A Study on Roll Damping of Bilge Keels for New Non-Ballast Ship with Rounder Cross Section

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ABSTRACT

A concept of a new non-ballast-water tanker and bulk carriers by introducing pod propulsions moving up and down to keep enough depth for the propellers was proposed by Ikeda et al. In the research project, the new hull form is rounder cross section for the parallel part near mid-ship to reduce the friction resistance.

In the present paper, the characteristic of roll motion of the new ship is experimentally investigated. The experimental results demonstrate that the roll damping created by bilge keels of the new ship is smaller than that of a conventional one with square cross sections. Therefore large resonant roll motion can be expected in higher waves. It is also confirmed that Ikeda's prediction method of the roll damping for conventional ships underestimates the roll damping of the new ship in large amplitude due to interaction effects of two bilge keels. To investigate the effects CFD calculations for tandem flat plates in oscillating flow is carried out.

KEYWORDS

Roll damping; Bilge keel; Non Ballast Ship; Round cross section; Ikeda's Prediction Method

INTRODUCTION

In recent years, reductions of fuel oil consumption are great issues for environmental pollutions and shipping economy. Almost all ship building companies are trying to develop new eco-ships to solve these problems. One of the authors proposed a concept design of new non-ballast-water tankers and bulk carriers by introducing pod propulsions moving up and down to keep enough depth for the propellers. A New Ship named NBK0-1 has been developed, and experimental studies demonstrate that the resistance acting on this concept ship with 80,000DWT can be reduced by 17.4% in full load condition and by 43.7% in light weight condition. Since the ship has rounder cross sections, its roll performances should be carefully investigated. This paper intends to reveal characteristics of the roll motion of the new ship NBK0-1, and to investigate the roll damping and the interaction effects of two bilge keels.

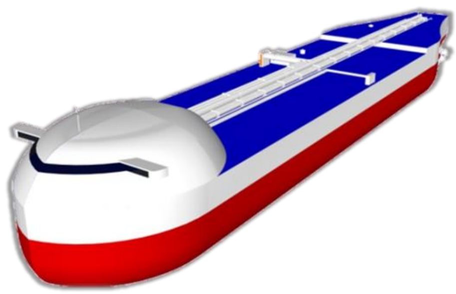


Fig.1 Image of New Non-Ballast Ship

CONCEPTS of NEW SHIPS

Tankers and bulk carriers are poured huge amount of water into ballast tank in light weight condition to prevent exposing its propeller above water surface. Conveying the ballast water causes several serious matters, for examples, increasing resistance and destroying an ecological system around the port. In the proposed non ballast ships, pod propulsions moving up and down are adopted to keep enough depth of the propellers without ballast water as the first concept.

The second concept is reducing trim angle in no ballast water condition by introducing a diesel-electric pod propulsion system. The system can arrange the engine room at bow, and this arrangement can reduce the trim angle in no ballast water condition.

Conventional large tankers and bulk carriers have long parallel bodies with square cross section to keep larger payload. The squared section causes increase of the wetted surface which make the frictional resistance increases. Therefore, as the third concept, the parallel part with rounder cross section is adopted.

The fourth concept is a buttock-flow stern shape. The shape reduces the viscous pressure resistance or the form factor of the ship. The body plan of the new ship is shown in Fig.2

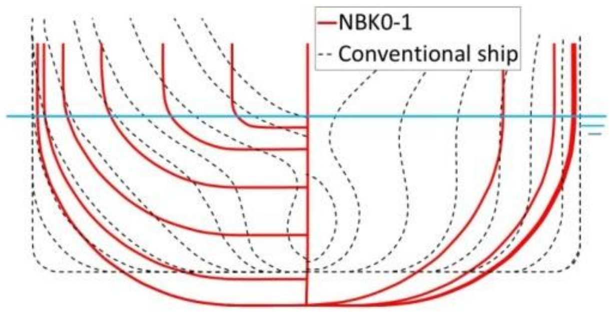


Fig.2 Body plan of ships

MEASUREMENTS OF ROLL IN WAVES

In order to investigate the characteristic of roll motion of the new ship, rolling tests are carried out in a tank. Length of the model is 2m and its bilge keels are 1.1cm in breadth and 1.1m (55% of L_{pp}) in length. Locations of the bilge keels are changed at ① or ④ as shown in Fig.3. The condition of the ship is in full load. Incident waves are regular and beam ones.

Table 1 Experimental conditions

	Full load condition		
Location of BK	without	①	④
GM	0.0592m	0.0591m	0.0584m
Natural roll period	1.01s	1.02s	1.03s

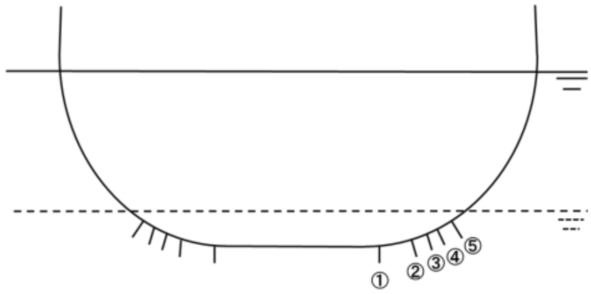


Fig.3 Location of bilge keel

The experimental results are shown in Fig.4. The solid line in the figure shows the calculated results of roll amplitude with a strip method (OSM) in which the roll damping is predicted by Ikeda's method. For a bare hull, agreement between the calculated and experimental results is fairly good. The figure also suggests that the roll amplitudes in resonant are decreased by the bilge keels and the bilge keels located at ④ are more effective than those located at ①.

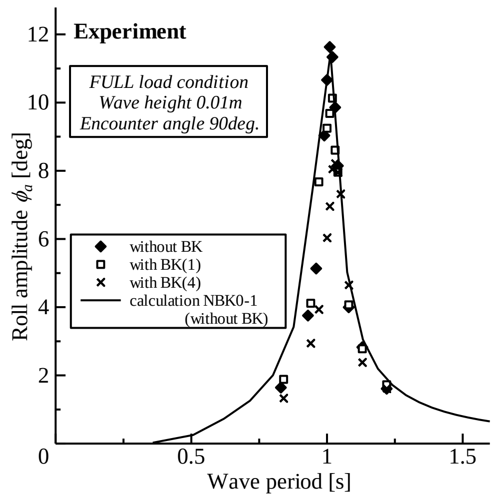


Fig.4 Roll amplitude of the new ship NBK0-1 in regular beam waves at full load condition

Fig.5 shows the result of comparison of resonant roll amplitudes of the new and conventional ships for various wave heights. In the experiments, wave period is fixed at the natural roll period. For the conventional ship, the roll amplitudes calculated by the strip method in the same condition with the experiments are shown. It should be noted that the area of bilge keels of the new ship is larger by four times than that of the conventional one. The results show that the bilge keels of the conventional ship reduce the resonant roll amplitude by about 40%, but the bilge keels of the new ship reduce it only by 10% at location ① and by 20-30% at location ④ even though the bilge keels are much larger.

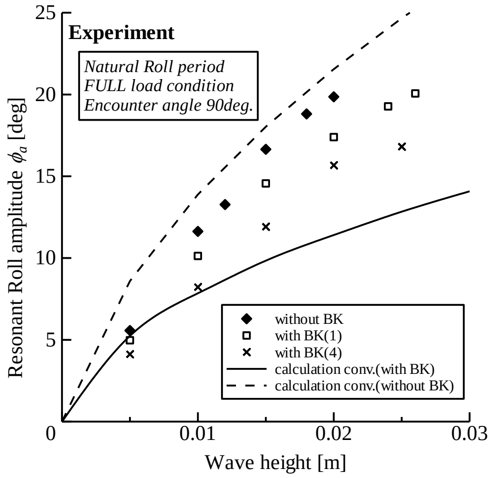


Fig.5 Comparison of resonant roll amplitudes between new ship and conventional ship at full load condition for various wave heights

CALCULATION by STRIP METHOD

Resonant roll amplitudes of the new and the conventional ships as 80,000 DWT tankers in regular beam waves are predicted by the strip method.

Predicted results of roll motion for the new and the conventional ships without bilge keels at zero advanced speed are shown in Fig.6 and Fig.7. Wave height is 2m in real scale. Resonant roll amplitude of the new ship is much larger than that of the conventional one at zero speed as shown in Fig.6. The resonant amplitude at advanced speed, however, becomes the same level with that of the conventional one as shown in Fig.7. This is because a large lift component of the roll damping which is proportional to advanced speed is generated due to its deep draft.

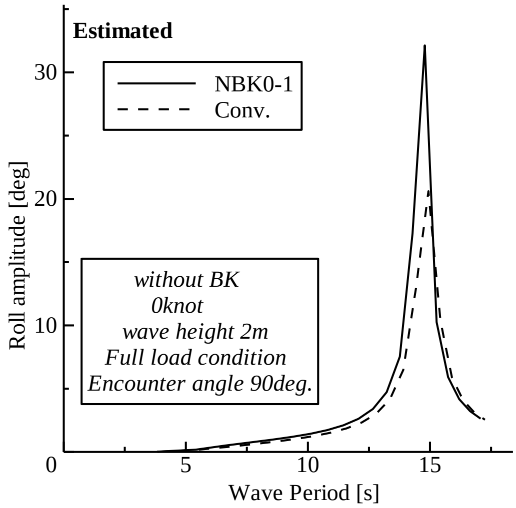


Fig.6 Estimated roll motions of ships without bilge keel at zero speed

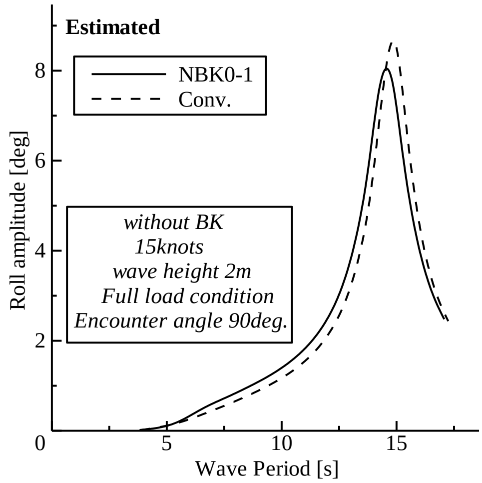


Fig.7 Estimated roll motions of ships without bilge keel at advanced speed

Predicted results of roll motion for them with and without bilge keels (length is 40% of L_{pp}; breadth is 1m) at zero advanced speed are shown in Fig.8 and Fig.9. In the calculation the bilge keels is attached at locations ① or ④ shown in Fig.3. The results clearly show that the bilge keels significantly increase resonant roll amplitude. The same tendency is seen in the calculated results with bilge keels at all locations shown in Fig.3.

Some experiments are carried out to confirm the strange phenomenon. However, the authors could not find the same characteristics in the experiments.

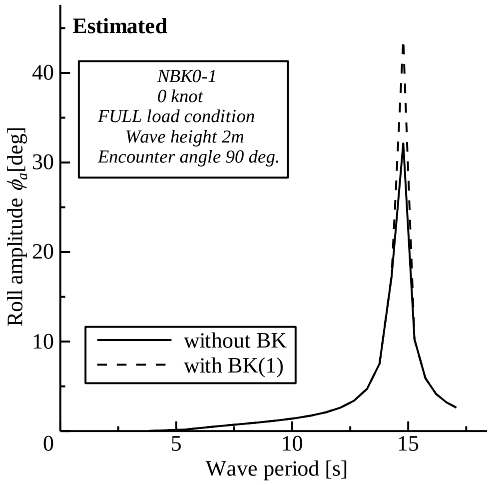


Fig.8 Estimated roll motions of the new ship with and without bilge keel at zero speed

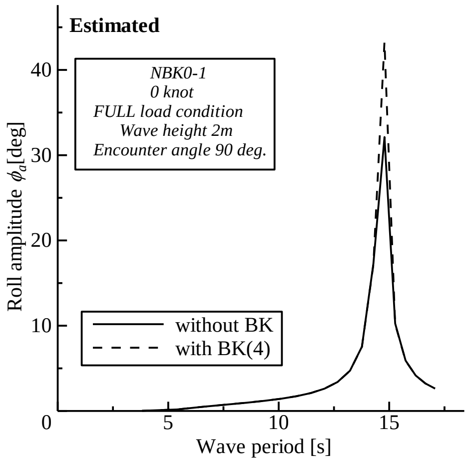


Fig.9 Estimated roll motions of the new ship with and without bilge keel at advanced speed

IKEDA'S PREDICTION METHOD for ROLL DAMPING and IT'S DEFECTS

In Ikeda's prediction method, the roll damping is divided into five components, friction, wave making, lift, eddy making and bilge keel components. The bilge keels component is divided furthermore two components, a normal pressure component by hydrodynamic force acting on bilge keel and a surface pressure component by pressure fluctuation which is created by bilge keels on the hull surface. In the surface pressure component, positive pressure is distributed on hull surface in front of a bilge keel and negative pressure is distributed on the surface in the rear of it as shown in Fig. 10. Positive pressure component is assumed that the positive pressure at just front of the bilge keel becomes maximum and reduces steadily in proportional to the distance from the bilge keel. Negative pressure component is assumed that the negative pressure at just rear of a bilge keel lasts a certain distance and reduces drastically at far from the point.

In the prediction method, the bilge keel component is calculated by integrating the assumed pressure over all surfaces. The pressure values and distributions depend on Kc number which relates to relative roll amplitude.

In Fig.10 the pressure distributions assumed in Ikeda's prediction method for the midship section of the new ship in moderate roll amplitude are shown. It should be noted that the pressure distributions except the positive pressure in front of the left bilge keel generate roll damping, but the negative pressure behind it generate negative roll damping. As roll amplitude increases, the length of the negative pressure behind bilge keels increases. Then the negative pressure grows over the center line of the body, and generates negative roll damping too.

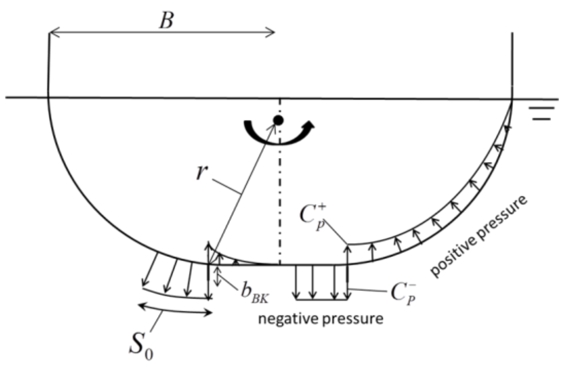


Fig.10 Assumed pressure distribution created by bilge keels in Ikeda's prediction method

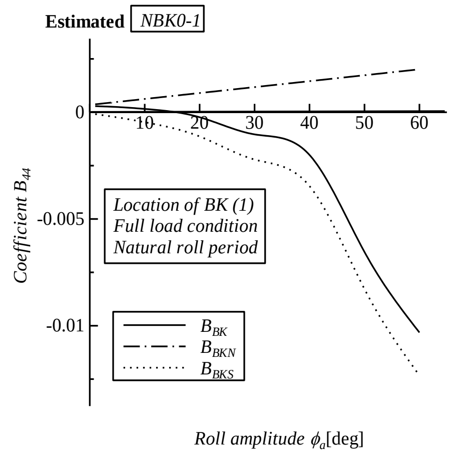
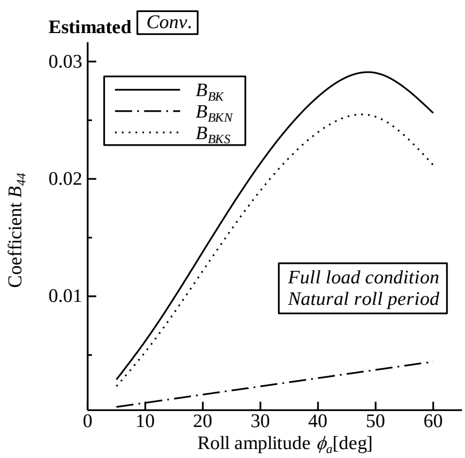


Fig.11 Total, normal-force and surface-pressure components of roll damping created by bilge keels predicted by Ikeda's method

Fig.11 shows the roll damping of the bilge keel components for the new and conventional ships calculated by Ikeda's method. The horizontal axis is roll amplitude and the vertical one is roll damping coefficient, B_{44}. The bilge keels for the new ship is attached at location ①, and area of keel for the new ship is about 2.6 times of that of conventional one. B_{BK} is total bilge keel component, B_{BKN} is normal pressure one, and B_{BKS} is surface pressure one. The predicted roll damping for the conventional tanker shown in the upper figure in Fig.11 shows that the surface pressure component is dominant as well known. We can see the roll damping by bilge keels increases with roll amplitude up to 40 degrees. The lower figure in Fig. 11 for the new ship, however, shows completely different characteristics. The surface pressure component decreases with increasing roll amplitude, and is in negative. This is because the surface pressure created by bilge keels generates negative damping as pointed out in the previous section.

The authors experimentally investigated this negative roll damping, but could not find it. This may suggest that Ikeda's prediction method which was made for conventional cargo ships cannot work properly for such hull forms with large bilge keels. It should be noted that improvement of the prediction method must be needed.



CFD CALCULATIONS

In Ikeda's prediction method, the pressure distribution front and behind a bilge keel was assumed on the basis of experimental results. To investigate the validity of the assumption, vortices generated by bilge keels are calculated by CFD. A commercial CFD code 'Fluent' is used. For the simplicity, a flat plate and a set of tandem flat plates standing on a flat floor are considered in the calculation.

Fig.12 show the calculated stream lines in a cycle around a plate in oscillating flow at Kc=15. The definition of Kc is $U_{max}T/2d$ (U_{max}: maximum velocity, T: period, d: height of the standing late).

In Figs.13 ～ 15, streamlines of the flows passing over a set of tandem plate plates are shown. The distances(Δx) of the two plates are changed as $\Delta x/d$=5, 10 and 20. Interaction effects between the plates are clearly seen from the calculated results.

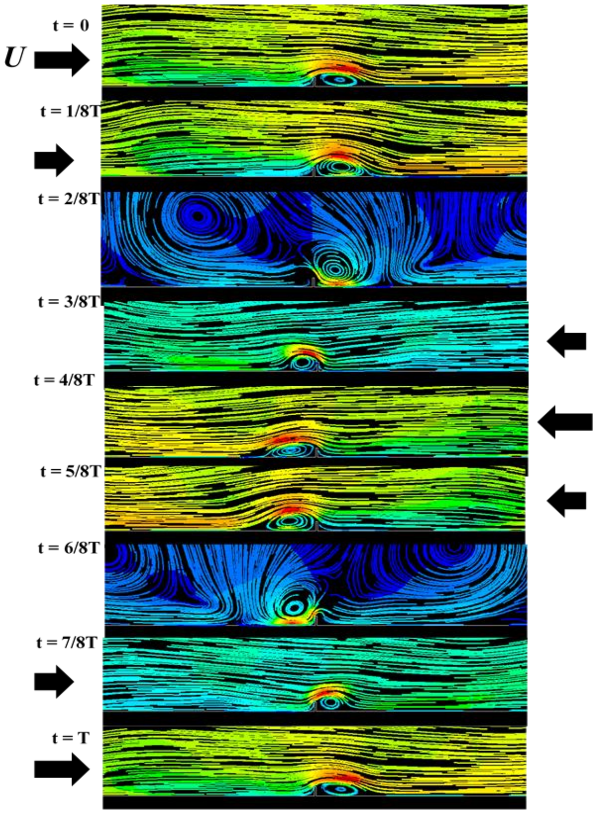


Fig.12 Calculated stream line around single plate at Kc=15

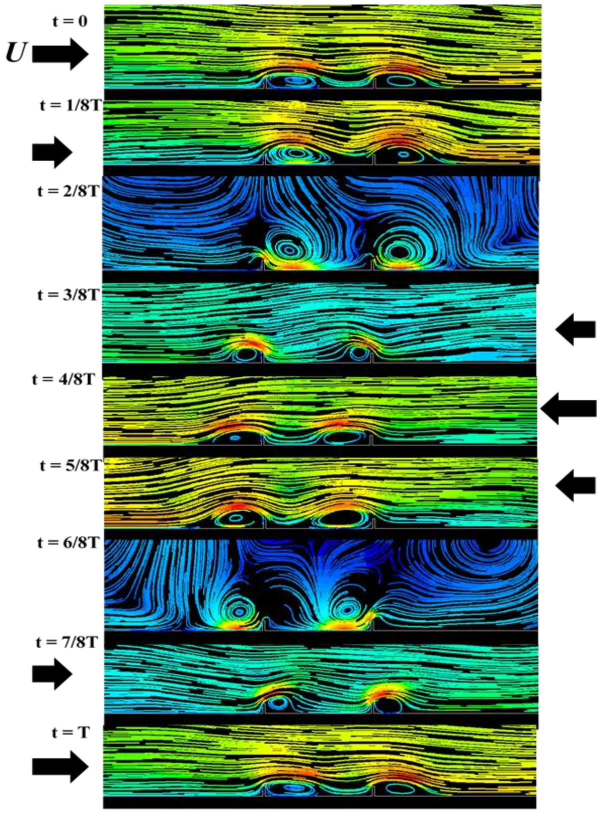


Fig.14 Calculated stream line around tandem plates Δx/d=10 at Kc=15

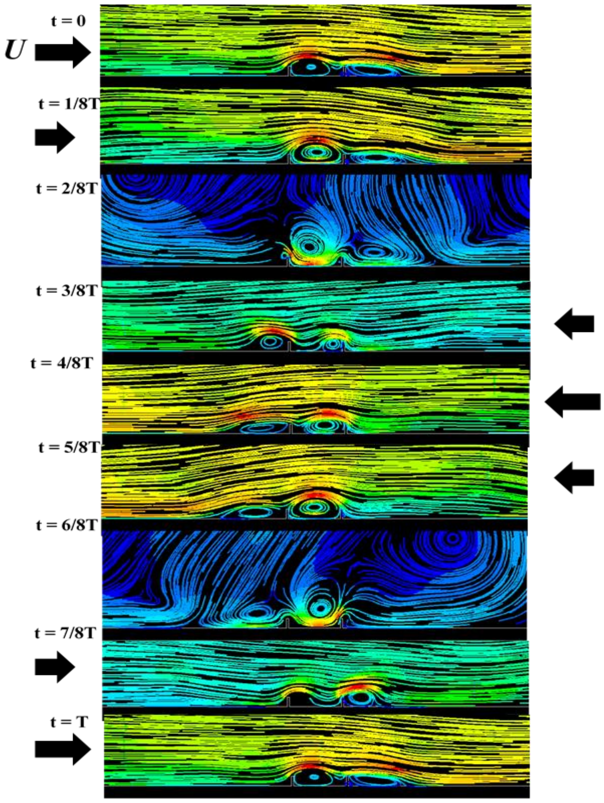


Fig.13 Calculated stream line around tandem plates Δx/d=5 at Kc=15

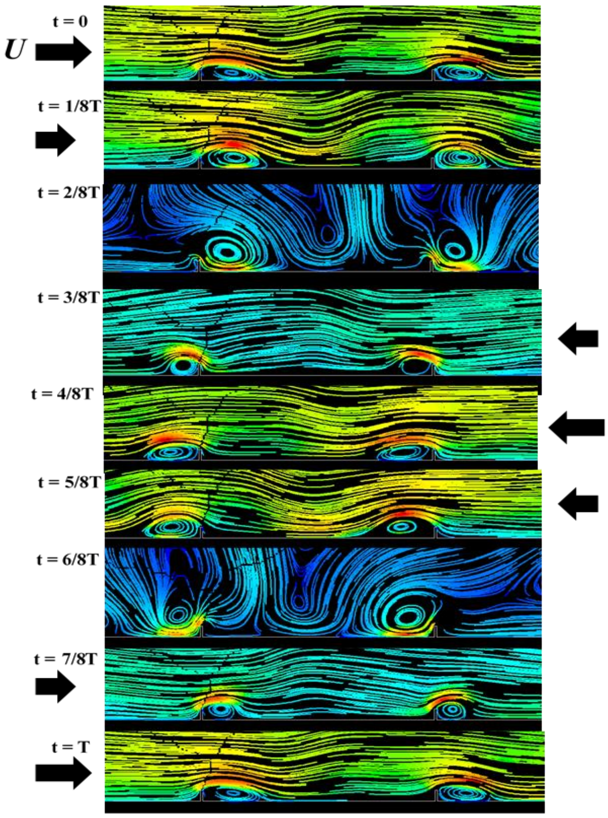


Fig.15 Calculated stream line around tandem plates Δx/d=20 at Kc=15

The lengths of vortices behind the front and rear plates are shown in Figs.16 and 17. The length depends on Kc number and the distance between two plates. The solid lines in these figures show the length of vortices for single plate. The differences between the single and the tandem plates are not so significant.

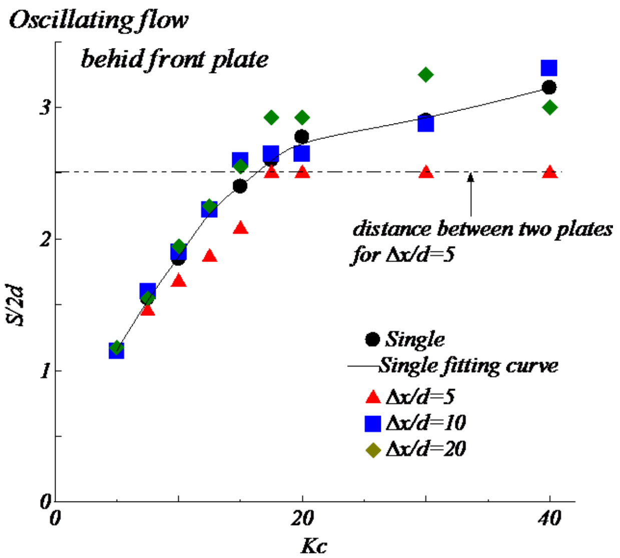


Fig.16 Vortex length at behind front plate in oscillating flow

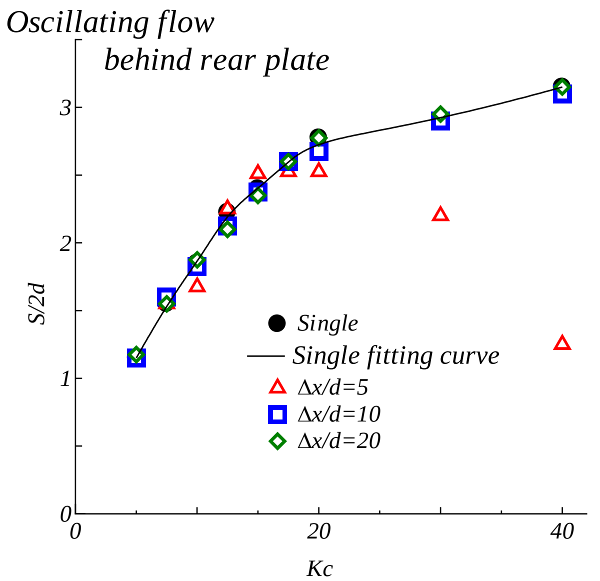


Fig.17 Vortex length at behind rear plate in oscillating flow

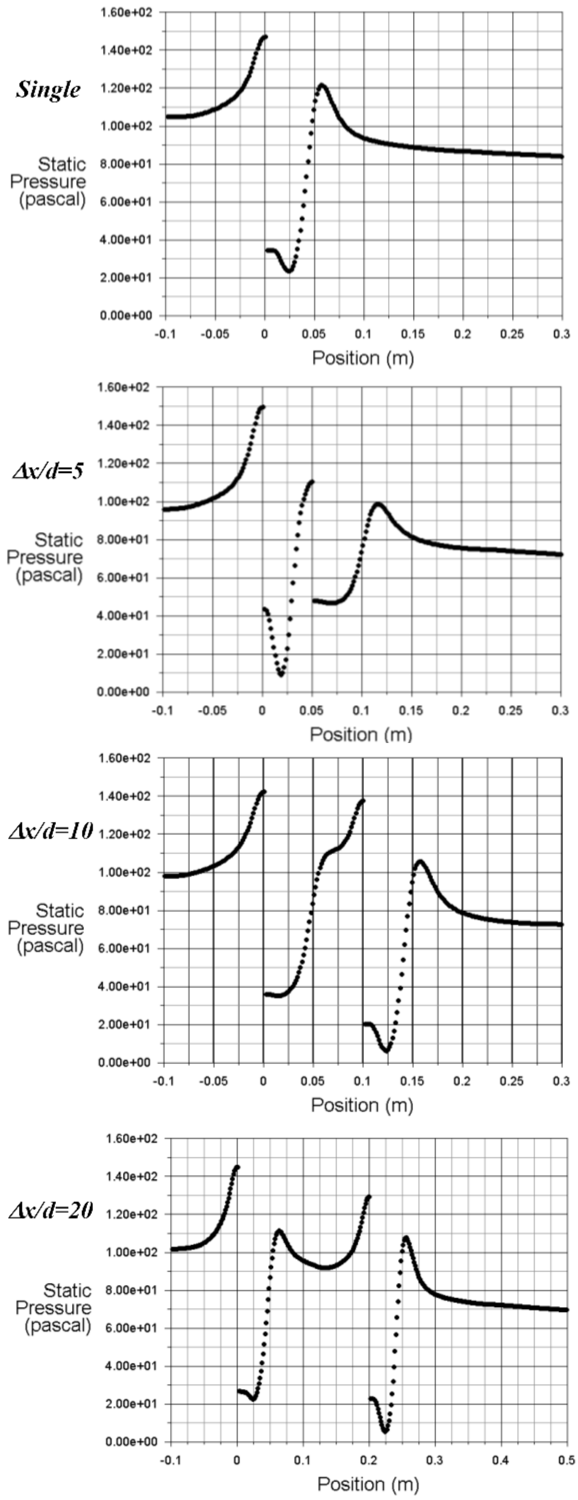


Fig.18 Static pressure distributions on the floor in respective intervals

Calculated pressure distributions on the floor are shown in Fig.18. We can see that positive pressure increases in front of a plate, and negative pressure acts on the floor behind the plate. It can be confirmed that the pressure distribution for single plate looks like the assumed one in Ikeda's prediction method. It should be noted that the pressure difference in front and behind a plate causes the drag force acting on the plate. The results of pressure distribution for $\Delta x/d=5$ demonstrates that the distributions of negative pressure behind the front and rear plates are significantly different. The magnitude of the differences decreases with increasing the distance between the two plates.

The calculated results suggest that interaction effects of vortices generated from plates should be properly taken into account in Ikeda's prediction method. To propose the modification of Ikeda's method, however, more information on interaction effects of two bilge keels which are nearly located as like the non-ballast water ships developed by the authors.

CONCLUSION

In the present study, characteristics of roll motion of the newly developed non-ballast ships with very rounder cross sections in the authors' laboratory are experimentally and theoretically investigated, and following conclusions have been obtained.

1) Model experiments in regular beam waves demonstrate that the ship without bilge keels rolls in larger amplitudes than a conventional ship at zero advanced speed.

2) At advanced speed, the severe roll motion at resonance will be restrained by larger roll damping which is created by lift component.

3) Calculated results by a strip method including Ikeda's prediction method for viscous roll damping show that bilge keels increase the resonant roll amplitudes of the new ship. However, any experimental confirmations of these phenomenon could not be obtained.

4) The reasons why Ikeda's prediction method gives such results are that the surface pressure created bilge keels which I assumed in the prediction method causes negative roll damping.

5) Some modification of Ikeda's prediction method for roll damping may be needed to apply it to rounder ship hulls with closer bilge keels like the new ship considering in the study

6) Experimental results show that the effect of bilge keels for such a rounder ship is much smaller than that for conventional ships with square cross section, and significantly depends on the attached locations of bilge keels.

7) Interaction effects between two bilge keels are investigated by using CFD. Problem of pressure distribution from the original assumptions in Ikeda's prediction method comes to light.

This study was carried out in a part of a joint research project for developing innovative "Non-Ballast & K0 Tankers and Bulk Carriers" with Osaka Prefecture University and 10 Japanese private companies including shipyards. The authors sincerely appreciate to all member companies for valuable suggestions and fundamental supports.

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