Non-linear Hydrodynamic Force Measurement System in Heavy Seas for Broaching Prediction

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ABSTRACT

Mathematical models for capsizing prediction due to broaching have been developed by several researchers. However prediction accuracy of these models still remains in qualitative. In the previous research, the effect of heel-induced hydrodynamic forces in severe following waves with large heel angles up to 50 degrees was examined by captive model experiment for realizing quantitative prediction. However the previous measurement system, which fixes 6 degrees of freedom of ship model, requires many extra runs to obtain the correction coefficients of heave and pitch. Therefore we try to develop new measurement system, which fixes 4 degrees of freedom but allows heave and pitch motions to be free. Firstly, the comparison of measured results between ordinary towing and measurement system and the new system was conducted. Then nonlinear heel-dependent hydrodynamic forces and directly measured wave-exciting forces were measured in severe following and quartering seas.

KEYWORDS

New Measurement System, Heel-Induced Hydrodynamic Force, Wave-Exciting Force, Large heel angle, Heavy Seas, Broaching Prediction

INTRODUCTION

Nowadays, theoretical prediction of extreme motions in following and quartering seas is required not only for qualitative purposes but also for quantitative one towards direct stability assessment as an alternative route of IMO IS Code. The mathematical model for capsizing due to broaching, which is one of the great threats to ships running in following and quartering seas, has been developed by several researchers. However, prediction accuracy of these models is not in quantitative but in qualitative even now.

Although hydrodynamic forces in heeled condition in heavy seas could be important for broaching prediction, these effects had not been examined not only theoretically but also experimentally. For realizing quantitative prediction of capsizing due to broaching, the effect of nonlinear heel-induced hydrodynamic forces in severe following waves with the various heel angles up to 50 degrees was examined by the authors (Hashimoto et al., 2004) (Hashimoto et al., 2004). As a result, the nonlinear heel-induced hydrodynamic forces with respect to heel angle both in calm water and waves were reported and their effect on the numerical result was examined. However the previous system, which fixes 6 degrees of freedom of ship model, requires many extra runs to obtain the correction coefficients of heave and pitch because exact running attitude in heavy seas with high forward speed cannot be estimated accurately, and the effect of the difference of running attitude on the measured result is significant.

Therefore we try to develop a new measurement system, which fixes 4 degrees of freedom but allows pitch and heave motions to be free as the more practical system.

NEW MEASUREMENT SYSTEM

Although the importance of heel-induced hydrodynamic forces on broaching prediction was pointed out (Renilson et al, 2000), it is difficult to do the model test in large heeled and severe wave conditions. Therefore, we developed a new measurement system to realise the measurement of heel-induced hydrodynamic forces even in severe waves with large heel angle. This system restricts surge, sway, yaw and roll but heave and pitch are in free. Photograph of the experimental setup is shown in Fig. 1.

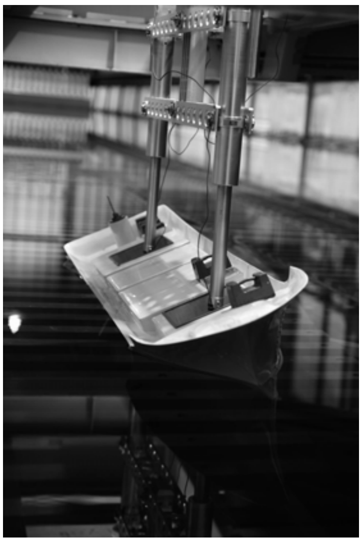

Fig. 1: New measurement system.

In this system, ship model is towed by two heaving rods. Heave and pitch motions are free and their values are measured by two potentiometers, respectively. Aft-rod can move in longitudinal to escape from the geometrical restriction due to large pitch motion. Surge and sway forces and yaw and roll moment are measured by a dynamometer located at the top of this system and above the centre of ship gravity.

EXPERIMENTAL RESULTS

The ship model used in this research is 1/25 scaled Japanese purse SEINER. Principal particulars are shown in Table 1.

Table 1 Principal particulars of the subject ship

Items	Values
length between perpendiculars: L_{pp}	34.5 m
breadth : B	7.60 m
depth : D	3.07 m
mean draught : d	2.65 m
block coefficient : C_b	0.597

Firstly practical resistance test with the new system was conducted with 0 degrees of heel. The measured sinkage, trim and resistance in calm water are shown in Figs. 2-3. In the figures, previous results with ordinary towing system, in which ship model is towed by a heaving road and pitch motion is in free with gimbals, are also shown. These figures indicate that there is small difference in sinkage and trim between the new and ordinary systems. This might be because the height of towing point is different. Measured resistance with 0 degrees of heel agrees well with existing results with an ordinary system. By utilising this new system, the resistance with large heel angles can be easily measured with no difficulty.

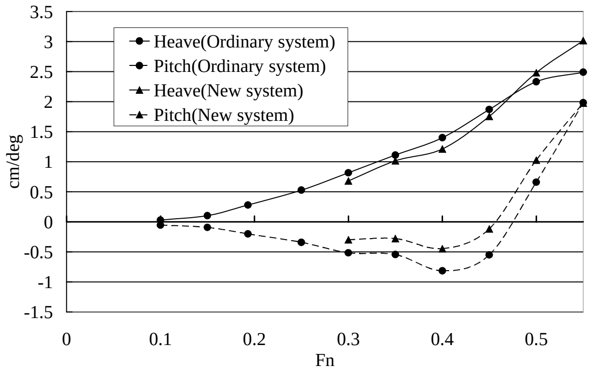

Fig. 2: Measured sinkage and trim in calm water.

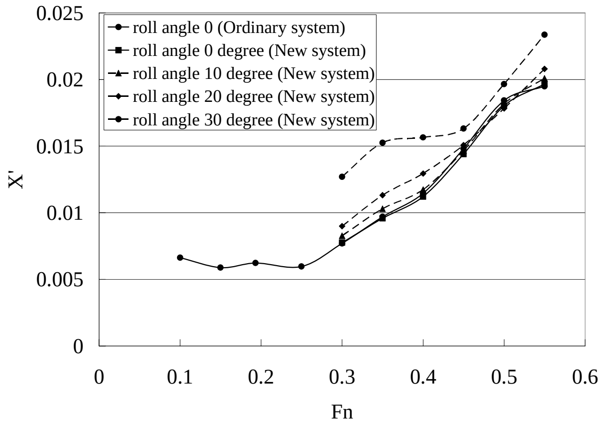

Fig. 3: Measured resistance with heel angles in calm water.

The experimental results of vertical motions in pure following seas are shown in Figs. 4-5, and the wave-exciting forces with 30 degrees of heel angle in quartering seas are shown in Figs. 5-6. Here wave length to ship length ratio, λ/L, is 1.5 and wave steepness, H/λ, is 1/10. These figures show that the new measurement system can measure surge and sway forces and yaw and roll moments even in severe quartering seas with large heel angle. These data could be useful for the validation of numerical codes for capsizing or large amplitude motion prediction.

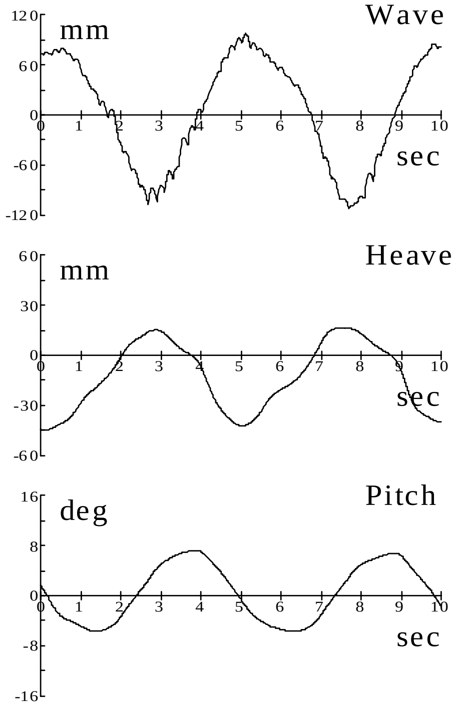

Fig. 4: Measured vertical motions and wave height with Fn=0.4, χ=0degrees, ϕ=0degrees

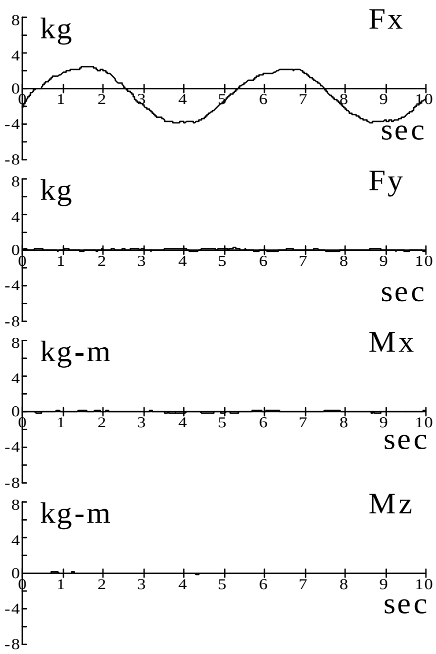

Fig. 5: Measured forces and moments with Fn=0.4, χ=0degrees, ϕ=0degrees

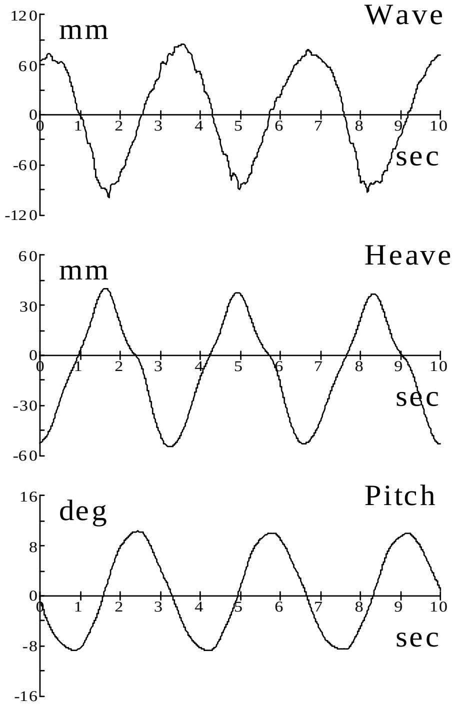

Fig. 6: Measured vertical motions and wave height with Fn=0.4, χ=30degrees, ϕ=30degrees

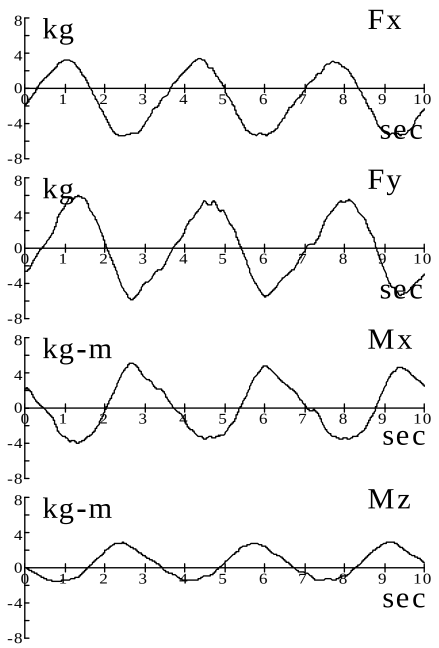

Fig. 7: Measured forces and moments with Fn=0.4, χ=30degrees, ϕ=30degrees

HEEL-INDUCED HYDRODYNAMIC FORCES AND MOMENTS WITH LRAGE HEEL ANGLE

Measured heel-induced hydrodynamic forces in calm water with the heel angles up to 30 degrees are show in Fig. 8. These forces are essential for quantitative broaching prediction. (Umeda and Hashimoto, 2007) Sway force has the linear relationship with heel angle. The nonlinearity of surge force, roll moment and yaw moment can be found particularly beyond 20 degrees of heel. This is because there is significant amount of water inflow into deck in that condition.

One example of roll moment variation with 30 degrees of heel in pure following seas is shown in Fig. 9. Here wave length to ship length ratio is 1.5. From the experimental result, roll moment increases as wave steepness increases around a wave crest, but it does not decrease around a wave trough. In high wave steepness, measured roll moment is not sinusoidal with encounter frequency.

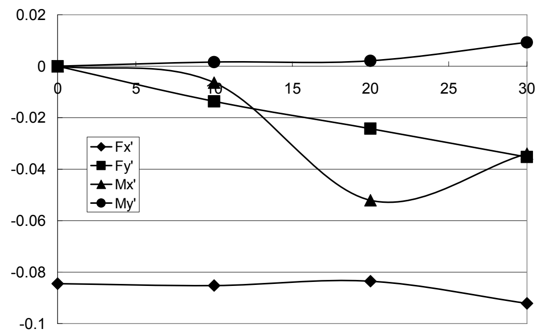

Fig. 8: Heel-induced hydrodynamic forces in calm water at Fn=0.4

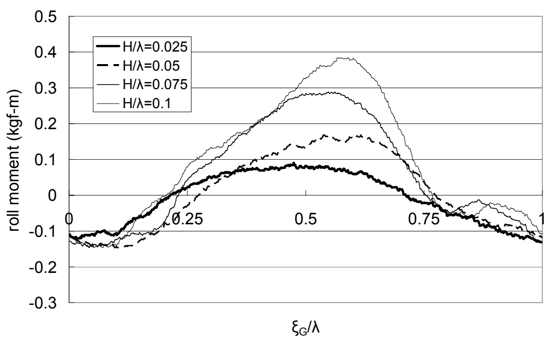

Fig. 9: Roll moment in following seas with 30 degrees of heel at Fn=0.4

CONCLUSIONS

Heel-induced hydrodynamic forces and wave-exciting forces in heavy seas were measured by the new measurement system. As a result, the following conclusions can be obtained:

1. The proposed new measurement system is applicable to measure non-linear hydrodynamic forces and moments with large heel angle even in severe following and quartering seas.
2. Heel-induced hydrodynamic surge force, roll moment and yaw moment in calm water have nonlinearity with respect to roll angle particularly beyond 20 degrees of heel angle.
3. Heel-induced roll moment in severe following seas was measured, and the characteristic of its variation was clarified.

Numerical simulation using measured non-linear heel-induced hydrodynamic forces and moments is planed to the next step.

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