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Experimental Study on Added Resistance of VLCC for Ship's Operating Condition in Waves

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Abstract : *In this study, experiments were performed using a model of a very large crude oil carrier (VLCC), which is a typical blunt ship, in a wave-making towing tank. The aim of the experiments was to determine the effect of added resistance in waves on the various operating conditions of a VLCC. An analysis of the results was conducted to determine the characteristics of resistance performance in waves. In addition, the characteristics of added resistance on a tanker were analyzed under irregular waves based upon the above result. The experimental results showed that added resistance was the highest around* $\lambda/L=1.0$, *and the added resistance increased with the increase of the ship speed. Furthermore, under even keel conditions, the added resistance was higher than that under the trim changes, and the smallest added resistance was measured at the trim by the stern. Based on the experimental results, this study proposes effective operating conditions by analyzing the characteristics of the mean added resistance and the expected extreme response in irregular waves.*

Key Words : *VLCC, Operating condition, Ship speed, Trim, Mean added resistance, Expected extreme response*

1. Introduction

Over the past few years, oil prices have increased and new regulations have been put in place to restrict carbon emissions. Regarding ships, it would be highly desirable to increase fuel efficiency and to reduce the usage of marine fuel in order to achieve economic and environmentally friendly sea voyages. Toward that end, studies have been performed in the shipbuilding industry to develop new hull forms to reduce energy and auxiliary devices to improve propulsion efficiency. In addition, the effects of the trim of ships on resistance performance in still water have been examined. Shipping companies have shown a great deal of interest in these innovations as well. However, the above developments are difficult to apply in existing vessels currently in operation, and their research scope is quite large. Therefore, much investment is needed in terms of time and cost.

Nominal speed loss is a phenomenon in which a ship's speed is reduced in real sea environments. This phenomenon is caused by four factors: wave force, wind force, forces due to drift motion, and steering. Among the four factors, the most influential is an increase in resistance due to wave force. Therefore, it is necessary to estimate this increase in resistance accurately(Ichinose et al., 2012).

Since wave-making and wave-breaking phenomena due to bulbous bows are generated more in a light load condition than a full load condition, it is more difficult to estimate added resistance. However, in the case of vessels such as tankers, which sail in a ballast condition for half of their entire operational time, both full load and light load conditions should be considered when estimating the added resistance resulting from wave force.

Ibata et al.(2013) conducted a study on the effects of wave height and ship speed on added resistance in waves. They reported that an increase in resistance was not necessarily proportional to the square of the wave height; rather it depended on hull form, wavelength, and ship speed. Furthermore, they asserted that the ship speed effect coefficient was highly dependent on wave height.

A number of studies have been done to examine the characteristics of resistance by trim in still water, but only a few studies have been conducted on the characteristics of added resistance due to changes in trim in waves. Park et al.(2013) studied the effect of ship trim on resistance in still water with respect to container ship, and they identified that a component of pressure resistance was more influential than a component of friction resistance. Lee et al.(2010) calculated the effect of ship trim on added resistance numerically with respect to a series 60 ship, and they proposed an evaluation method of added resistance

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in real sea environments. However, no studies have been performed yet on actual hull forms in operation and operating conditions. Thus it is necessary to conduct application studies that can be applied practically by conducting experiments with respect to various operating conditions, such as load conditions (full load or light load), trims (even keel, trim by the head, trim by the stern), and ship speeds.

In this study, the effects of a ship's operating conditions on added resistance were analyzed via towing tank experiments using a large tanker, which is a typical large-sized ship, without any new developments in hull forms and with no additional devices. This analysis yielded a guideline for real economical ship operations.

2. Model test in regular waves

In this study, experiments were performed using a model of a very large crude oil carrier (VLCC), which is a typical blunt ship, in a wave-making towing tank. The aim of the experiments was to determine the effect of added resistance in waves on the various operating conditions of a VLCC. An analysis of the results was conducted to determine the characteristics of resistance performance in waves. During the water tank experiments, observations of the added resistance on a tanker and shipside waveforms were compared with respect to operating conditions. In addition, the characteristics of added resistance and resistance propulsion performance in a tanker were analyzed under irregular waves based upon the above result.

In the model experiment, which was aimed at estimating the resistance performance of a tanker in waves, resistance and shipside waveforms were observed in the towing tank, and a model of a VLCC ship manufactured to 1/130.0 scale was used. The above model experiments were conducted in a towing tank whose dimensions were 12.0 m × 6.5 m × 1.3 m (L×B×D). Table 1 and Figs. 1 and 2 show the detailed specifications of the model ship and the views of the experiment. The model experiment was conducted at three speeds: Fn 0.091, 0.073, and 0.046 (which corresponded to 10, 7.7, and 5 knots of a real ship) based on a head sea of Beaufort scale 6 (wave height: 3 m). In addition, the experiment was carried out under full load and empty load conditions, trim by the head (2 m), trim by the stern (2 m), and an even keel of the operating position, thereby enabling a comparison of the characteristics of an increase in resistance in still water according to each of the operating conditions. Fig. 1 and 2 show the experimental scenes of full and empty load conditions at $\lambda/L=0.7$, Fn 0.091, and the even keel condition. The added resistance signifies the difference between the total resistance in waves and the still water resistance measured at the same condition. The measured data are adopted for 10 periods of waves. An added resistance value measured at each of the operating conditions was compared and analyzed according to ship speed, loading condition, and trim condition through a dimensionless process.

Table 1. Main Particulars of VLCC

	Actual	Model
Lpp (m)	325.0	2.5
Breadth (m)	53.0	0.408
Full load draft (m)	22.05	0.170
Ballast draft (m)	10.0	0.077
Cb	0.830	

Fig. 1. Wave pattern for VLCC model (even keel, $\lambda/L=0.7$, Fn 0.091, full load condition).

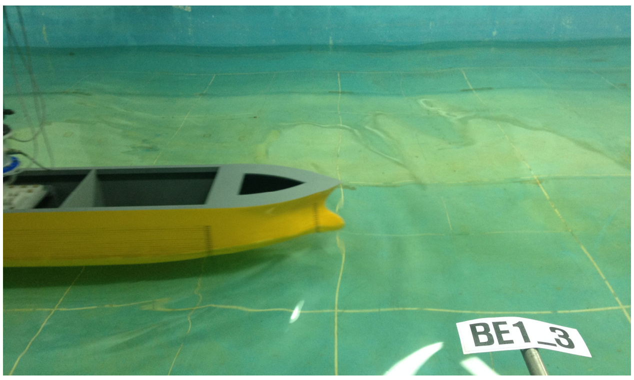


Fig. 2. Wave pattern for VLCC model (even keel, $\lambda/L=0.7$, Fn 0.091, ballast condition).

Fig. 3~5 show the added resistance values R_{AW} by each of the wavelengths (λ) among regular head waves, which are dimensionless, as per the following expression: $\rho g \zeta_a^2 B^2/L$.

First, the experimental results were analyzed for each ship speed(Fig. 3). As reported in a study by Lee et al.(2010) in which the maximum value of added resistance increased as the ship speed increased under the same conditions and a wave period that corresponded to the peak became longer, this experiment also verified that the added resistance value increased as the ship speed increased. This was because the response to the longitudinal motion of a ship, such as heaving and pitching, increased. It was also found that the added resistance value was the largest at around $\lambda/L=1.0$.

Next, the experimental results conducted under full and light load conditions showed that added resistance in waves under ballast conditions was considerably reduced over the $\lambda/L=1.0$ proximity and the overall short-wavelength region except for the long-wavelength region(Fig. 4).

Finally, the added resistance values in waves for the trim conditions under full load conditions showed that under an even keel, resistance was larger than under the trim, while the added resistance value was the smallest at the trim by the stern(Fig. 5). In addition, the wave length at peak in even keel condition is shorter than that in trim by the head and trim by the stern conditions.

As described above, the added resistance characteristics in waves differed depending on ship speed, loading conditions, and trim conditions. Thus, it is necessary to take into account multiple operating conditions of ships in real sea environments, such as irregular waves, to reduce CO_2 emissions and to increase fuel efficiency.

The non-dimensionalized added resistance values that were obtained through the experiment seemed relatively overestimated in the short-wavelength region compared with those obtained by other researchers. However, as the maximum value was revealed at around $\lambda/L=1.0$, the overall experimental results were represented well qualitatively. In general, experimental results differed from researcher to researcher when experiments on added resistance in the short-wavelength region were conducted iteratively. The reason for this was well explained in a study by Lee et al.(2013) in which the added resistance value had considerable uncertainty that was affected significantly by the experimental condition parameters. Park et al.(2014) studied the uncertainty analysis for added resistance experiment, and they identified the main sources of uncertainty. Thus, it is necessary to conduct a follow-up study in order to obtain study results that are consistent quantitatively. In this follow-up study, iterative experiments should be conducted under the same conditions in order to increase the reliability of the experimental results.

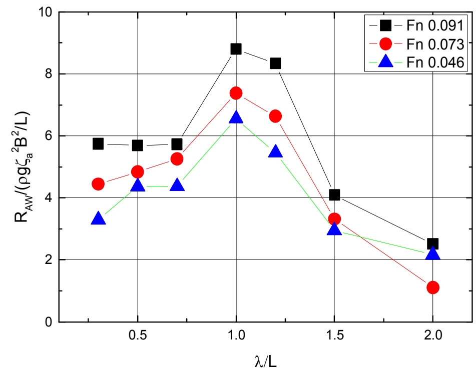


Fig. 3. Comparison of added resistance for different speed (even keel, full load condition).

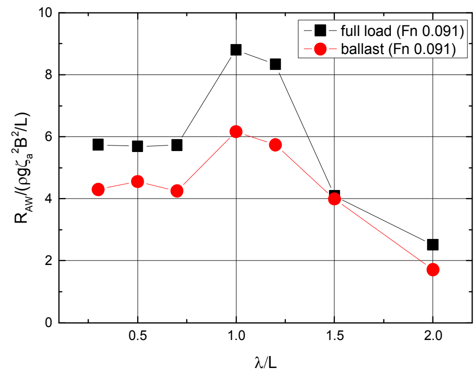


Fig. 4. Comparison of added resistance in full load and ballast condition (Fn 0.091, even keel).

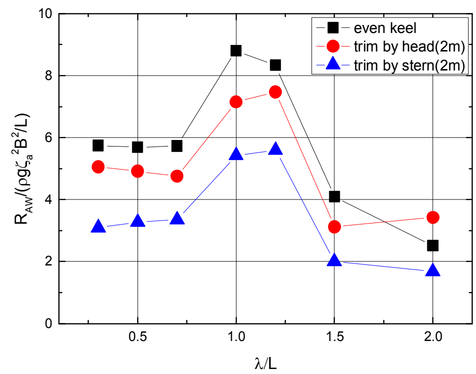


Fig. 5. Comparison of added resistance for different trim condition (Fn 0.091, full load condition).

3. Theoretical analysis of added resistance in irregular waves

The added resistance in a irregular seaway can be obtained in the same manner as in the case of regular ship motions using the linear superposition technique(Arribas, 2007). Therefore the mean added resistance in a irregular seaway is

$$\overline{R_{AW}} = 2\int_0^\infty S_\zeta(\omega_e)\,\frac{R_{AW}}{\zeta_a^2}(\omega_e)d\omega_e \qquad (1)$$

where ω_e is the encounter frequency of the ship, R_{AW} the added resistance obtained by model experiments, ζ_a the wave amplitude, and $S_\zeta(\omega_e)$ the encountered wave spectrum.

We have computed the encountered wave spectrum by using ISSC spectrum with a wave height of 3.0*m* and modal period of 6.7*s* (B.F. 6).

Assuming that the total number of the amplitude of motion response that is produced in a continuous certain time is N, the expected extreme response of the added resistance can be calculated as follows(Lee et al., 2010):

$$A_{1/N} = \alpha\sqrt{m_0} \qquad (2)$$

where $A_{1/N}$ is the expected extreme response, m_0 the area under the response spectrum for added resistance.

Fig. 6～8 show the mean added resistance and the 1/1000 expected extreme response of the added resistance that became dimensionless with $\rho g\zeta_a^2B^2/L$.

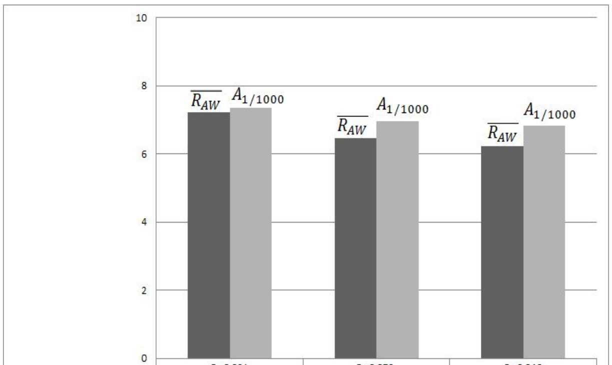
A ratio of mean added resistance to the expected extreme response accounted for 98.08 %, which was the smallest difference in the case of Fn 0.091 under the even keel condition, as shown in Fig. 6. The biggest difference (73.41 %) was evident in the trim by the stern, as shown in Fig. 8. Such a difference occurred because the added resistance value was relatively large in the short-wavelength region in the case of Fn 0.091, whereas it was relatively small in the case of the trim by the stern, so that the ratio of mean added resistance was smaller than the expected extreme response.

Next, the characteristics of the mean added resistance for each of the operating conditions were discussed. First, the characteristics based on ship speed in the full loading condition showed that the mean added resistance was reduced by approximately 10 % at Fn 0.073 and by approximately 14 % at Fn 0.046 compared to that at Fn 0.091(Fig. 6). That is, we can expect that when a ship's speed is reduced from 10 to 5 knots in real ship environments, the mean added resistance can be reduced by approximately 14 %.

Next, the characteristics of the mean added resistance for the loading conditions showed that it was reduced by approximately 24 % more in the light loading condition than in the full loading condition(Fig. 7). That is, an increase in resistance due to waves can be relatively larger in the full loading condition than in the light loading condition.

Finally, the mean added resistances for the trim conditions were compared with each other, and approximately 13 % reduction in the case of the trim by the head and approximately 44 % reduction in the case of the trim by the stern were revealed under the even keel condition at the full loading condition(Fig. 8). Under the light loading condition, the obtained results were similar to the results of the above study. That is, under the light loading condition, resistances under no trim and trim by the stern were compared. When there was no trim, added resistance in waves was considerably larger than that in the case of trim by the stern(Ichinose et al., 2010).

As published elsewhere, it is expected that the trim by the stern is a highly effective way to reduce added resistance in waves. As described above, according to the discussion on the mean added resistance characteristics for each operating condition, it can be estimated that the best way to reduce added resistance in waves is to reduce ship speed and to navigate the ship with the trim by the stern under light loading conditions.



	Fn 0.091	Fn 0.073	Fn 0.046
mean added resistance	7.211	6.464	6.224
expected extreme response	7.352	6.961	6.831

Fig. 6. Comparison of mean added resistance and expected extreme response for different speed (even keel, full load condition).

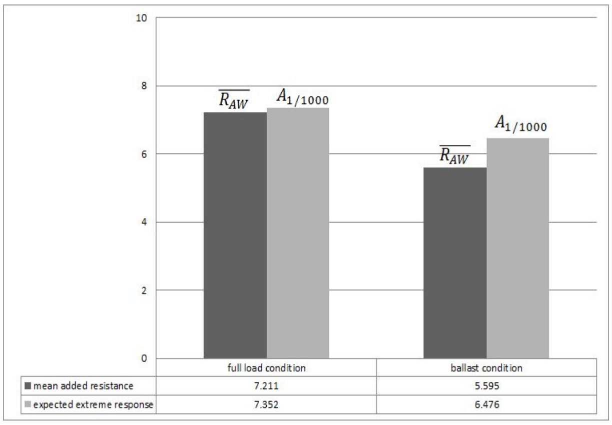


Fig. 7. Comparison of mean added resistance and expected extreme response in full load and ballast condition (Fn 0.091, even keel).

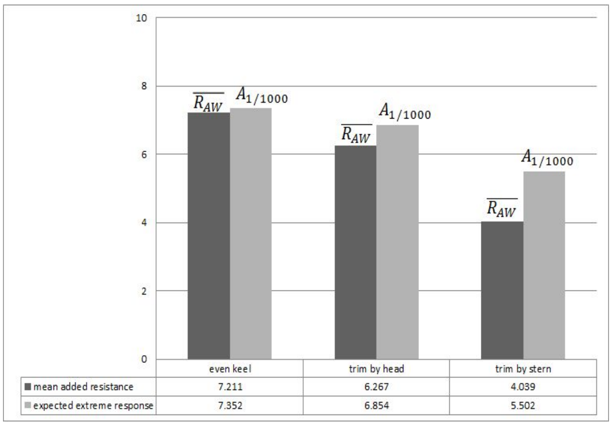


Fig. 8. Comparison of mean added resistance and expected extreme response for different trim condition (Fn 0.091, full load condition).

4. Conclusions

In this study, experiments were conducted to examine the effects of the various operating conditions on added resistance of real ships. The conditions included three ship speeds, full and light ship loading conditions, and trim conditions. Experiments were set to regular waves at the head based on B.F. 6. The experimental results showed that added resistance was the highest around $\lambda/L=1.0$, and the added resistance increased with the increase of the ship speed. Furthermore, under even keel conditions, the added resistance was higher than that under the trim changes overall, and the smallest added resistance was measured at the trim by the stern. Based on the above experimental results, this study proposes effective operating conditions by analyzing the characteristics of the mean added resistance and the expected extreme response in irregular waves.

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References

[1] Arribas, F. P.(2007), Some Methods to obtain the Added Resistance of a Ship Advancing in Waves, Ocean Engineering, Vol. 34, pp. 946-955.

[2] Ibata, S., H. Furakoshi, S. Miyake and Y. Ikeda(2013), An Experimental Study on the Effects of Wave Height and Ship Speed on the Added Resistance Acting on a Large Blunt Ship, Proceedings of the Japan Society of Naval Architects and Ocean Engineers, Vol. 17, pp. 281-284.

[3] Ichinose, Y., M. Tsujimoto, N. Sogihara, K. Shibata and K. Takagi(2010), Estimation of Added Resistance in Waves in a Ballasted Condition, Journal of the Japan Society of Naval Architects and Ocean Engineers, Vol. 11, pp. 109-116.

[4] Ichonose, Y., M. Tsujimoto, K. Shiraishi and N. Sogihara (2012), Decrease of Ship Speed in Actual Seas of a Bulk Carrier in Full Load and Ballast Conditions, Journal of the Japan Society of Naval Architects and Ocean Engineers, Vol. 15, pp. 37-45.

[5] Lee, J. H., H. Kawabe, B. W. Kim and M. K. Ha(2010), Comparison Calculation of the Added Resistance According to Trim Change of Ship with Forward Speed, Proceedings of the Annual Spring Meeting of the Society of Naval Architects of Korea, pp. 1086-1091.

[6] Lee, J. H., D. M. Park, M. G. Seo and Y. H. Kim(2013), Experimental Study on Added Resistance of KVLCC2, Proceedings of the Annual Spring Meeting of the Society of Naval Architects of Korea, pp. 1322-1329.

[7] Park, D. W., S. B. Lee, S. S. Chung, H. W. Seo and J. W. Kwon(2013), Effects of Trim on Resistance Performance of a Ship, Journal of the Society of Naval Architects of Korea, Vol. 50, No. 2, pp. 88-94.

[8] Park, D. M., J. H. Lee and Y. H. Kim(2014), Uncertainty Study of Added Resistance Experiment, Journal of the Society of Naval Architects of Korea, Vol. 51, No. 5, pp. 396-408.

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