric height (*GM*) are changed systematically to investigate the relationship between freeboard, transverse metacentric height and capsizing risk. The Japanese Government (JG) has freeboard rules and stability rules for fishing vessels[1]. JG provide for the minimum freeboard (*f*) as follows:

$$\left.\begin{array}{ll} D < 6m: & f \geq \dfrac{D}{15} + 0.20 \\ D \geq 6m: & f \geq \dfrac{D}{10} \end{array}\right\}$$

(1)

where D is depth. The minimum metacentric height (GM_{min}) is provide as follows:

$$\left.\begin{array}{l} L < 40m: \quad GM_{\min} = \dfrac{B}{25} + 0.54\dfrac{B}{D} - \alpha \\ L \geq 40m, B < 7m: GM_{\min} = \dfrac{B}{25} + 0.12 \\ B \geq 7m: GM_{\min} = \dfrac{B-7}{12} + 0.40 \end{array}\right\} \quad (2)$$

where α is defined by the ratio of freeboard to depth. The International Maritime Organization (IMO) has intact stability criteria A. 749[2] for all ships.

(a) The area under the righting lever curve (GZ curve) shall not be less than 0.055 metre-radians up to 30 degrees angle of heel and not less than 0.090 metre-radians up to 40 degrees or the angle of flooding θ_f if this angle is less than 40 degrees. Additionally, the area under the righting lever curve (GZ curve) between the heel angles of 30 degrees and 40 degrees or between 30 degrees and θ_f, if this angle is less than 40 degrees shall not be less than 0.030 metre-radians. θ_f is the angle of heel at which openings in the hull, superstructure or deckhouses which cannot rapidly be closed watertight commence to immerse. In applying this criterion, small openings through which progressive flooding cannot take place need not be considered as open;
(b) The righting lever GZ shall be at least 200 millimetres at an angle of heel equal to or greater than 30 degrees;
(c) The maximum righting lever GZ_{max} shall occur at an angle of heel preferably exceeding 30 degrees but not less than 25 degrees;
(d) The initial metacentric height GM shall not be less than 350 millimetres for single deck vessels. In vessels with complete superstructure or vessels of 70 meters in length and over the metacentric height may be reduced to the satisfaction of the Administration but in no case shall be less than 150 millimetres.

Figs. 3, 4 show the GZ-curves of these models.

Under conditions where the models are free running. The models are steered by autopilots whose rudder gain is one and a maximum rudder angle is 35 degrees. Propeller revolution is changed from ship speed in still water Fn=0.15 to 0.46 systematically. Roll, pitch and yaw angles are measured by gyroscopes. The wave conditions are heavy regular following and quartering seas. Umeda et al. (1995) [3)] reported that the capsizing risk of the ship, that never occurs in regular waves, is small in irregular waves whose significant wave height is equal to one in regular waves. The ratio of wavelength to ship length (λ/L_{pp}) is 1.41, and steepness (H_w/λ) is 1/8.8. Each models was tested more than 200 runs.

Table 3 Ship conditions of 80GT purse seiners

	draft m	GM m	JG (Freeboard)	JG (Stability)	IMO
A	2.25	1.65	○	○	○
B	2.25	1.49	○	○	×
C	2.25	1.36	○	○	×
D	2.30	1.43	×	○	×
E	2.30	1.32	×	○	×

Table 4 Ship conditions of 39GT purse seiners

	draft m	GM m	JG (Freeboard)	JG (Stability)	IMO
F	1.90	1.46	×	○	×
G	1.90	1.56	×	○	×
H	2.05	1.36	×	○	×
I	2.05	1.49	×	○	×

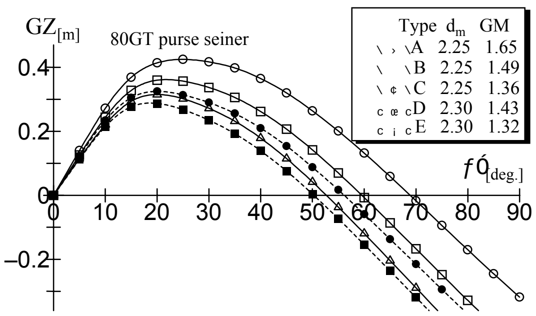

Fig. 3 GZ-curve of the 80GT purse seiner

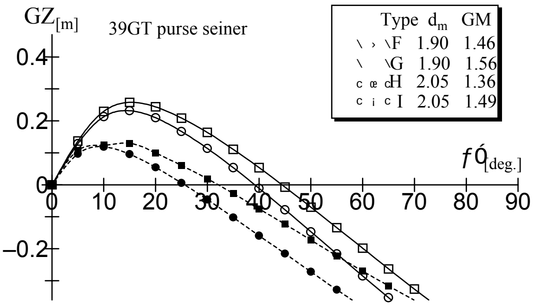

Fig. 4 GZ-curve of the 39GT purse seiner

2.2. Experimental results

The results of capsizing experiments are shown in Table 5. The circle marks show the non-capsize condition, and the cross marks show the capsize condition. Capsizing occurs at high ship speeds (Fn$\geq$0.40) that are close to wave velocity, because the encounter period becomes lower. The experimental results demonstrate that the 80GT purse seiner whose condition satisfied the JG standard capsize in following and quartering seas (see the type C). For the 80GT purse seiner, capsizing occurs with 2 types of small transverse metacentric height (type C and E), and the influence of different freeboards on capsizing is small. From the results of model experiments, the cause of capsizing for the 80GT purse seiner is pure loss of stability on the wave crest and broaching-to. However, in the case of the 39GT purse seiner, the risk of capsizing with small freeboard is smaller than a large one. Type F and I are the same transverse metacentric height. Capsizing occurs with the type F with a large freeboard, and type I with a small freeboard doesn't capsize. The cause of capsizing for the 39GT purse seiner is pure loss of stability on the wave crest only. Figs. 6-8 show the time series of roll, pitch, yaw, rudder angles and propeller revolution for the 80GT and the 39GT purse seiner that capsize in following and quartering seas. The time series of these figures are shown by actual ship scale. The coordinate systems are shown in Fig. 5. Fig. 6 shows the data of type C (80 GT) that is capsized by pure loss of stability on the wave crest. When pitching amplitude crosses from minus to plus, the mid ship is on the wave crest. Heel angle becomes larger at 35 seconds on the wave crest. Fig. 7 shows the data of type F (39GT) that is capsized by pure loss of stability. Mid ship is running on the wave crest and heel angle increases, finally it capsizes. Fig. 8 shows the time series of type E (80GT) that is capsized by broaching-to. Yaw angle is increased negative, and rudder angle increases at 37seconds. This means that the rudder doesn't control yaw, and this feature is the characteristic of broaching-to. On the other hand, surf-riding doesn't cause capsizing with the 39GT purse seiner with a small freeboard. The results of the model experiments demonstrate that surf-riding is harder with the 39GT purse seiner in comparison with the 80 GT purse seiner. Moreover, surf-riding is harder with the 39GT purse seiner with a small freeboard than with a large one.

Table 5 The results of capsizing experiments

	80GT		39GT
A	○	F	×
B	○	G	○
C	×	H	×
D	○	I	○
E	×	○:non capsize×:capsize	

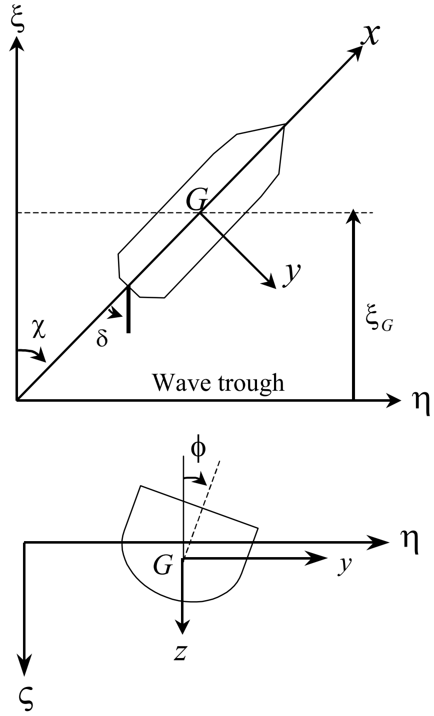

Fig. 5 Coordinate systems

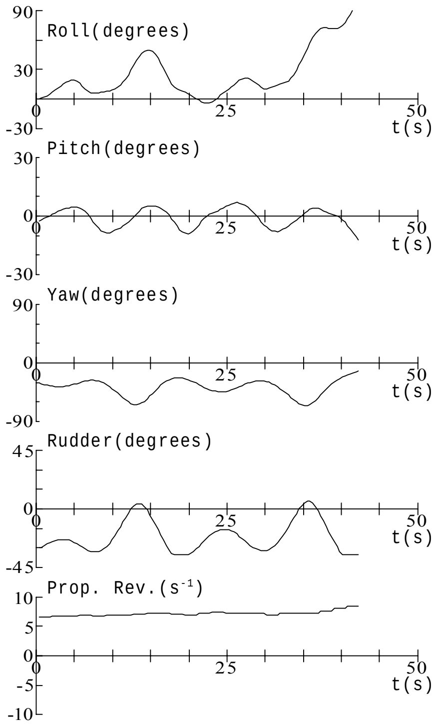

Fig. 6 Time series for type C of the 80GT (capsize due to pure loss of stability Fn=0.43, χ =-60deg.)

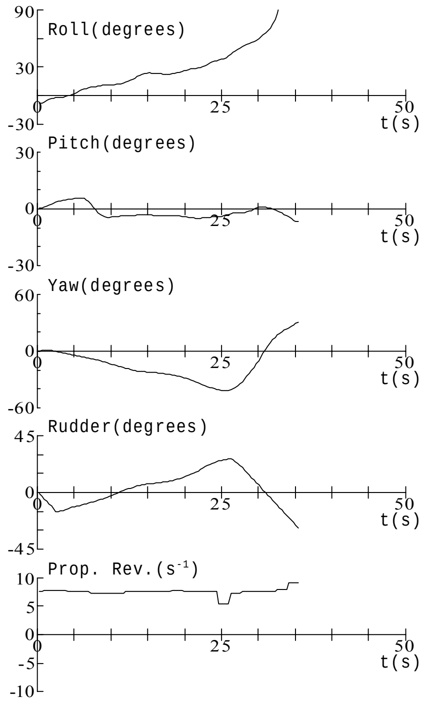

Fig. 7 Time series for type F of the 39GT (capsize due to pure loss of stability Fn=0.43, χ =-15deg.)

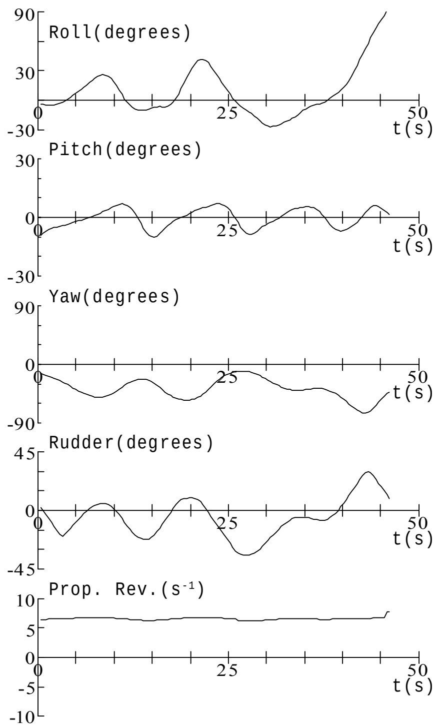

Fig. 8 Time series for type E of the 80GT (capsize due to broaching-to Fn=0.43, χ =-45)

3. STUDY TO FIND RELATION BETWEEN FREEBOARD AND CAPSIZING RISK

As mentioned in the previous chapter, the model experimental results demonstrate that 80GT Japanese purse seiners capsize in following and quartering seas by pure loss of stability and broaching-to. However the cause of capsizing for the 39GT purse seiner is pure loss of stability only. Moreover, the capsizing risk of the 39GT purse seiner with a small freeboard is smaller than with a large one. Surf-riding is harder with the 39GT purse seiner than with the 80GT purse seiner, and surf-riding is harder with the 39GT purse seiner with a small freeboard than with a large freeboard.

Stability of the ship in beam seas has been investigated to discuss stability criteria, because in beam seas condition is regarded as having a high capsizing risk for the ship. However, The stability criteria in following and quartering seas should consider three modes of capsizing. There are: pure loss of stability, broaching-to and parametric oscillation. In this chapter, the relationship between the freeboard and capsizing risk for Japanese purse seiners is found in ship motions in beam seas, pure loss of stability in following seas and surf-riding that induces broaching-to in following seas.

3.1. Ship motions in beam seas

It's well known that, in beam seas condition is one of the dangerous conditions for the ship. Large amplitude of ship motions in beam seas has been investigated to discuss stability.

Figs. 9, 10 show the calculated results of roll amplitudes of 80GT and 39GT purse seiners in beam seas by Ordinary Strip Method[4)], in which the roll damping is calculated by Ikeda's method[5)]. The experimental results show that type C and E of 80GT purse seiners capsize.

Calculated results show that roll amplitudes of type C and E are larger than the other types at $\lambda/L_{pp} = 1.41$. For the 39GT purse seiner, the calculated results show that types F, G and H have much the same roll amplitudes at $\lambda/L_{pp} = 1.41$, and roll amplitude of type I is the smallest of all types. It should be noted that type F and I are the same transverse metacentric height. The freeboard of type I is smaller than type F. However, the experimental results show that type I with a small freeboard does not capsize, and type F with a large freeboard capsizes. The calculated results express this tendency.

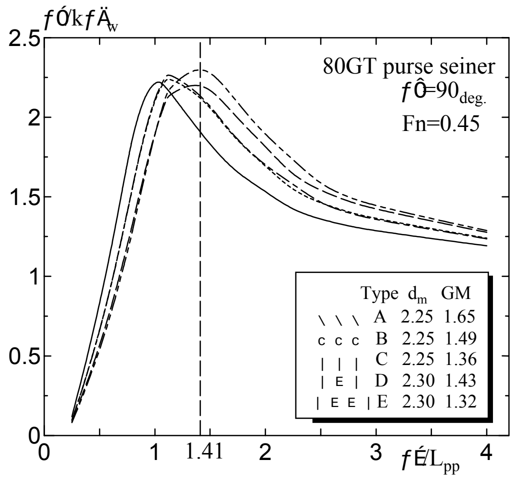

Fig. 9 Calculated roll amplitudes of the 80GT purse seiner in beam seas

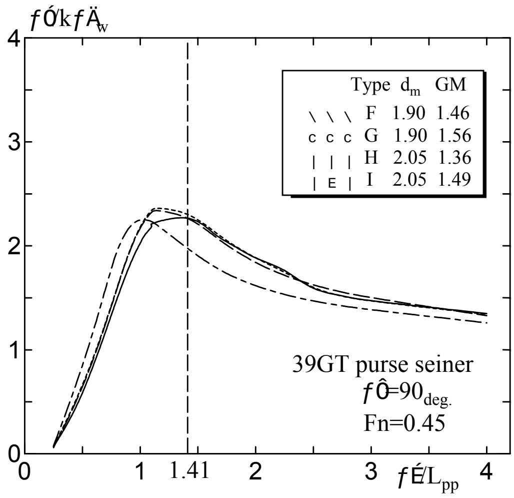

Fig. 10 Calculated roll amplitudes of the 39GT purse seiner in beam seas

In order to investigate the influence of the freeboard on ship motion, roll amplitudes of the 39GT purse seiner with changing draft in beam seas are calculated. In this calculated condition, transverse metacentric height is constant and forward speed is zero. Fig. 11 shows that calculated roll amplitudes for various freeboards. The calculated results show that roll amplitude decrease remarkably at d_m=2.05 whose condition is type I. Type I does not satisfy JG and IMO standards, but capsizing risk is small from the viewpoint of the roll motion in beam seas.

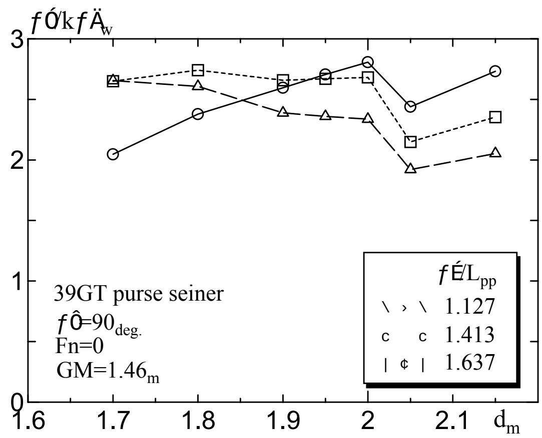

Fig. 11 Calculated roll amplitudes of the 39GT purse seiner for various draft in beam seas

3.2. Stability in following seas

When the ship runs in following seas, encounter frequency becomes lower and heave and pitch motions can be regarded as tracing a static balance[6)]. Hence, ship stability in following seas can be discussed in static stability. The stability as mid ship stays on the wave crest significantly decreases and this condition is kept for a long time in following seas. Small stability on the wave crest for ships is acted by lateral exciting force and capsizing occurs by pure loss of stability.

In order to investigate the influence of the freeboard on stability of the 39GT purse seiner in following seas, static stability curves (GZ-curve) for various freeboards in following seas are calculated. In this calculation, transverse metacentric height is constant at *GM*=1.36m in still water and the ship's locations are in still water, on the wave trough and crest. The wave condition is λ/L_{pp}=1.41 and H_w/λ=1/9. Fig. 12 and Fig. 13 show calculated roll angles at maximum righting arms (ϕ_{max}) and vanishing angles (ϕ_v) with several drafts for the 39GT purse seiner. Roll angles at maximum righting arms and vanishing angles are almost constant in each ship's location. The calculated results indicate that if transverse metacentric height is constant, roll angles at maximum righting arms and vanishing angles in following seas are almost constant even if the size of the freeboard is changed. It should be noted that roll angles at maximum righting arms and vanishing angles are zero on the wave crest.

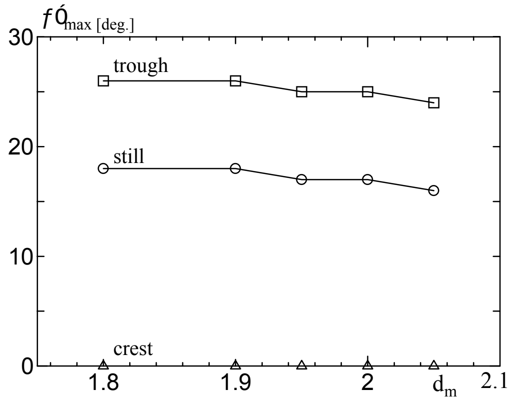

Fig. 12 roll angles at maximum righting arms for various drafts (39GT purse seiner)

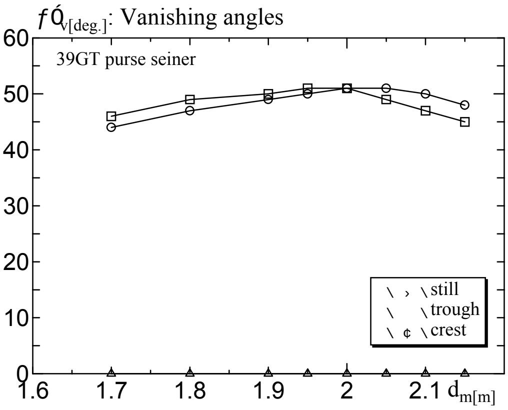

Fig. 13 Vanishing angle for various drafts

3.3. Surf-riding for Japanese purse seiner

A ship in waves usually runs with periodic surging motions. However, in heavy following seas, the ship may accelerate and run with a wave velocity, which is called surf-riding and can be regarded as a kind of non-linear phenomenon. Under the surf-riding condition, the ship may suddenly yaw desired course despite application of maximum opposite rudder. This phenomenon is well known as broaching-to and possibility causes capsizing. Thus, the surf-riding is a prerequisite for broaching-to to occurring.

Fig. 14 shows ship velocity for type F (d_m=1.9m) and I (d_m=2.05m) of the 39GT purse seiner in following and quartering seas obtained by the experimental data. In this condition, ship speed is Fn=0.4 in still water, and wave velocity is 7.12m/sec (Fn=0.47 for 39GT purse seiner). In the case of d_m=1.90m, the ship velocity is accelerated to wave velocity by the forward wave force, and broaching-to due to surf-riding occurs. On the other hand, for d_m=2.05m, the ship velocity is decelerated by wave force.

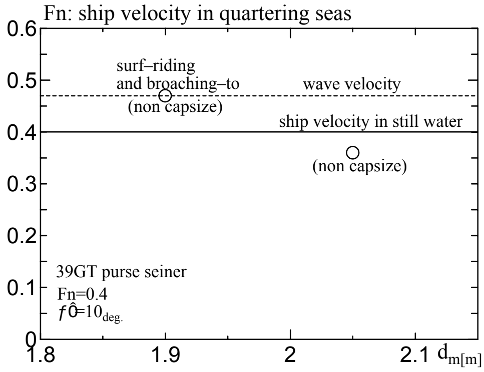

Fig. 14 ship velocities for various drafts in quartering seas

Generally, when the wave crest meets the stern of the ship, the ship velocity increase as the stern is lifted by the wave. If the ship speed accelerates enough to cause surf-riding at the time, broaching-to and capsizing might occur. However, the 39GT purse seiner with a small freeboard does not have enough buoyancy at the stern. Fig. 15 shows that rate of under water area R_{aw} for various relative water levels z_r at the stern (A.P.) of the 39GT purse seiner. R_{aw} is defined by dividing increasing the under water area A_w by the under water area in still water.

$$R_{aw} = \left(A_w - A_{w(still)}\right) / A_{w(still)} \tag{3}$$

For the small freeboard (*dm*=2.05m), the rate of increase for the under water area is smaller than with a large freeboard (*dm*=1.90m). It should be noted that the rate of under water area is constant over z_r =2.6m, because the stern deck submerges into the wave. In the case of a small freeboard, the stern does not lift, and waves pass over the deck. When a bow meets the crest of wave, the bow is lifted and ship velocity decreases, because the buoyancy at the bow of the ship is enough. Thus, ship velocity for the 39GT purse seiner with a small freeboard running in following and quartering seas is decelerated and it is harder for surf-riding and broaching-to that induces capsizing to occur. Moreover, in this condition, green water acts on the stern deck and the ship's deck submerges in wave. Hence, the influence of waves on the hull is small, and roll amplitudes of ship motions decrease in waves. It is noted that, this condition is dangerous for the actual ship because the deck is always washed by the wave, and crew and fishing-nets are swept away in the wave.

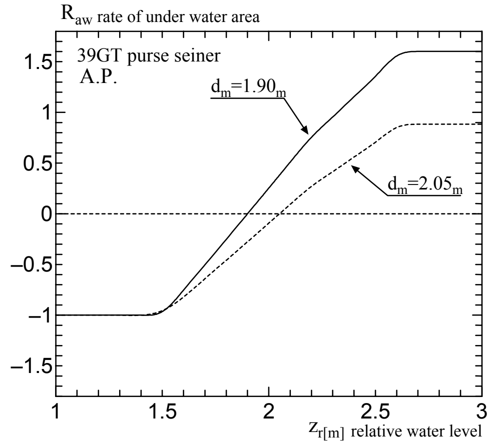

Fig. 15 Rate of under water area for various relative water levels

Umeda[7), 8)] proposes a method to predict probability of surf-riding for the ship in regular and irregular seas. Since the ship is slender, the coupling effect on the surging motion is negligible. The surging motion is expressed by one freedom equation as follows:

$$m\ddot{\xi}_G = F_X - R + T + VM \tag{4}$$

where m, F_X, R, T and VM are the mass of the ship, the wave force acting on the ship in x direction, the resistance of the ship in still water, the thrust due to the propeller and inertia force due to the virtual mass of the ship, respectively. As for the wave force F_X, the Froude-Krylov hypothesis is effective. Under the surf-riding condition where the ship velocity equals the wave velocity, this Froude-Krylov force can be regarded as the first order approximation for an exact potential theory and can be explained as the interaction between ocean waves and ship generated waves. Fig. 16 shows calculated longitudinal wave force in following seas for the 39GT, the

80GT and the 135GT purse seiners and the 15000GT container ship. Model experiments demonstrate that the 80GT, the 135GT purse seiners and the 15000GT container ship are capsized by broaching-to in following and quartering seas. Non-dimensional longitudinal wave force $F_X{}'$ is defined by dividing the wave force by the volume of displacement. Forward wave force acting on the hull accelerates ship velocity, and induces surf-riding when ship speed equals wave velocity. The calculated results demonstrated that forward wave force of the 39GT purse seiner is small. It means that the 39GT purse seiner has a small probability of surf-riding in comparison with the 80GT, the 135GT purse seiners and the 15000 GT container ship.

Fig. 17 shows the calculated longitudinal wave force of the 39GT purse seiner for various freeboards in following seas. The calculated results demonstrate that forward wave force slightly decreases with the decreasing freeboard. This means that the probability of the surf-riding becomes smaller with the decreasing freeboard. It should be noted that, in the case of d_m=2.05m and 2.15m, the calculated results are over estimated, because non-linear features in heavy seas and the influence of green water are not taken into the prediction method. In the model experiments, the stern deck of the 39GT purse seiner with a small freeboard is attacked by green water and the deck submerges. It is necessary to consider non-linear features in rough seas, the influence of green water and the submerged deck, and to calculate the limitation of surf-riding to prevent capsizing.

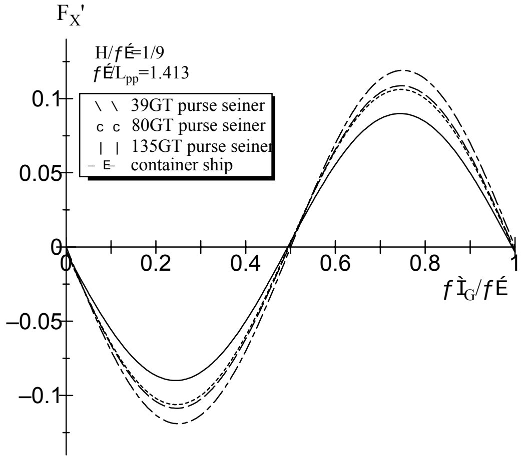

Fig. 16 Calculated longitudinal wave force for several ships in following seas

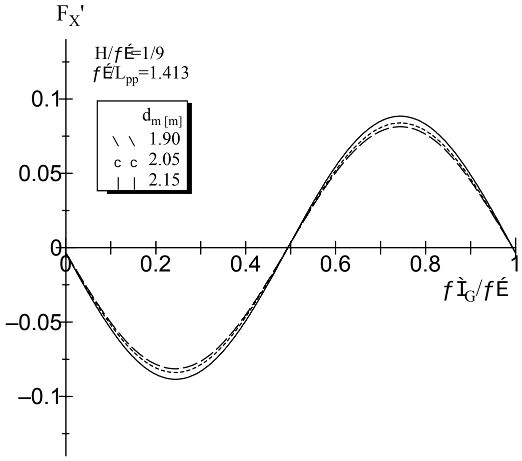

Fig. 17 Calculated longitudinal wave force for various freeboard in following seas.

4. CONCLUSION

The relationship between freeboard and capsizing risk for the Japanese purse seiner is experimentally investigated. From this research we concluded as follows:

1) Capsizing free running model experiments demonstrate that the influence of difference freeboards on capsizing for the 80GT Japanese purse seiner is small. On the other hand, the capsizing risk for the 39 GT Japanese purse seiner with a small freeboard is smaller than with a larger one.

2) Surf-riding is harder with the 39GT Japanese purse seiner in comparison with the 80GT Japanese purse seiner. Moreover, surf-riding is harder with the 39GT Japanese purse seiner with a small freeboard than with a large one.

3) The capsizing risk of the 39GT Japanese purse seiner with a small freeboard at d_m=2.05m, is small in comparison with other drafts from the viewpoint of roll motion in beam seas.

4) If the transverse metacentric height is constant, roll angles at maximum righting arms and vanishing angles in following seas are almost constant even if the size of the freeboard is changed.

5) Surf-riding is harder with the 39GT Japanese purse seiner with a small freeboard, because the stern of the ship submerges without being lifted on the wave crest.

6) The calculated forward wave force of the 39GT Japanese purse seiner is small in comparison with the 80GT, the 135GT purse seiners and the 15000GT container ship, and the probability of surf-riding for the 39GT Japanese purse seiner is small.

5. ACKNOWLEDGMENTS

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