A Study on the Effect of Parametric Rolling on Heave and Pitch Motions in Head Seas

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ABSTRACT

The methods to be used for direct stability assessment of parametric rolling are now under development by the International Maritime Organization (IMO) in the second generation intact stability criteria. In order to provide a reliable numerical method for predicting parametric rolling, the effects of parametric rolling on heave and pitch motions in regular head seas are investigated by simulations and experiments. Firstly, a coupled heave-roll-pitch mathematical model based on a nonlinear strip theory is used to calculate heave and pitch motions in regular head seas with parametric rolling taken into account. Secondly, model experiments are conducted to investigate the effect of parametric rolling on heave and pitch motions where an optical tracker is used to measure ship motions. Finally, time-domain heave and pitch motions are analyzed in the frequency-domain by the Fourier transformation. The both results of experiments and simulations show that heave and pitch motions are obviously affected by parametric rolling and one distinct phenomenon is newly observed that the pitch motions in experiment include subharmonic component when parametric rolling occurs. However the distinct phenomenon does not clearly reproduced in numerical simulation, therefore the effects of parametric rolling on heave and pitch motions should be further investigated in the numerical method for direct stability assessment of parametric rolling.

KEYWORDS

Parametric rolling; heave; pitch; second generation intact stability criteria;IMO

INTRODUCTION

The methods to be used for direct stability assessment of parametric rolling are now under development by the International Maritime Organization (IMO) in the second generation intact stability criteria (IMO SLF55, 2013). In case of following waves, the encounter frequency is much lower than the natural frequencies of heave and pitch so that coupling with heave and pitch is almost static. In addition, added resistance in following waves is generally small. Thus several successful predictions of parametric rolling in following waves were reported (Munif and Umeda, 2000). In particular, clear experimental records of capsize due to parametric rolling in following waves were published by one of the authors (Umeda et al,1995).In case of head waves, however, prediction of parametric rolling is not so easy because dynamic coupling with heave and pitch are significant and added resistance cannot be ignored. Effect of dynamic heave and pitch motions on parametric rolling was investigated so far by many researchers and is well established: restoring arm variation in head waves depends on dynamic heave and pitch motions (Taguchi et al. 2006). Effect of added resistance on parametric rolling was investigated by some researchers (Jensen et al, 2007; Umeda et al, 2008; Umeda and Francescutto, 2008; Lu et al, 2011a).

In linear ship dynamics the frequency of ship oscillations is equal to encounter frequency, and no roll, sway and yaw motions occur in longitudinal waves, and the effect of parametric rolling on other motions and added resistance in head seas cannot be discussed in ship seakeeping theory. Two of the authors develops a new formula based on Maruo's theory and theoretical studies on the effect of parametric rolling on added resistance in regular head seas while the effect of parametric rolling on heave and pitch motions is ignored which could also affect added resistance in waves(Lu et al,2011b).

In ship seakeeping theory, the effect of roll on heave and pitch motions is little, coupling from heave and pitch to parametric rolling is taken into account but not vice versa in published papers (Umeda et al, 2008; Lu et al, 2011a).A small difference of restoring arm variation could result in a large difference of roll amplitude in prediction of parametric rolling (Hashimoto et al, 2007). Restoring arm variation in head waves depends on dynamic heave and pitch motions (Taguchi et al. 2006) In order to provide a reliable numerical method for predicting parametric rolling, the effects of parametric rolling on heave and pitch motions in head seas should be investigated.

Because there is no theory can be used to investigate the effects of parametric rolling on heave and pitch motions in head seas, the authors attempt to use a coupled heave-roll-pitch mathematical model (Hashimoto and Umeda, 2012) based on a nonlinear strip theory and conduct model experiments using an optical tracker to investigate the effect of parametric rolling on heave and pitch motions in regular head seas.

MATHEMATICS

A coupled heave-roll-pitch mathematical model as followed based on a nonlinear strip theory (Hashimoto and Umeda, 2012) is used to calculate heave and pitch motions in regular head seas with parametric rolling taken into account.

$$\begin{aligned}&(m + A_{33}(\phi)\ddot{\zeta} + B_{33}(\phi)\dot{\zeta} + A_{34}(\phi)\ddot{\phi} \\ &+ B_{34}(\phi)\dot{\phi} + A_{35}(\phi)\ddot{\theta} + B_{35}(\phi)\dot{\theta} \\ &= F_3^{FK+B}(\xi_G/\lambda,\zeta,\phi,\theta) + F_3^{DF}(\phi)\end{aligned} \tag{1}$$

$$\begin{aligned}&(I_{xx} + A_{44}(\phi)\ddot{\phi} + N_1\dot{\phi} + N_3\dot{\phi}^3 + A_{43}(\phi)\ddot{\zeta} \\ &+ B_{43}(\phi)\dot{\zeta} + A_{45}(\phi)\ddot{\theta} + B_{45}(\phi)\dot{\theta} \\ &= F_4^{FK+B}(\xi_G/\lambda,\zeta,\phi,\theta) + F_4^{DF}(\phi)\end{aligned} \tag{2}$$

$$\begin{aligned}&(I_{yy} + A_{55}(\phi)\ddot{\theta} + B_{55}(\phi)\dot{\theta} + A_{53}(\phi)\ddot{\zeta} \\ &+ B_{53}(\phi)\dot{\zeta} + A_{54}(\phi)\ddot{\phi} + B_{54}(\phi)\dot{\phi} \\ &= F_5^{FK+B}(\xi_G/\lambda,\zeta,\phi,\theta) + F_5^{DF}(\phi)\end{aligned} \tag{3}$$

Nonlinear Froude-Krylov forces are calculated by integrating the incident wave pressure around the instantaneous wetted hull surface. Radiation and diffraction forces are calculated for the submerged hull considering time-dependant roll angle with the static balance of sinkage and trim. Two-dimensional hydrodynamic forces are calculated by strip theory. Hydrodynamic forces for the heave, pitch and diffraction models are calculated with the encounter frequency while those for roll mode are done with half the encounter frequency assuming parametric rolling. Linear and cubic roll damping coefficients are used in mathematic model which are obtained from roll decay test in experiment. Here in order to investigate the effect of parametric rolling on heave and pitch motions, roll damping coefficients is adjusted to tune amplitudes of parametric rolling.

EXPERIMENTS

The free running experiment with a 1/65.5 scaled model of the post Panamax C11 class containership was conducted at the seakeeping basin (length: 69m, breadth: 46m, height: 4m) of China Ship Scientific Research Center, in which the ship model was drove by a propeller in regular head seas. Pitch and roll amplitude are measured by the MEMS (Micro Electro-

Mechanical System)-based gyroscope placed on the ship model and wave elevation was measured by a servo-needle wave height sensor attached to the towing carriage. In order to directly measure the heave motion, an optical tracker attached to the towing carriage is also used to measure ship motions. Here the optical tracker is only used to measure ship motion at zero speed because the towing carriage has mechanical vibrations with forward speed which affects the precision measure of the optical tracker. The principal particulars and body plan of the C11 class containership are shown in Table 1 and Fig.1, respectively. The ship model in experiment is shown Fig.2.

Table 1: Principal particulars of the C11 Containership

Items	Ship	Model
Length:L	262.0m	4.000m
Draft:T	11.5m	0.176m
Breadth:B	40.0m	0.611m
Depth:D	24.45m	0.373m
Displ.:W	67508ton	240.2kg
C_B	0.560	0.560
GM	1.928m	0.029m
T_φ	24.68s	3.05s
K_{YY}	0.24L	0.24L

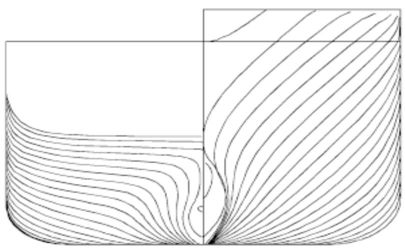


Fig. 1: Lines of C11 container ship

Fig.2The ship model in experiment

RESULTS OF EXPERIMENTS

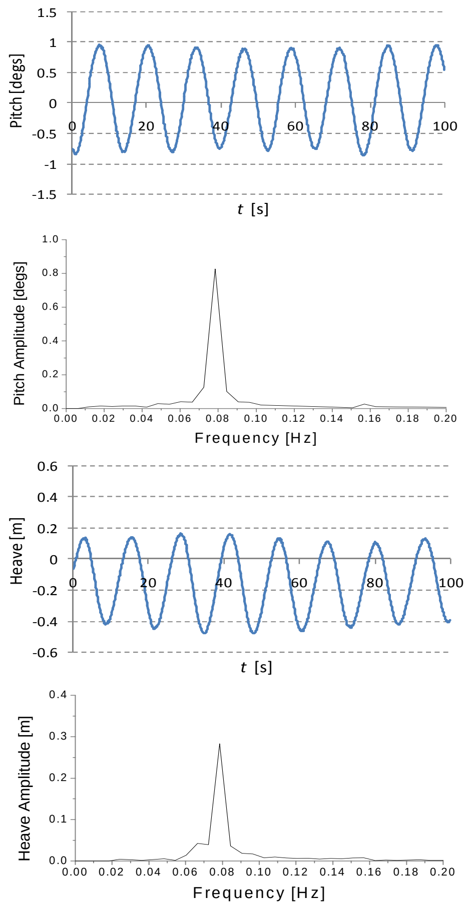
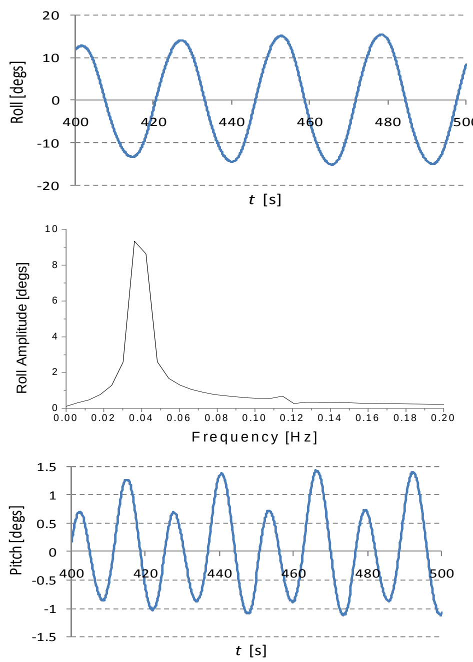


Fig.3 Pitch and heave motions in time and frequency domains before parametric rolling occurs with λ/L_{pp}=1.0, H/λ=0.01, χ=180^0, Fn=0.0, 1/(Te) =0.0772HZ.



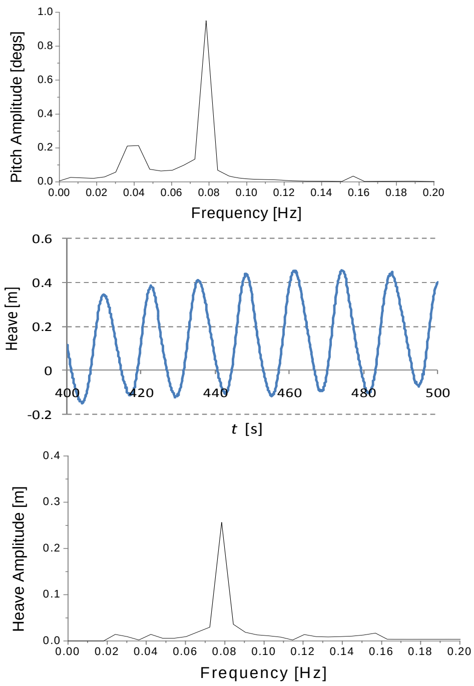


Fig.4 Pitch and heave motions in time and frequency domains when parametric rolling occurs with λ/L_{pp}=1.0, H/λ=0.01, χ=180^0, Fn=0.0, 1/(Te) =0.0772HZ.

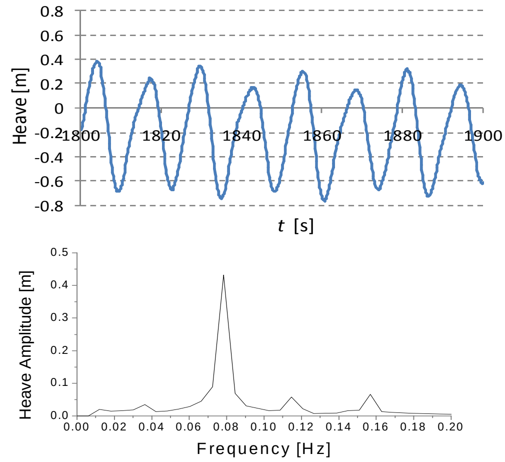
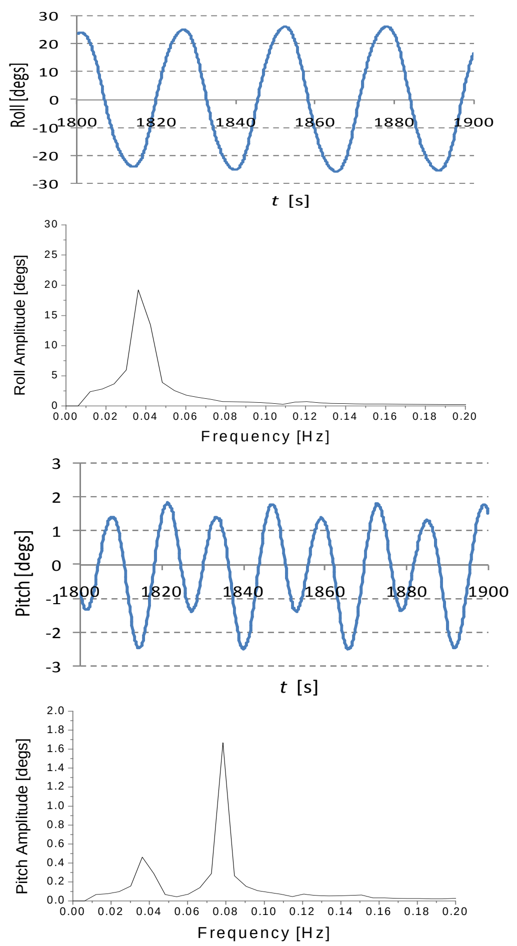
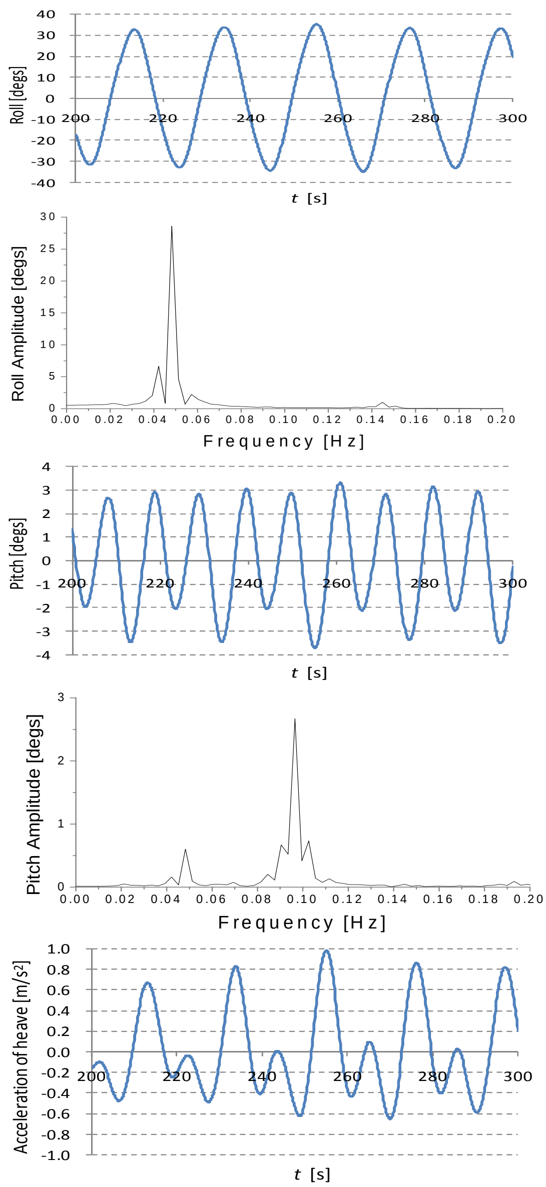


Fig.5 Pitch and heave motions in time and frequency domains when parametric rolling occurs with λ/L_{pp}=1.0, H/λ=0.02, χ=180^0, Fn=0.0, 1/(Te) =0.0772HZ.





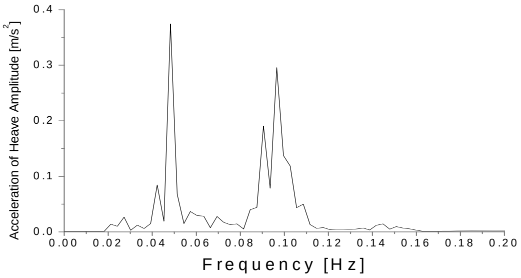


Fig.6 Pitch and acceleration of heave motions in time and frequency domains when parametric rolling occurs with λ/L_{pp}=1.0, H/λ=0.04, χ=180^0, Fn=0.1, 1/(Te) =0.0965HZ.

RESULTS OF SIMULATIONS

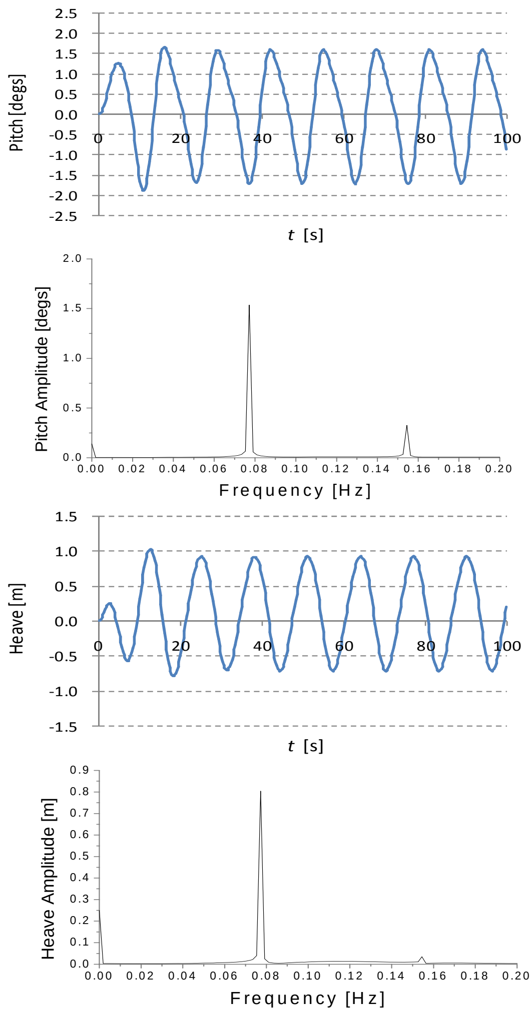


Fig.7 Pitch and heave motions in time and frequency domains without parametric rolling with λ/L_{pp}=1.0, H/λ=0.02, χ=180^0, Fn=0.0, 1/(Te) =0.0772HZ. (Simulation)

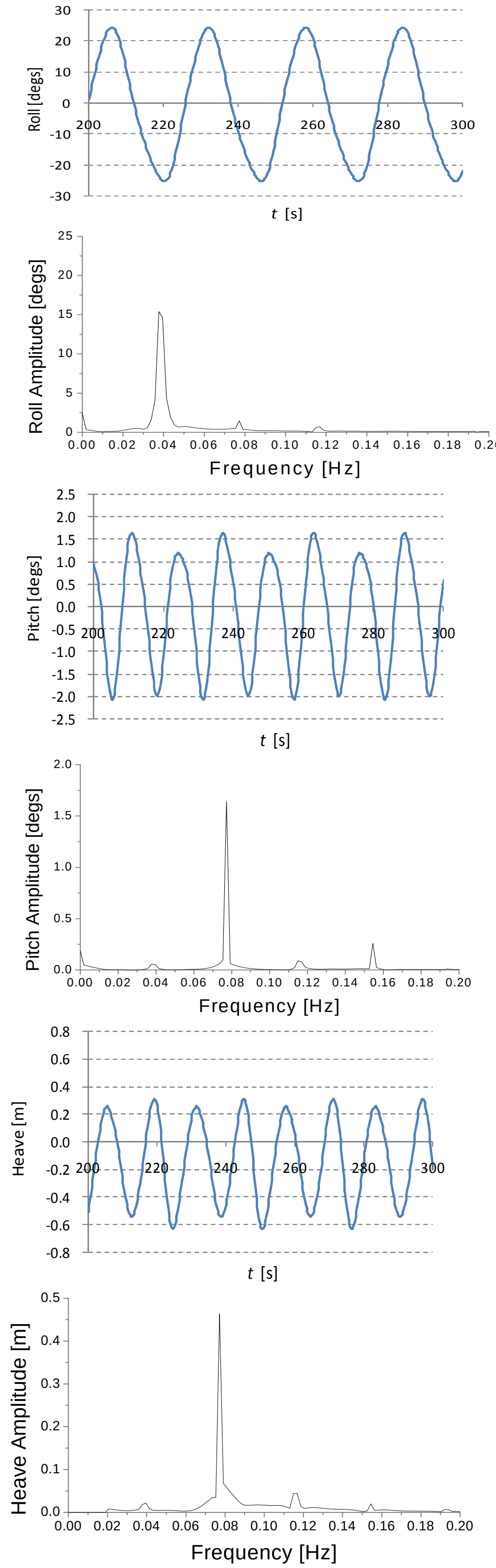


Fig.8 Parametric rolling, pitch and heave motions in time and frequency domains when the amplitude of parametric rolling is 25degs with λ/L_{pp}=1.0, H/λ=0.02, χ=180^0, Fn=0.0, 1/(Te) =0.0772HZ. (Simulation)

DISCUSSIONS

The results of experiments and simulations indicate the frequency of heave and pitch motions is equal to the encounter wave frequency without parametric rolling as shown in Figs.3 and 7 which coincide with a linear seakeeping theory. When parametric rolling occurs with amplitudes of 15degrees and 25degrees as shown Figs.4 and 5 in experiments and Fig.8 in simulations, heave and pitch motions are affected by parametric rolling and their large and small amplitudes alternatively appear. This phenomenon seems like “subharmonic pitch” and “subharmonic heave”. The heave and pitch motions are analyzed in the frequency-domain by the Fourier transformation. One distinct phenomenon was newly observed that the pitch motions in the experiments has both half the encounter wave frequency and the encounter wave frequency components when parametric rolling occurs while this phenomenon is not obvious in heave motions.

The acceleration of heave motions was also measured by an accelerometer in the MEMS-based gyroscope system when the ship model has the forward speed, as shown in Fig.6, and the acceleration of heave motions is obviously affected by parametric rolling which has both half the encounter wave frequency and thee encounter wave frequency when large parametric rolling occurs. However this distinct phenomenon did not occurs in heave motion directly measured by the optical tracker at zero forward speed.

Although pitch and heave motions are affected by parametric rolling in numerical simulations, the distinct phenomenon of pitch motions in experiments cannot reproduced in numerical simulations. Therefore, in order to provide a reliable numerical method for predicting parametric rolling, the simulation model should be updated and the effects of parametric rolling on heave and pitch motions in head seas should be precisely taken into account.

CONCLUSIONS

As a result of experimental and numerical studies on the effect of parametric rolling on heave and pitch motions in regular head seas, the following remarks and recommendations are noted:

1) The nature of heave and pitch motions affected by parametric rolling in regular head seas is firstly presented; the large and small amplitudes alternatively appear.

2) The pitch motions in the experiments are consist of both half the encounter wave frequency and one the encounter wave frequency components when parametric rolling occurs while this phenomenon is not obvious in heave motions.

3) The simulation model should be updated so that the effects of parametric rolling on heave and pitch motions in head seas should be precisely taken into account for providing a reliable numerical method for direct stability assessment of parametric rolling.

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