ROLL DAMPING CHARACTERISTICS OF FISHING BOATS WITH AND WITHOUT DRIFT MOTION

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Abstract

In the present study, the prediction method of viscous roll damping proposed by Ikeda et al. is modified for applying to a special vessel with round hull form and a long and wide bar keel (deadwood). The modified method is applied to a typical Indonesian fishing vessel, and the prediction results by the method are confirmed to be in fairly good agreement with experimental results. Effects of bilge keels on roll damping of such a vessel are also examined by the prediction method and experiments. Roll motion of such a vessel in regular beam waves is measured to find that strip methods using the modified roll damping prediction method give good results of roll responses in moderate waves but significantly overestimate the roll responses in heavy waves. It is experimentally confirmed that rapid drift motion in heavy waves increases the roll damping and decrease wave exciting roll moment in heavy seas, and that these phenomena causes the discrepancy of roll responses in heavy seas.

1. INTRODUCTION

As well known, strip theories based on a potential flow theory should take into account viscous effects on the roll damping to get reasonable prediction results near in roll resonant frequency regions. In practice, the viscous roll damping is predicted by empirical formulas. A roll damping prediction method for a conventional-shape hull was developed by Ikeda et.al.[1],[2], and is widely used in strip theories. The prediction method has been modified for various ships with and without many kinds of appendages [3].

The hull designs of Indonesian fishing boats are rather different from those in other countries. A typical boat has a conventional round hull shape with a long bar keel (deadwood). In the present study, at first, a roll damping prediction method is deduced for such kind of hull shape with a bar keel on the basis.

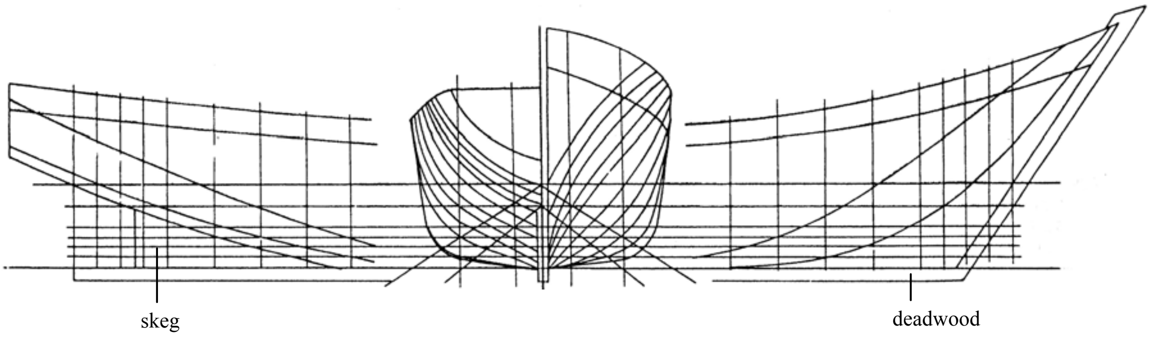

Fig. 1 Lines of Indonesian fishing boat

of the original Ikeda's method. The predicted results by the modified method are compared with measured ones for a scale model of a typical Indonesian fishing vessel by forced rolling tests.

Roll motions of the model in regular beam waves in moderate wave heights are also measured, and the results are compared with predicted ones by Ordinary Strip Method (OSM) in which the modified prediction method of roll damping proposed in the paper is used. The agreements between predicted and measured roll motion in moderate seas are fairly good. In high waves, however, large discrepancies between them appear in roll response for wide frequency ranges. The cause of these phenomena is confirmed to be effects of drift motion induced by high waves on roll damping and wave exciting roll moment.

2. MODEL

In the present study, one of typical Indonesian fishing boats, KM. Mina BPPT-01, is selected. This boat has been operated at Lampung – South Java fishing ground. The hull form of the boat is conventional round hull shape with a long bar keel combined a skeg as long as the ship length. Fig. 1 and Table 1 show the lines of the hull and principal dimensions of a 1/13 scale model of her. Although most Indonesian fishing boats have no roll damping device like bilge keels, effectiveness of bilge keels for ship motion reduction is also evaluated in the experiments. Bilge keels of 0.015 m width are fitted between Stations 3 and 7.

Table 1 Principal dimensions of model

Loa	1.580 m
Lpp	1.310 m
B	0.335 m
d	0.092 m
Δ	20.10 kg
Cb	0.54
Cm	0.79
Cw	0.78
KG	0.114 m
GM	0.055 m
scale	1 : 13

3. ROLL DAMPING PREDICTION

3.1 Modification of roll prediction method

The original Ikeda's prediction method for roll damping of a ship predicts the roll damping by summing up the predicted values of roll damping components, which are friction B_f, eddy B_e, wave B_w, bilge keel B_{bk} and skeg B_{sk}.

The total roll damping coefficient B_{44} can be expressed as follows.

$$B_{44} = B_f + B_e + B_w + B_{bk} + B_{sk} \qquad (1)$$

Ikeda et. al [1],[3] proposed a calculation formula to predict the skeg component, but only for a hardchine craft. In the present study, the prediction formula for skeg component (deadwood and skeg) is modified to be applicable for any types of hull shapes.

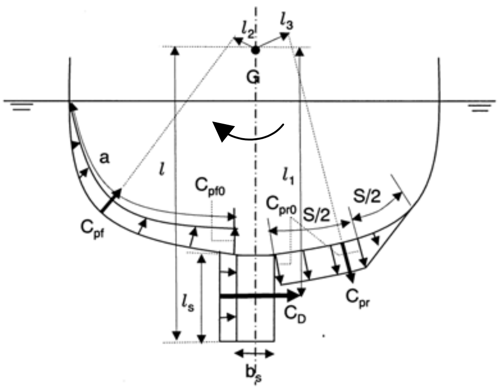

Fig. 2 Assumed pressure distribution due to separated eddies created by skeg.

The skeg component of the roll damping is obtained by integrating the assumed pressure created by a skeg shown in Fig.2 over the skeg surface and the hull surface [1],[3].

Then, the skeg component of the roll damping for unit length can be expressed as follows.

$$B_{sk} = \frac{4}{3\pi} \phi_a l^2 \omega \rho (C_D l_s l_1 - C_{pf} a l_2 + C_{pr} S l_3) \qquad (2)$$

$$C_D = (C_{pf0} - C_{pr0}) = C_{D0} e^{(\frac{-0.38 bs}{ls})} \qquad (3)$$

$$C_{pf0} = 1.2 \qquad (4)$$

$$C_{D0} = 2.425 K_c \quad 0 \le K_c \le 2$$
$$= -0.3 K_c + 5.45 \quad K_c > 2 \qquad (5)$$

$$K_c = \frac{U_{max} T}{2 l_s} = \frac{\pi \phi_a l}{l_s} \qquad (6)$$

$$S = 1.65 K_c^{\ 2/3} \ . \ l_s \qquad (7)$$

ϕ_a in radian

where C_{pf}, C_{pr} and l_2, l_3 denote representative pressure coefficients and their moment levers obtained by integrating the pressure distribution on hull surface in front and the back faces of a skeg respectively, K_c is Keulegan-Carpenter number for the skeg, U_{max} the maximum speed of the edge of the skeg, T the period of roll motion and S the distribution length of negative pressure on the hull surface created by the skeg.

3.2 Comparison with experimental result

Roll damping is measured by a forced rolling test at zero forward at a towing tank of Osaka Prefecture University. The model is forced to roll with constant amplitude and frequency.

The results of roll damping by experiment and prediction are given as a non-dimensional roll damping coefficient $\hat{B}_{44}$ defined as follows.

$$\hat{B}_{44} = \frac{B_{44}}{\rho \nabla B^2} \sqrt{\frac{B}{2g}} \qquad (8)$$

where ρ, g, ∇ and B denote density of fluid, acceleration of gravity, displacement volume and breadth of the model, respectively.

The measured results are shown in Figs. 3 and 4. Fig. 3 shows the comparison of predicted results and measured ones for the model with and without bilge keels. These results demonstrate that the method deduced in the present paper can predict the roll damping in fairly good accuracy. Fig. 4 shows the contribution of the skeg component including the bar keel as well as other components to the total roll damping. A Skeg significantly increases the viscous roll damping by creating eddies at its edge. It should be noted that at large roll amplitude the contribution of the skeg is dominant for the model without bilge keels. The bilge keel component is large in whole amplitude range. To improve the seakeeping quality of Indonesian fishing vessels, the authors recommend attaching bilge keels to them.

4. ROLL MOTION CHARACTERISTICS IN BEAM SEAS

4.1 Roll motion in moderate seas

Measurements of roll motion in regular beam seas are carried out, and the results are compared with the predicted results by OSM in which the modified method for roll damping prediction is used. In the experiments, roll, sway, heave and drift motions are in free. The ship is at zero forward speed. Relative wave height of the regular waves are $H_w/d = 0.11$, 0.16 and 0.76, and wave length varies from $\lambda/L_{pp} = 0.58$ to 2.94 for the model with and without bilge keels, respectively.

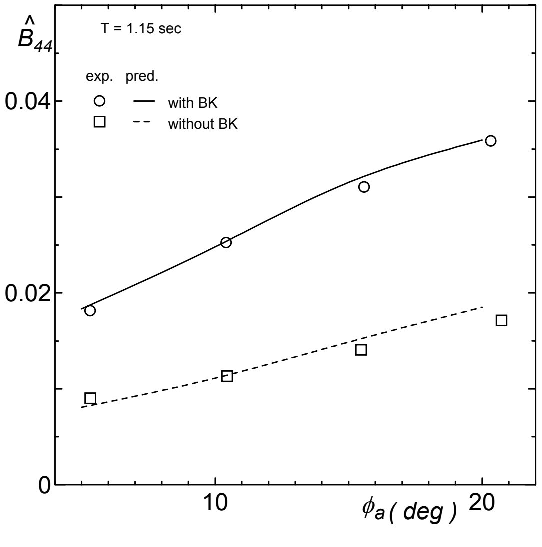

Fig. 3. Roll damping coefficient with and without bilge keel at forward speed.

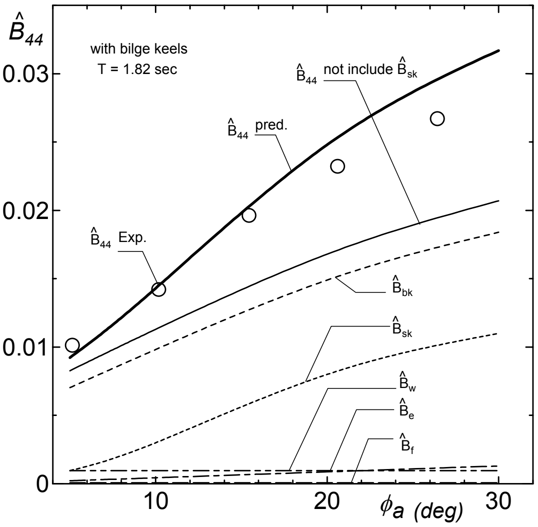

Fig. 4. Contribution of each component on roll damping prediction

The metacentric height was set to be the standard condition and checked by an inclining test. A roll decay test is also carried out to obtain the natural roll period. The roll natural period, T_ϕ , for the model with bilge keels is 1.39 seconds and 1.30 seconds for the model without bilge keels. Fig. 5 shows roll decay test results for the model with and without bilge keels respectively.

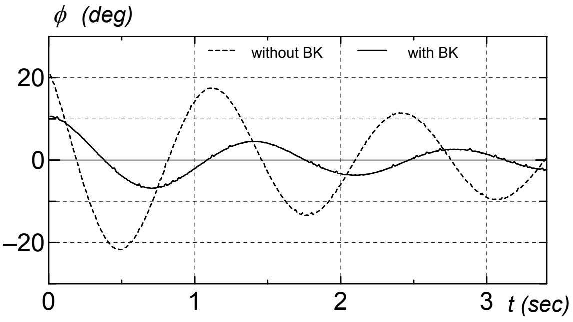

Fig. 5 Roll decay test

As shown in Fig. 6 the roll motion prediction results including the skeg component B_{sk} in the roll damping prediction are in fairly good agreement with the experimental results. The figure shows that the bilge keels reduce the resonant roll amplitude by 40%, and shift the resonance to longer wave region.

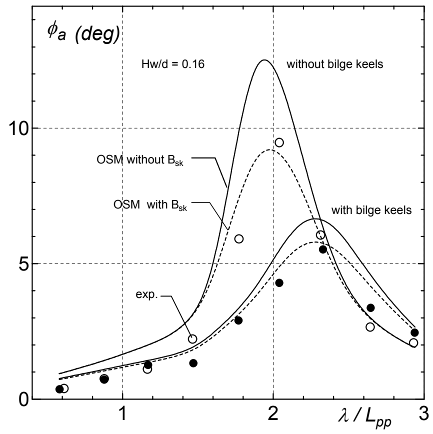

Fig. 6 Effect of skeg component of roll damping prediction on roll motion prediction.

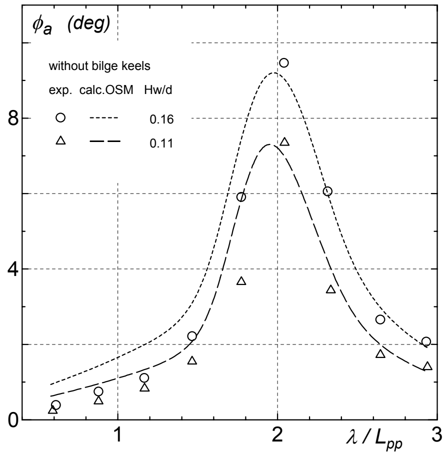

Fig. 7 Comparison between predicted and measured roll amplitudes for model without bilge keels in moderate regular waves

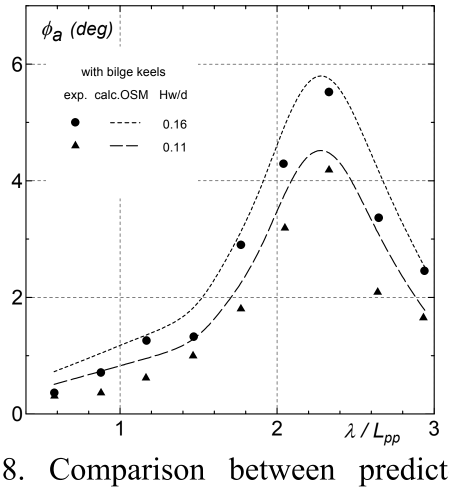

Fig 8. Comparison between predicted and measured roll amplitudes for model with bilge keels in moderate regular waves

Figs. 7 on and 8 show the comparison between predicted and measured roll responses in moderate regular beam seas for the model without and with bilge keels, respectively. The results demonstrate that the agreements with them are fairly good in moderate seas.

4.2 Roll Characteristics in Heavy Seas

Roll motion in heavy seas

Measurements of roll response of the model in regular waves with large wave height are carried out. Figs. 9 and 10 show the experimental results with the calculated ones by OSM. The peaks of resonant roll motion shift from resonance frequency at moderate waves to shorter wave length, and the calculated results overestimates. Particularly the discrepancy between the calculated and measured results is much larger for the case with bilge keels than for the case without bilge keels. Kuroda et al. [4] pointed out that roll motion in heavy seas is significantly affected by rapid drift motion. Therefore, the experimental results in Figs. 9 and 10 are re-plotted with measured encounter frequencies as shown in Figs. 11 and 12. The discrepancies between them can be clearly seen for heavy waves in these figures too.

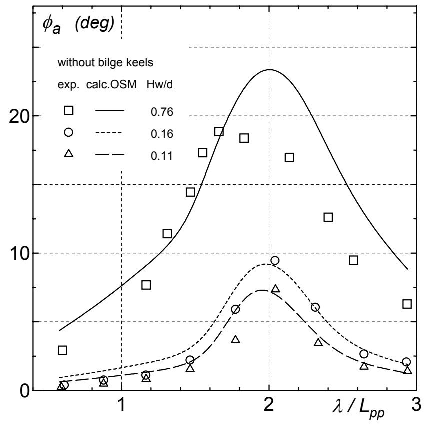

Fig. 9 Roll response in large wave amplitude for model without bilge keels.

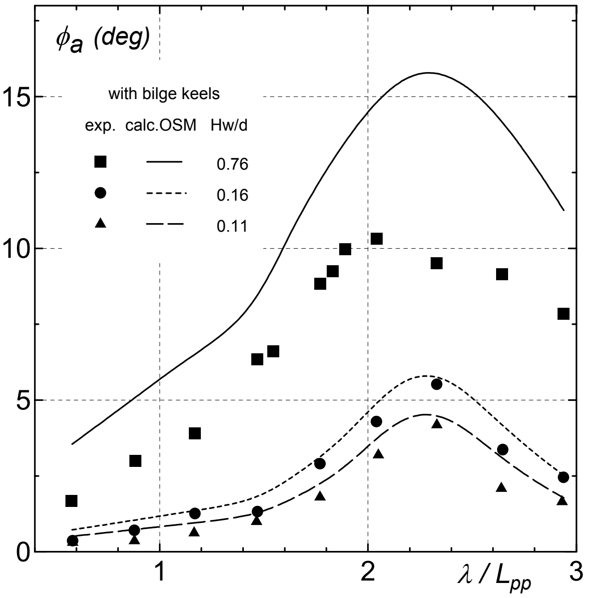

Fig. 10 Roll response in large wave amplitude for model with bilge keels

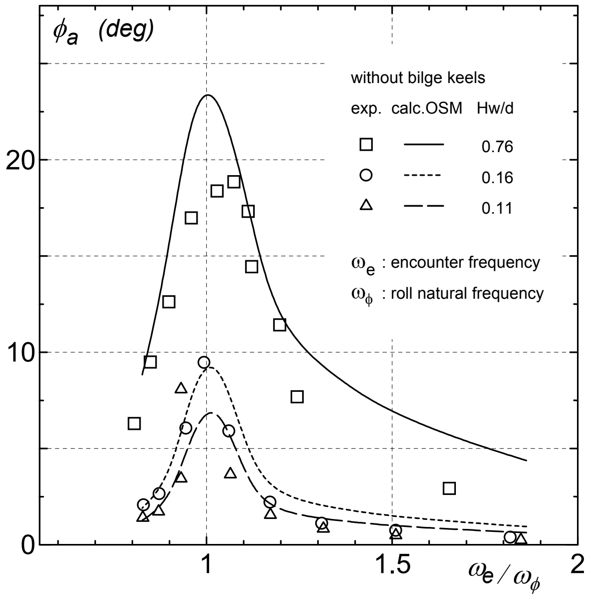

Fig. 11 Re-plotted roll amplitude with measured encounter frequency for model without bilge keels

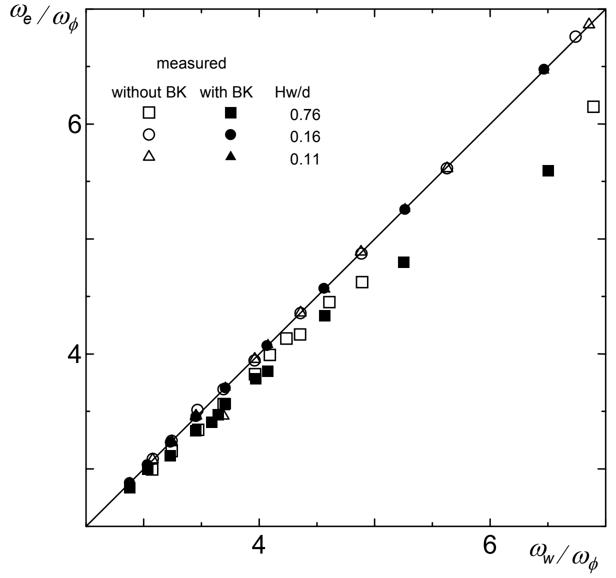

Fig. 13. Relationship between encounter frequency of roll motion and incident wave frequency.

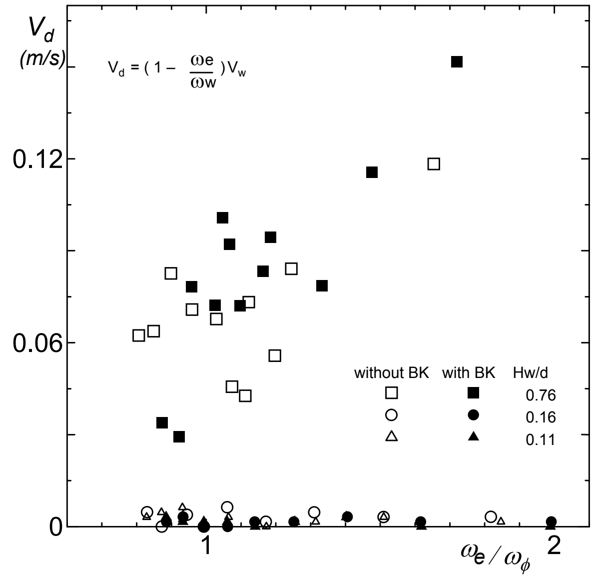

Fig. 14. Drifting velocity calculated by measured encounter frequency.

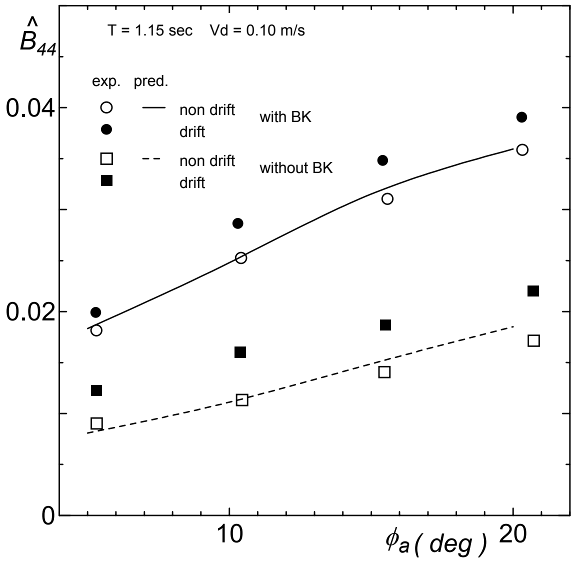

Fig. 15. Effect of drift motion and roll damping for various roll amplitude.

From the experimental data, relation between encountering frequency obtained from measured roll motion and incident wave frequency in the same experiment can be plotted as shown in Fig. 13. The figure shows that the encounter frequency in high waves becomes lower than the wave frequency with increasing frequencies. The results suggest that drifting velocity of the model due to waves increases in heavy seas. Fig. 14 shows the drifting velocity calculated by measured encounter frequency. In small wave height drifting velocities are almost zero. In high waves, however, the drifting velocities of the model with and without bilge keels are large, and increase with increasing encounter frequency rapidly.

Effect of drift motion on roll damping

To confirm the effect of drift motion on the roll damping, forced rolling tests in drift motion are carried out. In order to make drifting condition, the model is towed in transverse direction by a towing carriage at a constant drifting velocity. The drifting velocity V_d is changed systematically up to 0.13 m/s which is the maximum drifting velocity obtained in the experiment shown in Fig. 14.

Fig. 15 shows the experimental results of the roll damping with and without drift motion for various roll amplitudes. The results suggest that drift motion increases the roll damping of the model with and without bilge keels. In Figs. 16 to 19 measured roll damping for various drifting velocity are shown. Increase of the roll damping depends on bilge keels, roll amplitudes and roll frequency.

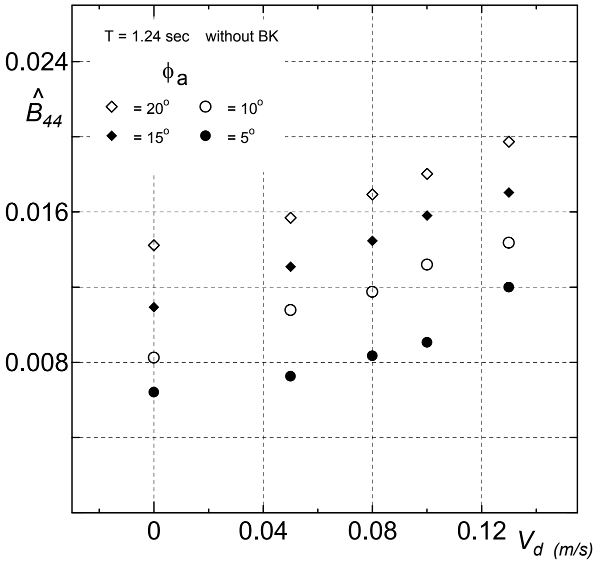

Fig. 16. Effect of drift motion on roll damping for various roll amplitude without bilge keels.

These experimental results may suggest that discrepancies of the predicted and measured roll motion in high waves near roll resonance frequency are partly because of increase of the roll damping due to rapid drift motion.

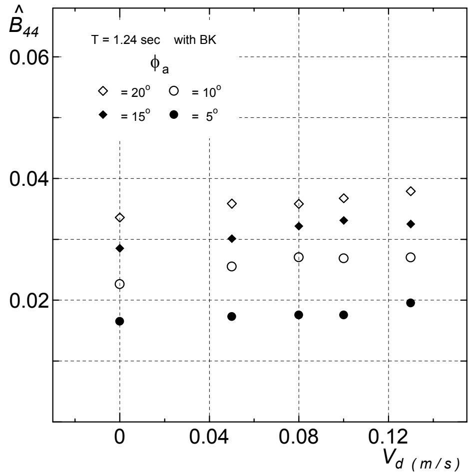

Fig. 17. Effect of drift motion on roll damping for various roll amplitude without bilge keels

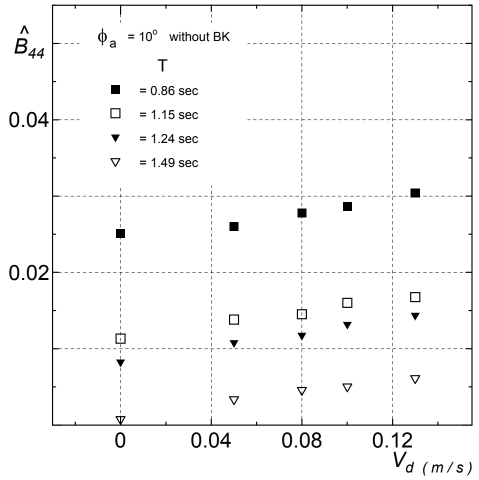

Fig. 18. Effect of drift motion on roll damping for various roll period without bilge keels.

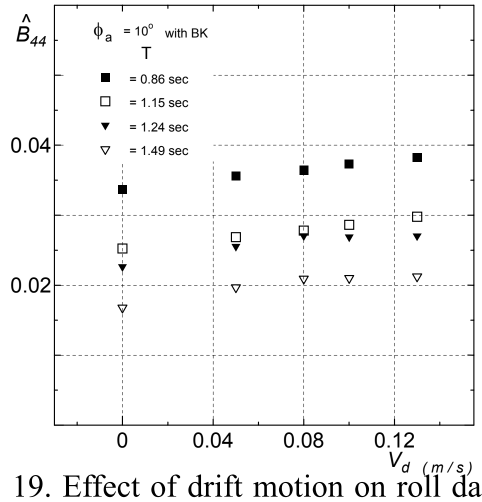

Fig. 19. Effect of drift motion on roll damping for various roll period with bilge keels.

<u>Wave exciting moment</u>

Another possibility of the reasons for the discrepancies between the predicted and measured roll motions in heavy waves can be the effect of drift motion on the wave exciting roll moment acting on a ship. Rapid drift motion changes encounter frequency of wave forces acting on the hull. As well known the wave exciting forces depends on encounter frequency. This is common for vertical motions of a ship sailing in waves, but unusual for transverse motions because drift motion in beam seas is assumed to be small.

Measurements of the roll moment acting on the model fixed on a carriage running in a constant transverse speed are carried out. The direction and speed of the carriage are changed in two cases, respectively. The measured moments by a three-component load-cell are translated into the moment about the standard location of the center of gravity of the model.

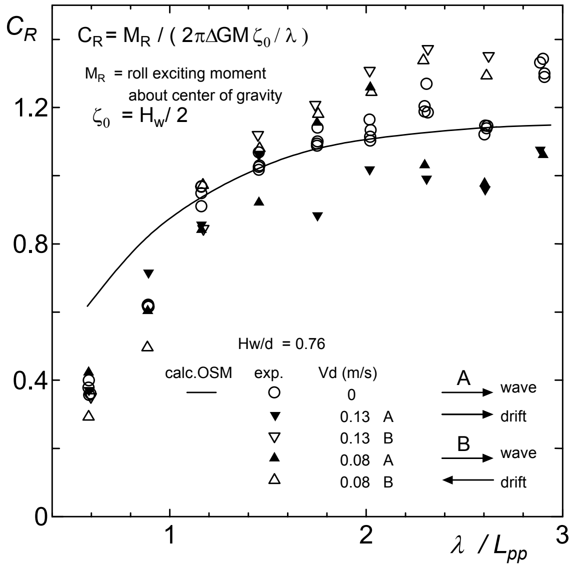

Fig. 20. Effect of drift motion on roll exciting moment by beam regular waves.

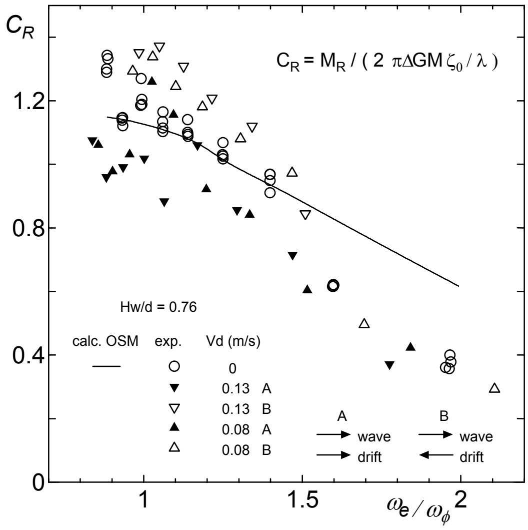

Fig. 21. Re-plotted figure of wave exciting roll moment with encounter frequency

Measured results of the roll excitation moment are shown with the calculated one by OSM in Fig. 20. In the figure, the results are expressed in non-dimensional coefficient C_R versus wave length of incident regular waves. The results in longer wave length region show that the wave exciting roll moment with drift motion against waves is larger than that with zero drift motion and that with drift motion following waves is smaller than that with zero drift motion. In shorter wave length region, however, the dependency on drift directions disappears. The measured data of wave exciting roll moment are re-plotted for encounter frequency in Fig. 21. In lower encounter frequency region in the figure, the experimental results scatter around the calculated results by OSM. In higher encounter region, however, the experimental results are much smaller than the calculated one. These results suggest that the discrepancies between the calculated and measured roll motions in larger encounter frequency regions shown in Figs.11 and 12 are caused by the reduction of the wave exciting roll moment due to rapid drift motion as shown in Fig.21. We are left to explain, however, why the exciting moment decreases with increasing drift velocity. Physical reasons for the phenomena should be investigated.

5. CONCLUSIONS

Through the present experimental studies, following conclusions are obtained.

1. A prediction method of the roll damping of a ship with any shape of hull and a large bar keel is deduced. The method is confirmed to give a good prediction result for a typical Indonesian fishing boat.
2. Predicted results of roll response by a strip method with the roll damping predicted by the deduced method are in fairly good agreement with experimental ones in moderate seas.
3. Predicted results by a strip method overestimate experimental ones in heavy seas.
4. The disagreement between the predicted and measured results is caused by rapid drift motion in heavy beam seas.
5. Drift velocity causes increase of the roll damping.
6. Drift velocity decreases the wave exciting roll moment in higher encounter frequency region.
7. A ship motion theory including steady drift motion is necessary for accurate prediction of roll motion of a ship in heavy seas.

6. ACKNOWLEDGEMENTS

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7. REFERENCES

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