A STUDY ON NUMERICAL MODELLING FOR THE PARAMETRIC ROLLING

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ABSTRACT

A series of model tests in head seas by means of a post-panamax container carrier is carried out to examine the hydrodynamic heeling moment when parametric rolling occurs. Having compared with experiments, the practical computation method, which takes hydrostatic and hydrodynamic force of the instantaneous wetted surface of the hull into account, is verified. Based on those comparisons, the applicability of the present computation method and the effect of surge motion on parametric rolling are discussed.

Keywords: *parametric rolling, righting arm variation, container carrier, nonlinear strip method*

1. INTRODUCTION

It is well known that the parametric roll is expected to occur when the wave encounter frequency is close to the double of the natural roll frequency of the vessel. In recent years, significance of evaluation of parametric rolling becomes more important because the recent modern container carrier becomes larger and induces the serious cargo damage due to parametric rolling particularly in the head seas. For the improvement of safety against such dynamic stability failures, the International Maritime Organization (IMO) decided to develop the new-generation intact stability criteria for three major capsizing modes, which contains the parametric rolling.

Many studies have been carried out to evaluate the parametric rolling. In particular, several studies, which are mainly focused on the periodic change of the restoring force as the ship advances through the waves, have been investigated to analyze the phenomenon (e.g. Belenky et al., 2006; Neves, 2006). In addition, intensive studies for the parametric rolling in head regular and irregular waves have been carried out in last decade years (e.g. Hashimoto et al., 2008).

Although a substantial progress has been achieved to evaluate the parametric rolling as a result of those intensive studies, there are some rooms for the improvement of the evaluation of the parametric rolling in waves. It is considered that problems for the improvement of evaluation are not only its non-ergodic nature but also the hydrodynamic model for evaluation.

Based on these backgrounds, an examination for further improvement of hydrodynamic model of computation is carried out.

Firstly, the hydrodynamic heeling moment in head seas is measured to examine the righting arm variation when parametric rolling occurs. The model tests were conducted by means of container carrier with heeling angle. Secondly, having compared with experiments, the present method in accordance with the nonlinear strip method approach is verified.

Finally, the applicability of the present method for the computation of righting arm variation and the effects of surge motion on parametric rolling in regular head seas are examined.

2. COMPUTATION OF PARAMETRIC ROLLING

2.1 Numerical Model

Ship motions were estimated by the time domain simulation program, developed by the National Maritime Research Institute of Japan (Ogawa et al., 2005) in accordance with a nonlinear strip method approach (Fujino et al., 1983).

The program, NMRIW, was developed by means of the latest results of a seakeeping and maneuvering study. The NMRIW's numerical model is based on a nonlinear strip theory approach in which forces due to the linear and nonlinear potential flow are combined with maneuvering forces and viscous drag forces. Generally, it is difficult to compute nonlinear ship motion and wave loads in bow and quartering seas by means of the conservative time domain estimation method. Using the present method, ship motions and wave loads in bow and quartering seas can be estimated rationally.

The Froude-Krylov force, which has considerable effect on the nonlinearity of ship motions, is estimated by the integration of the hydrostatic and hydrodynamic wave pressure along the instantaneous wetted surface of the hull at each time step.

With respect to the sectional wave radiation force and potential value at each time step, the integral equation method is used. Source and doublet are distributed at the origin of each section to avoid the irregular frequency, in accordance with Ohmatsu's method (Ohmatsu, 1975).

In terms of the sectional diffraction force in the present method, it was computed by solving the Helmholtz equation at each time step. The viscous effect of roll damping due to ship hull and bilge keels can be estimated with empirical formula (Ikeda et al., 1978).

2.2 Mathematical Model of Roll Motion

In the present study, the degrees of freedom of numerical model was narrowed down to three (heave, roll, pitch) or four (heave, roll, pitch, surge) because the main purpose is to examine the parametric roll using the practical model without cumbersome computations. Using this model, the numerical procedure of yaw in larger sea state with slower ship speed was neglected.

On the basis of the assumption, the equation of roll motion can be described as follows:

$$\left(I_{xx}+J_{xx}\right)\ddot{\phi}+a\dot{\phi}+b\dot{\phi}\left|\dot{\phi}\right|+W\left\{GZ_0(\phi)+GZ_w(\phi;t)\right\} = M(t) \quad (1).$$

Here I_{xx} denotes an inertia moment in roll and J_{xx} denotes an added inertia moment in roll. a and b denote the linear and quadratic damping coefficient. W denotes the displacement. GZ_0 and GZ_w denote the restoring arm and restoring arm variation due to wave. M denotes the heel-induced hydrodynamic roll moment. Roll moment owing to other mode, i.e. heave pitch and so forth, is considered in this term.

In terms of the numerical simulation of the parametric roll in irregular waves, incident wave was realized by the sum of 200 components of waves in accordance with the 1964 ISSC spectrum. To take account of the practically non-ergodic nature of parametric roll, 20 times simulations with the duration of 2500 seconds of ship scale were carried out in each condition. The combination of phase angle of each wave component was varied in each simulation.

Fig. 1 shows the examples of the probability density function of instantaneous values of pitch and roll amplitude. The horizontal axis denotes the pitch and roll angle. Dotted lines show the approximation of Gaussian distribution of those computed probability density function. It is found that the probability density function of the computed pitch amplitude of 20 times simulations with the duration of 2500 seconds can be approximated by the Gaussian distribution. However, it is also found that the probability density function of the computed roll amplitude is much different with the Gaussian distribution due to practically non-ergodic nature of parametric roll although a certain distribution can be approximated.

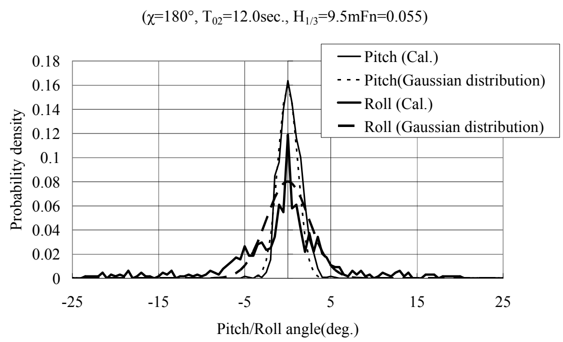

Figure 1. The probability density function of pitch and roll amplitude (χ=180deg., Fn=0.055, T02=12.0sec., H1/3=9.5m).

3. EXPERIMENTS

A detailed explanation of experiments has been published previously (Ogawa et al., 2007). In this paper, the part relevant to the present study is repeated here. A series of tests in head seas by means of the model of a heeled post-panamax container carrier was carried out to measure righting arm variation in waves.

3.1 Model and Measuring Instruments

The tests were conducted at the model basin (150m×7.5m×3.5m) of the National Maritime Research Institute of Japan. Table 1 presents the ship's main particulars. Before the test, the model was ballasted to the correct draft, trim and the GM.

For the examination of the righting arm variation in waves, a hydrodynamic heeling moment of a heeled hull (Heel angle 10 deg. and 15 deg.) in waves was measured by means of load cell attached at the centre of gravity of the model ship. Longitudinal ship motions (heave and pitch) of heeled hull were also measured by means of potentiometer. Other motions were basically fixed through the tests. For the examination of effect of surge motion on heave, pitch and righting arm variation, tests with free surge motion were carried out in some conditions.

Table 1. Principle particulars of the container carrier

	Ship	Model
Length (L_{pp}) (m)	283.8	2.6
Breadth(B) (m)	42.8	0.39
Draft(d) (m)	14.0	0.13
GM (m)	1.08	0.0099
Displacement (ton)	107072	0.082
Longitudinal radius of gyration	------	0.247

3.2 Conditions

A series of tests in regular and irregular head seas was carried out to allow a comparison with an analytical study. Based on the results of model tests by means of same container carrier (Taguchi, 2006), tests are carried out at conditions, i.e. ship speed and wave height, that parametric roll frequently occurs. Ship speed was varied in the range of Froude number from 0.05 to 0.2. Wave heights were varied from 4.0m to 10.0 m in ship scale.

Tests in irregular waves were also carried out in head seas with 6.0m of significant wave heights. The 1964 ISSC spectrum was used for a wave spectrum of irregular waves. The mean wave period, T02, was 11.4sec. The ship speed (Froude number: Fn) was set as Fn = 0.1.

3.3 Effect of surge on longitudinal motion and heel moment in waves

Figures 2 and 3, respectively, show the heave and pitch amplitude with free/fixed surge motion in various wave heights and various ship speeds. Fundamental frequency components, Z and θ, are divided by wave amplitude ς and wave slope kς (k = wave number). It is found that heave and pitch motion with free surge motion has no significant difference with those with fixed surge motion.

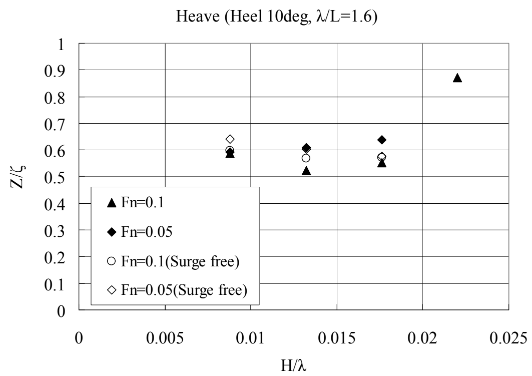

Figure 2. Heave amplitude of container carrier with 10 degree of heel in various wave height (Head Seas, λ/L=1.6, Heel angle: 10deg.).

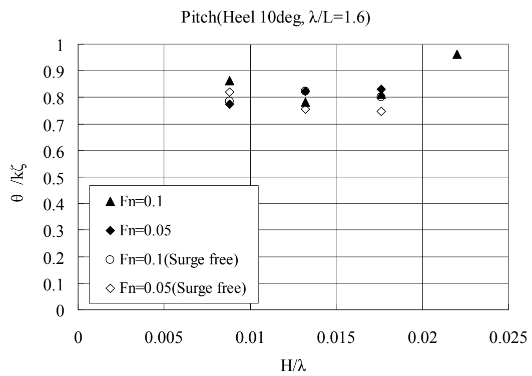

Figure 3. Pitch amplitude of container carrier with 10 degree of heel in various wave height (Head Seas, λ/L=1.6, Heel angle: 10deg.)

Figure 4 shows the righting arm variation with free/fixed surge motion in various wave heights and various ship speeds. Fundamental frequency components of righting arm variation are divided by ship length L_{pp}. At slower ship speed, it is found that righting arm variation with free surge motion has no significant difference with that with fixed surge motion. In the meanwhile, at faster ship speed, it is found that righting arm variation with free surge motion has a slight difference with that with fixed surge motion. It is considered that the effect of surge motion on righting arm variation becomes significant as surge motion becomes larger.

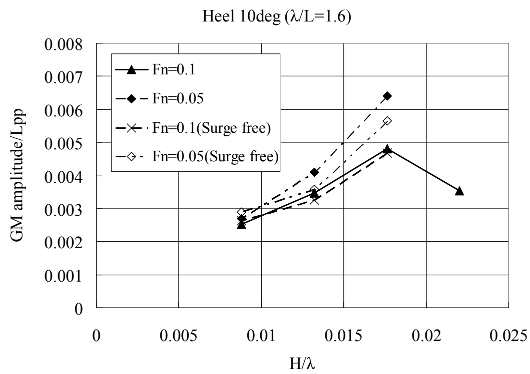

Figure 4. Righting arm variation in waves (Head Seas, λ/L=1.6, Heel angle: 10deg.)

4. COMPARISON OF COMPUTATIONS WITH EXPERIMENTS

4.1 Ship Motion

Figures 5 and 6, respectively, show the heave and pitch amplitude of 10 degree of heeled container carrier in various wave heights. Figures 7 and 8, respectively, show the heave and pitch amplitude of 15 degree of heeled container carrier in various wave heights.

It is found that computed ship motions in various wave heights show ample agreement with experiments, although there are some discrepancy between computed pitch motion and experiments. It is clarified that present method, which takes hydrostatic and hydrodynamic force of the instantaneous wetted surface of the hull into account, is practical for the estimation of ship motion of heeled hull in waves.

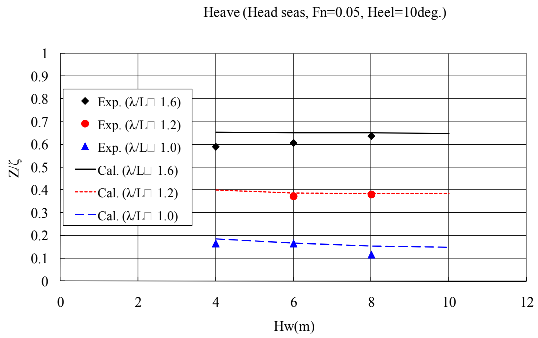

Figure 5. Heave amplitude of container carrier with 10 degree of heel in various wave height (Fn=0.05).

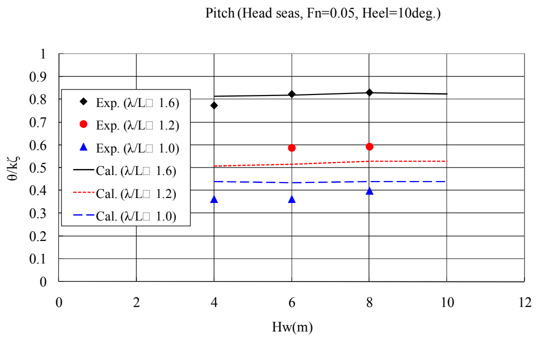

Figure 6. Pitch amplitude of container carrier with 10 degree of heel in various wave height (Fn=0.05).

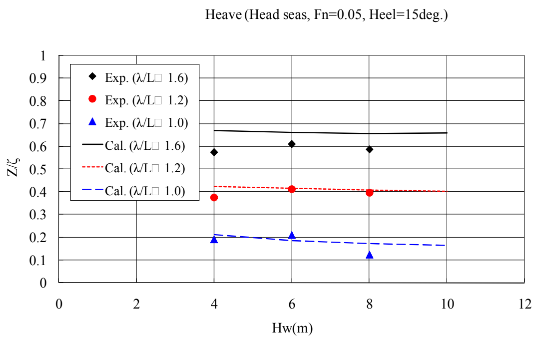

Figure 7. Heave amplitude of container carrier with 15 degree of heel in various wave height (Fn=0.05).

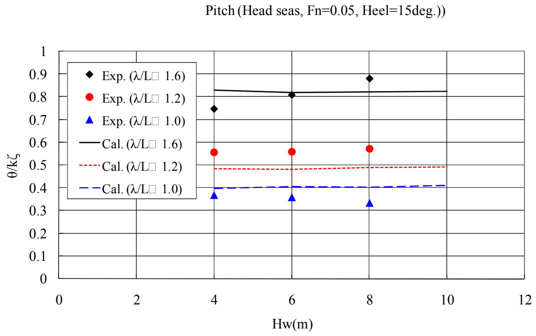

Figure 8. Pitch amplitude of container carrier with 15 degree of heel in various wave height (Fn=0.05).

4.2 Righting arm variation in waves

Figure 9 and 10 show the righting arm variation of 10 degrees heeled hull in various wave heights, respectively. Figure 11 shows the righting arm variation of 15 degrees heeled hull in various wave heights. Fundamental frequency components of righting arm variation are divided by ship length L_{pp}. It is found that computation of righting arm variation in various wave heights show ample agreement with experiments. It is clarified that present method is practical for the estimation of righting arm variation in waves.

In the meanwhile, it is found that computation in large wave height shown in Figures 10 and 11, in which deck wetness occurred, has a certain difference with experiments. For the improvement of the accuracy of righting arm variation in large waves, it is clarified that the effect of deck wetness in computation should be taken into account.

Based on the results of 15 degrees heeled hull, it is considered that the effect of lift, which becomes significant as heel angle becomes larger or ship speed becomes faster, should also be taken into account.

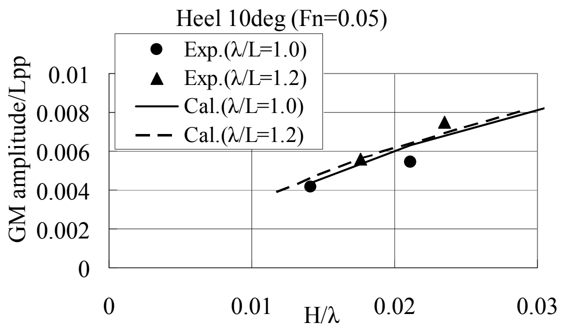

Figure 9. The effect of wave height on the variation of GM in waves (Heel angle=10deg, Head Seas, Fn=0.05).

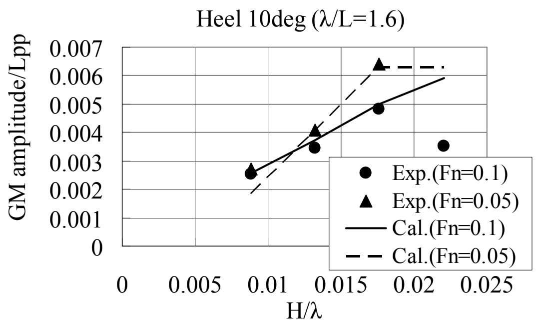

Figure 10. The effect of wave height on the variation of GM in waves (Heel angle=10deg, Head Seas, λ/L=1.6).

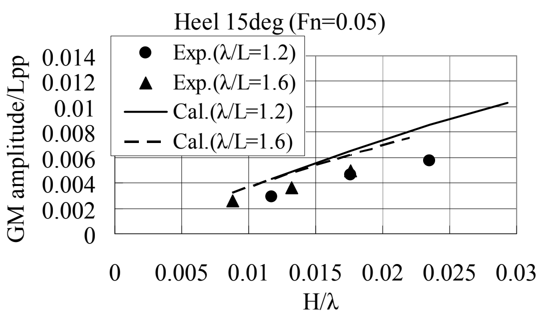

Figure 11. The effect of wave height on the variation of GM in waves (Heel angle=15deg, Head Seas, Fn=0.05).

4.3 Parametric rolling in regular head seas

Fig. 12 shows the example of amplitude of parametric roll as a function of wave encounter period. Both 3-DOF (heave, pitch and roll) and 4-DOF (surge, heave, pitch and roll) computation by means of the present method are also shown. The horizontal axis is the ratio of the wave encounter period, T_e, to the natural roll period, T_Φ. It is found that computed range, in which parametric rolling resonance occurs, gives good agreement with measured range. It is verified that the computed amplitude of parametric roll by means of the present method gives good agreement with experiments.

However, it is difficult to draw concrete conclusion about the degree of freedom of motion in computation of parametric rolling in head seas. As a whole, it is found that 4-DOF computation gives better solution of range and amplitude. In the meanwhile, 4-DOF computation overestimates the amplitude, in which parametric rolling strongly occurs. It is considered that further verification for the conclusion should be carried out.

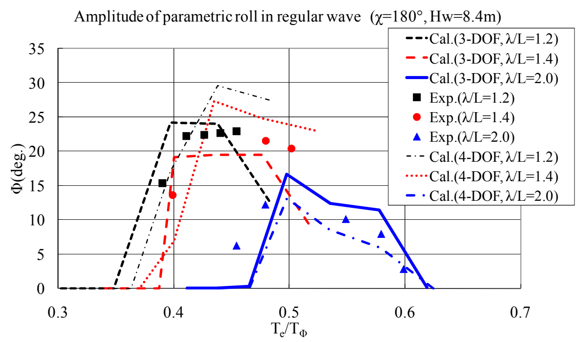

Figure 12. The effect of wave height on the variation of GM in waves (Heel angle=15deg, Head Seas, Fn=0.05).

5. CONCLUSIONS

Having compared with experiments, the applicability of the present method for the computation of righting arm variation and the effects of surge motion on parametric rolling in regular head seas are examined. Conclusions are as follows:

1) There is a case that the effect of surge motion on righting arm variation becomes significant as surge motion becomes larger.

2) Present computation method, which takes hydrostatic and hydrodynamic force of the instantaneous wetted surface of the hull into account, is practical for the estimation of ship motion and righting arm variation of heeled hull in waves.

3) Computed amplitude of parametric roll by means of the present method gives good agreement with the measured amplitude in regular waves.

4) Although 4-DOF computation gives better solution of range and amplitude od parametric rolling, 4-DOF computation overestimates the amplitude, in which parametric rolling strongly occurs.

In terms of the superiority of degree of freedom, further verification for the conclusion will be carried out in future study.

6. ACKNOWLEDMENTS

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