PREDICTION METHODS FOR PARAMETRIC ROLLING WITH FORWARD VELOCITY AND THEIR VALIDATION –FINAL REPORT OF SCAPE COMMITTEE (PART 2) -

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ABSTRACT

Regarding parametric rolling of ships with forward velocity, this paper reports experimental, numerical and analytical studies conducted by the SCAPE committee, together with critical review of theoretical progress on this phenomenon. Here experimental results of a containership in regular, long-crested and short-crested irregular head waves, and those of a PCTC (pure car and truck carriers) are also shown. They are compared with several numerical predictions to realize quantitative prediction of parametric rolling. The restoring variation, which is main cause of parametric rolling, is investigated with model experiments and potential theories. Application of time-varying coefficient vector autoregressive model is also attempted. Furthermore, the effect of devices preventing parametric rolling is investigated. Based on these outcomes, the SCAPE committee also proposes draft stability criteria consisting of vulnerability criterion and direct assessment as a candidate for the new generation criteria at the IMO (International Maritime Organization).

KEY WORDS: Parametric Rolling, Restoring Variation, Regular and Irregular Head Waves, Containership, Pure Car and Truck Carrier, Non-ergodicity, Spectrum Analysis, Grim's Effective Wave, Anti-Rolling Tank

INTRODUCTION

Parametric rolling is roll motion induced by time-varying restoring arm. Roll frequency of parametric rolling is multiple of half of the encounter frequency and is nearly equal to the natural roll frequency. In case the roll frequency is half of the encounter frequency, this roll motion could be most significant, and is called as low cycle resonance or principal resonance. The main reason why the restoring arm changes with time is that the water plane area and the underwater hull volume change as the waves pass along the ship. Because recent large containerships have exaggerated bow flare and transom stern, this change can be significant in longitudinal waves.

As a result, serious accidents of parametric rolling for modern containerships and PCTCs have been reported in recent years. These accidents triggered off a review of the Intact Stability Code (IS Code) of the IMO, and it has been discussed to set performance-based criteria as an alternative to the existing prescribed criteria. The new performance-based criteria are requested to cover three major capsizing scenarios including parametric rolling as one of roll restoring variation problems. In this stage, a prediction method for parametric rolling with quantitative accuracy is required. For this purpose, all relevant factors of parametric rolling should be systematically investigated to develop a standard numerical simulation technique for the use of performance-based criteria.

HISTORICAL REVIEW

Although parametric rolling itself is well known among theoretical researchers, it has been regarded as rather an exceptional event in actual ocean waves for a long time. However, a recent model experiment showed that a container ship complying with the IS Code of IMO could suffer severe parametric rolling even in short-crested irregular following waves and could capsize in long-crested irregular following waves (Umeda et al., 1995). Moreover, severe parametric rolling in head seas at the Pacific Ocean was reported for a post-Panamax C11 class container ship (France et al., 2003), and similar incident of head-sea parametric rolling was reported for a PCTC in the Azores Islands waters (Hua et al., 2006). The former forced to describe parametric rolling in the IMO operational guidance, MSC Circ. 707, and the latter resulted in the review of the IMO IS Code to open the door to performance-based criteria instead of existing prescriptive criteria. For this purpose, prediction of parametric rolling is required to have quantitative accuracy and identify all potential danger both in regular and irregular waves.

Theoretical studies on parametric rolling can be found in the thirties with linear restoring (Watanabe, 1934). Later, in the fifties, linear and nonlinear damping was taken into account (Kerwin, 1955). These studies enable us to discuss parametric rolling with the Mathieu equation. Then, to investigate capsizing, nonlinearity of restoring moment in still water was taken into account. At this stage, nonlinear dynamical system approach including geometrical and analytical studies is required to identify all potential danger among co-existing states. Such examples can be found in Sanchez and Nayfeh (1990), Kan and Taguchi (1992), Soliman and Thompson (1992) for uncoupled roll models, Oh et al. (2000) for coupled pitch-roll model and Umeda et al. (2004) for uncoupled model with realistic modelling of roll restoring variation.

On the other hand, several six degrees-of-freedom models such as Hamamoto and Akiyoshi (1988), De Kat and Paulling (1989), Munif and Umeda. (2000), Matsusiak (2001) have been developed for numerical prediction in time domain. Here the relationship between wave steepness and restoring moment is fully taken into account. The works using these detailed models only show time series from the limited number of initial condition sets, however, there is a possibility to overlook some potential danger because of nonlinearity of the system. In addition, the minimum requirements for the numerical modelling were not established well. Thus, the ITTC (International Towing Tank Conference) conducted a benchmark testing of numerical codes, which are requested to reproduce experimental runs of a 150m–long containership (known as the ITTC Ship A-1) in regular following waves (Umeda et al., 1995), but it was found only one code can successfully predict the occurrence of parametric rolling and capsizing (Umeda and Renilson, 2001). After the ITTC benchmark testing, further efforts on numerical modelling were reported; Ribeiro et al. (2003), Belenky et al. (2003), Neves and Rodriguez (2005), Brunswig et al. (2006), Spanos and Papanikolaou (2006). It is noteworthy here that such recent efforts mainly focus on head-sea parametric rolling responding to the recent accidents.

Regarding the parametric rolling in irregular waves, Roberts (1982) applied stochastic averaging technique and derived the Fokker-Plank equation as a prerequisite for existence of stationary process of roll. Bulian et al. (2003) experimentally investigated the applicability of the Markov process approach for a Ro-Pax, and confirmed the agreement is good for a narrow band spectrum. Levadou and van't Veer (2006) also showed that the Markov process approach can well predict the critical wave height of parametric rolling in irregular waves. Bulian and Francescutto (2006) proposed a fully analytical approach for the determination of the stochastic stability threshold of parametric rolling, and it overestimates roll motion without a tuning factor. Themelis and Spyrou (2006) proposed a probabilistic assessment of parametric rolling by assuming probability of occurrence of instability is represented by that of encountering the critical or worse wave groups. Belenky et al. (2003) and Belenky (2006) simulated parametric rolling in irregular waves with 50 realisations and numerically confirmed that roll motion is practically non-ergodic while heave and pitch motions are not.

It is also important to estimate the restoring variation in longitudinal waves, which is a principal cause of parametric rolling. Paulling (1960) reported that the Froude-Kylov prediction can explain captive model test results. However, the Froude-Krylov prediction is not always sufficient, particularly for modern ships. To overcome this difficulty, Nechaev (1989) developed an empirical formula from his series of captive model experiments. This formula includes not only the Froude-Krylov component but also hydrodynamic ones. To evaluate such hydrodynamic components theoretically, Boroday (1990) applied a strip theory to a heeled fishing vessel hull, and then good agreement was found by considering the sum of the Froude-Krylov and added-mass related terms. It was expected to pursue this research direction further.

OUTCOMES FROM SCAPE COMMITTEE ACTIVITIES

Experimental Study on Parametric Roll

Free running model experiments for a 6600 TEU post-Panamax containership were conducted at NRIFE (National Research Institute of Fisheries Engineering) with a 1/100 scaled model and NMRI (National Maritime Research Institute) with a 1/76.7 scaled model. This ship is designed by NMRI and her principal particulars and body plan are shown in Table 1 and Fig. 1, respectively. Model experiments were systematically conducted in regular waves, long-crested and short-crested irregular waves. Hashimoto et al. (2006A) investigated the effect of wave height on parametric rolling in regular head waves, as shown in Fig. 2. This result indicates that amplitude of parametric roll does not always increase with wave steepness. Taguchi et al. (2006A) investigated the effect of initial steady heel on parametric rolling in regular head waves, as shown in Fig. 3. Here the initial steady heel angle is 3 degrees. Occurrence region of parametric roll without the steady heel is larger than that with steady heel to some extent. Influence of significant wave height and encounter angle in long-crested irregular waves were examined by Taguchi et al. (2006B), as shown in Fig. 4 and Fig. 5. Maximum roll angle of parametric rolling increases with significant wave height and decreases with deviation from pure head wave condition. Effect of ship speed on parametric rolling was examined in regular, long-crested, short-crested irregular head waves by Hashimoto et al. (2006A), as shown in Fig. 6. In smaller Froude number, roll angles both in long-crested and short-crested irregular waves are slightly smaller than that in regular seas. In the region of Froude number greater than 0.1, small parametric rolling in irregular waves occurs while no parametric roll occurs in regular waves.

Fig. 7 shows the probability density function of instantaneous pitch and roll in short-crested irregular waves (Hashimoto et al., 2006A). Non-Gausssian property is experimentally confirmed even in short-crested irregular waves, and those in regular and long-crested irregular waves are more remarkable.

Table.1 Principal particulars of the post-Panamax containership

Items	*Ship*	*NRIFE*	*NMRI*
length between perpendiculars: L	*283.8m*	*2.838m*	*3.700m*
breadth: B	*42.8m*	*0.428m*	*0.558m*
depth: D	*24.0m*	*0.24m*	*0.318m*
draught: T	*14.0m*	*0.14m*	*0.183m*
block coefficient: C_b	*0.630*	*0.630*	*0.630*
pitch radius of gyration: K_{yy}/L_{pp}		*0.258*	*0.247*
metacentric height: GM	*1.06m*	*0.0106m*	*0.014m*
natural roll period: T_ϕ	*30.3s*	*3.20s*	*3.460s*

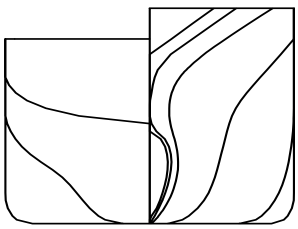

Fig. 1 Body plan of the post-Panamax container ship

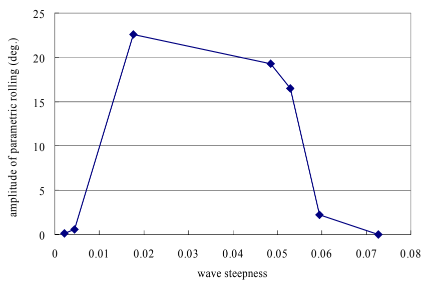

Fig. 2 Influence of wave height on parametric rolling in regular head waves with λ/L=1.6 at $\omega_e=2\omega_\phi$ (Hashimoto et al., 2006A)

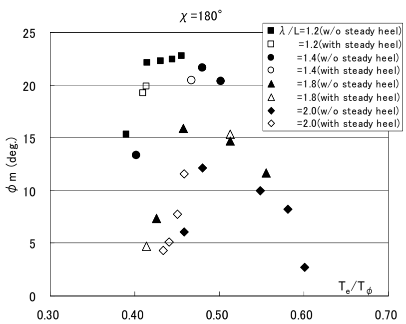

Fig. 3 Influence of initial steady heel angle on parametric rolling in regular head waves with H =11cm (Taguchi et al., 2006A)

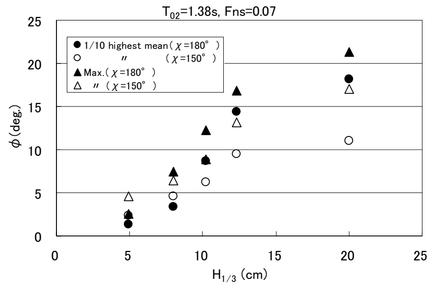

Fig. 4 Influence of significant wave height on parametric rolling in long-crested irregular head waves with T_{02}=1.38sec. (Taguchi et al., 2006B)

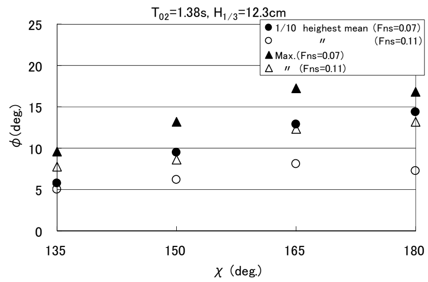

Fig. 5 Influence of encounter angle on parametric rolling in long-crested irregular waves with $H_{1/3}$=12.3cm and T_{02}=1.38 sec. (Taguchi et al., 2006B)

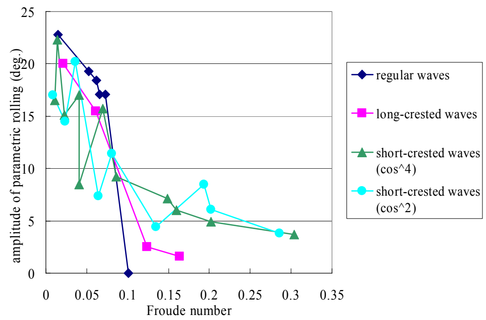

Fig. 6 Influence of ship speed on parametric rolling in regular and irregular head waves (Hashimoto et al., 2006A)

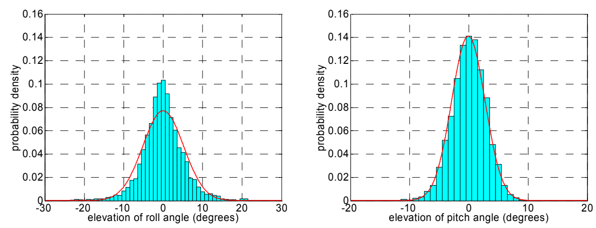

Fig. 7 Probability density functions of instantaneous roll and pitch angle in short-crested irregular waves (histogram: experiment; line: Gaussian distribution) (Hashimoto et al., 2006A)

Free running model experiment for a latest PCTC was conducted at Osaka University. Principal particulars are shown in Table.2, and its 1/64 scaled model was used in the experiment. Roll amplitude of parametric rolling in regular head waves is shown in Fig. 8 (Hashimoto et al., 2007A). Most significant parametric rolling was found from λ/L=1.0 to 1.3. Maximum roll amplitude of parametric rolling with constant wave height of 0.05m is 23 degrees at Fn=0, which is at similar level as that of the post-Panamax containership. PCTCs could be more prone to meet critical wave groups with their mean wave length is comparable to ship length because their length is generally smaller than latest containerships. Therefore, further researches on parametric rolling for PCTCs are desirable.

Table.2 Principal particulars of the pure car and truck carrier

item	*value*
length: L	*192.0 m*
breadth: B	*32.26 m*
depth: D	*37.0 m*
mean draught: T	*8.18 m*
block coefficient: C_b	*0.54*
metacentric height: GM	*1.25 m*
natural roll period: T_ϕ	*22.0 s*

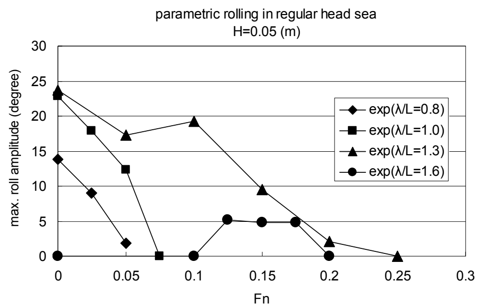

Fig. 8 Maximum roll amplitude of parametric rolling in regular head waves with H=0.05m for the PCTC (Hashimoto et al., 2007A)

Theoretical Estimation of Roll Restoring Variation

Roll restoring variation of the post-Panamax containership and the ITTC Ship A-1 containership, which has less significant flare as shown in Fig. 9, was measured in model scale. The models were towed with the constant heel angle of 10 degrees in regular head and following waves at a towing tank and the reaction moment were detected as the restoring moment (Umeda and Hashimoto, 2006; Nakamura et al., 2007). Here the models were free in heave and pitch. Nakamura et al. (2007) conducted a comparative study on the mean and amplitude of metacentric height (GM) variation for these two different containerships, as shown in Fig. 10 and Fig. 11. Here GM variation is curve-fitted with mean and amplitudes of first and second harmonic components. Amplitude of first harmonic GM variation of the post-Panamax containership is much larger than that of the ITTC containership. This is because the amplitude of restoring variation mainly depends on the slope of ship side-wall (Hamamoto & Fujino, 1986) and the modern post-Panamax containership has exaggerated bow flare and transom stern, which allows increasing the number of onboard containers. On the other hand, little difference in the mean of GM variations was found. Ogawa et al. (2007A) investigated the effect of wave height and influence of restraint of surge motion on GM variation by a model experiment for the post-Panamax containership, and the result is shown in Fig. 12. The experimental result demonstrates that the amplitude of GM variation linearly increases with wave steepness and the effect of surge motion restraint on restoring variation is negligibly small.

Since the estimation of roll restoring variation is important for quantitative parametric roll prediction, a numerical estimateion of the roll restoring variation based on a potential theory was attempted (Umeda et al., 2005). In the proposed calculation, roll restoring variation is obtained as the sum of nonlinear Froude-Krylov component by integrating the wave pressure up to wave surface with taking instantaneous heave and pitch motions calculated by a linear strip theory into account, and radiation component induced by vertical motions of a heeled hull and diffraction component due to an asymmetric hull calculated by a linear strip theory. In Fig. 13, the measured amplitude of roll restoring variation is compared with the Froude-Krylov calculation on its own, and the sum of the Froude-Krylov, radiation and diffraction components for the post-Panamax containership (Nakamura et al., 2007). Consideration of the hydrodynamic components improves the prediction accuracy of restoring variation. This means that parametric roll danger could be underestimated if these components are neglected in the modelling. Fig. 14 shows the comparison of probability density function of GZ between the experiment and the calculation in long-crested irregular waves (Hashimoto et al., 2006B). Here, measured heave and pitch motions are used for the Froude-Krylov force calculation, and instantaneous wave height distribution along a ship is obtained by the Fourier analysis with measured data and is directly used in the calculation. As a result, the amplitude of roll restoring variation in long-crested irregular waves can be well explained as the sum of nonlinear Froude-Krylov and heel-induced hydrodynamic components.

Since the measured mean of roll restoring variation, which changes natural roll period in waves, is not negligibly small, estimation of the mean of roll restoring variation is also important to predict the occurrence region of parametric rolling accurately. Ogawa and Ishida (2006) attempted to calculate the mean of roll restoring variation by applying a momentum theory with Kochin function obtained by Kashiwagi(1991)'s enhanced unified slender body theory. Here steady roll moment is expressed by Kochin function. Comparison of the calculated result with the captive model experiment (Umeda et al., 2005) is shown in Fig. 15. Steady roll moment in head waves decreases with increase of Froude number. From the comparison with captive mode experiment, the calculation can estimate its trend with respect to wave steepness but underestimates the experimental result particularly in high Froude number. This might be because a hydrodynamic lift effect on heeled hull in high speed region becomes significant.

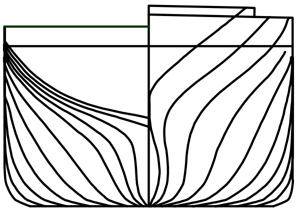

Fig. 9 Body plan of the ITTC ShipA-1 containership

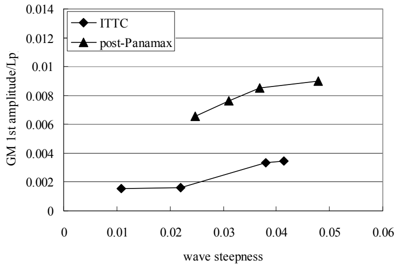

Fig. 10 Amplitude of 1st harmonic GM variation at Fn=0.1 and heel angle of 10deg. (Nakamura et al., 2007)

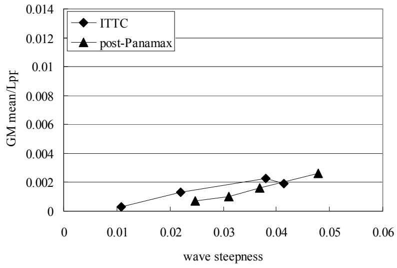

Fig. 11 Mean of GM variation at Fn=0.1 and heel angle of 10deg. (Nakamura et al., 2007)

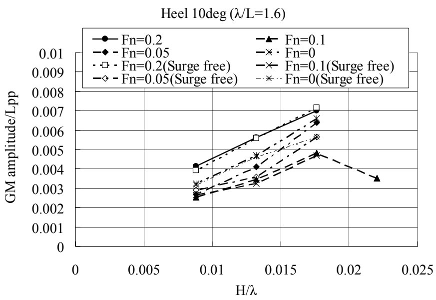

Fig. 12 Influence of surge motion on roll restoring variation in regular head waves with λ/L=1.6 (Ogawa et al., 2007A)

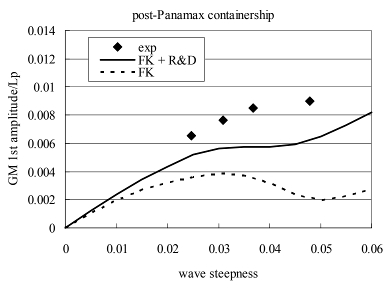

Fig. 13 Comparison of amplitude of 1st harmonic GM variation at Fn=0.1 and heel angle of 10 deg. (Nakamura et al., 2007)

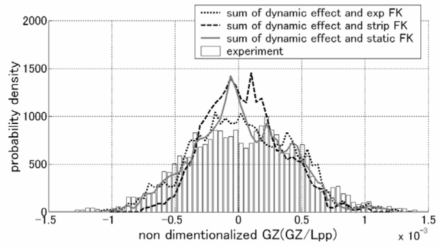

Fig. 14 PDF of restoring arm in long-crested irregular waves with $H_{1/3}$=0.057m and T_{01}=1.35sec. at Fn=0.1 (Hashimoto et al., 2006B)

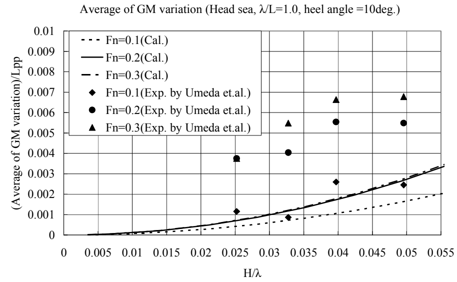

Fig. 15 Comparison of mean of GM variation in regular head waves with λ/L=1.0 and heel angle of 10deg. (Ogawa and Ishida, 2006)

Numerical Prediction of Parametric Rolling

Numerical models for parametric roll prediction should be validated not only in regular waves but also in irregular waves because the relation between roll restoring variation and wave height is inherently nonlinear. Therefore the Grim's effective wave concept (Grim, 1961) was adopted firstly for the prediction of parametric rolling in irregular waves. The idea of the effective wave concept is that irregular wave surface around a ship is replaced with equivalent regular wave, which length is equal to ship length, by a least square method. By introducing the effective wave, the relationship between the ocean wave and the effective wave amplitude becomes linear so that the restoring variation can be calculated by a linear superposition with nonlinear but non-memory relationship between the roll restoring moment and the effective wave amplitude. In the calculation, roll restoring variation in irregular waves is calculated as the sum of nonlinear Froude-Krylov force with heave and pitch obtained by hydrostatic balance for an instantaneous effective wave, radiation and diffraction components calculated under the assumption that it has a linear relation with wave steepness and roll angle. By utilising the above modelling, uncoupled roll model was applied to parametric rolling prediction. Here the roll damping is estimated from a roll decay test without forward velocity, and long-crested irregular wave is assumed to follow the ITTC spectrum and is expressed as the sum of 1000 components of sinusoidal waves with their random phases. Fig. 16 shows the comparison of maximum roll angle of parametric rolling of a post-Panamax containership between free running model experiment and numerical simulation (Hashimoto et al., 2006A). Both calculations excessively overestimate the maximum roll angle of parametric rolling. Bulian et al. (2006) modified Grim's effective wave concept to improve the approximation accuracy of random wave surface by adjusting its wave crest position as an additional random variable. This modification (named Improved Grim Effective Wave, IGEW) improves prediction of the pitch moment and/or static pitch equilibrium angle, while the roll moment prediction itself is sufficient even with the original concept.

By following these studies, the numerical prediction method was upgraded as follows. Firstly the Froude-Krylov force is directly calculated around the instantaneous irregular wave surface with the heave and pitch motions predicted by a strip theory for an upright condition. Roll decay test with forward velocities was conducted and modelled as a function of Froude number. Taguchi et al. (2006C) reported that modelling with such Froude-Krylov prediction improves the agreement in comparison with the experimental result for the post-Panamax containership in moderate regular head waves as shown in Fig. 17. By utilising the Froude-Krylov component with dynamic heave and pitch effect and the radiation and diffraction effect, Hashimoto et al. (2007A) show the comparison of maximum roll angle of parametric rolling for the PCTC in regular head waves as shown in Fig. 18. Numerical prediction still overestimates maximum roll angle in some cases. Since some discrepancies with the measured restoring variation are found as well, it is still required to improve the estimation accuracy of roll restoring variation for quantitative prediction of parametric rolling. Fig. 19 shows the comparison of experimentally and numerically obtained parametric rolling in long-crested irregular waves (Hashimoto et al., 2007A). Here, model and numerical runs were repeated with 4 realisations for each case, and the maximum values in their realisations are plotted. The comparison of roll restoring variation in irregular waves between numerical estimation and experiment is also shown in Fig. 20. These results indicate that small difference of the estimation of roll restoring variation could result in significant difference of maximum angle of parametric roll in irregular waves. Fig. 21 shows the measured and calculated maximum roll angles of parametric roll for 4 different realisations. Practical non-ergodicity of parametric roll is confirmed both in experiment and calculation. Therefore, how to overcome this practical non-ergodicity of parametric rolling in irregular waves is important for the validation of the code and practical stability assessment. Bulian et al. (2008) investigated this problem further based on more extensive model experiments of the post-Panamax containership.

A time domain simulation code for coupled sway, heave, roll and pitch motion was applied to parametric rolling prediction. Here the local added mass and wave-making damping are calculated for instantaneous water surface as well as the roll restoring. The wave exciting force is calculated by solving the Helmholtz equation, which allows shorter waves. (Ogawa et al., 2007A) Ogawa (2007) conducted numerical simulations in long-crested irregular waves for the post-Panamax containership. In the calculation, irregular waves are expressed as a superposition of 200 sinusoidal waves following the ISSC1964 spectrum. Fig. 22 shows the comparison of the amplitude of parametric rolling in regular head waves between free running model experiment and numerical prediction. The calculation well explains the experimental result of the steady amplitude and occurrence region of parametric roll. Fig. 23 shows the comparison of maximum and 1/10 highest mean of roll angle of parametric rolling in long-crested irregular waves (Ogawa, 2007). Numerical calculation results as the ensemble average of 20 realisations quantitatively agrees with experimental result in 1/10 highest mean of roll angle but not so that in maximum roll angle. It is expected here to identify the crucial factors in this modelling to realise the agreement with model experiments. Furthermore, the application of a CFD approach based on the RANS equation is now underway with the collaboration between Osaka University and the University of Iowa.

The nonlinear strip method can predict parametric rolling both in regular and irregular waves with practical accuracy as mentioned above. By utilising this numerical model, horizontal and vertical accelerations during parametric rolling were calculated (Ogawa et al., 2007B). The results, shown in Fig. 24, indicate the gravitational effect on horizontal acceleration acting on a secured container is dominant.

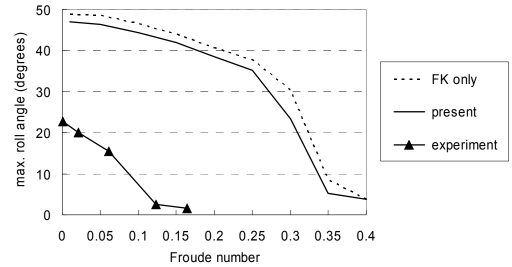

Fig. 16 Comparison of maximum roll angle of parametric rolling in long-crested irregular head waves with $H_{1/3}$=0.221m and T_{01}=1.32sec. (Hashimoto et al., 2006A)

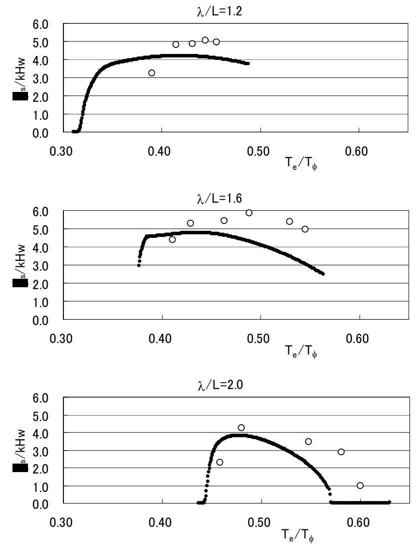

Fig. 17 Influence of encounter period on the amplitude of parametric rolling in regular head waves with H=0.11m (Taguchi et al., 2006C)

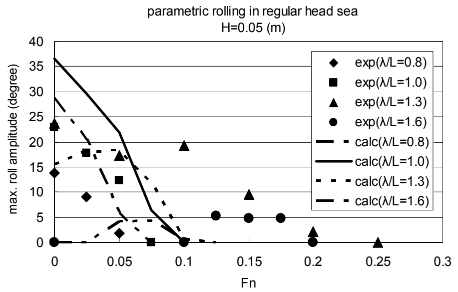

Fig. 18 Comparison of maximum roll amplitude of parametric rolling in regular head waves with H=0.05m (Hashimoto et al., 2007A)

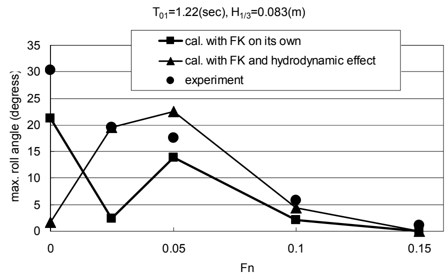

Fig. 19 Comparison of maximum roll angle of parametric rolling in long-crested irregular head waves with $H_{1/3}$=0.083m and T_{01}=1.22sec. (Hashimoto et al., 2007A)

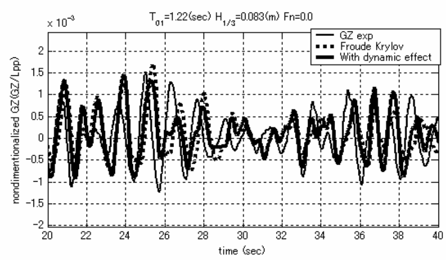

Fig. 20 Comparison of GZ variation in long-crested irregular waves with $H_{1/3}$=0.083m and T_{01}=1.22sec. (Hashimoto et al., 2007A)

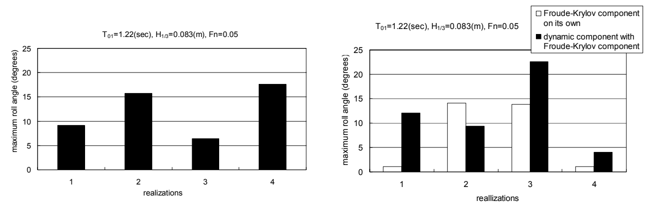

Fig. 21 Maximum roll angle of parametric rolling in long-crested irregular waves for 4 realisations (left: experiment, right: calculation) (Hashimoto et al., 2007A)

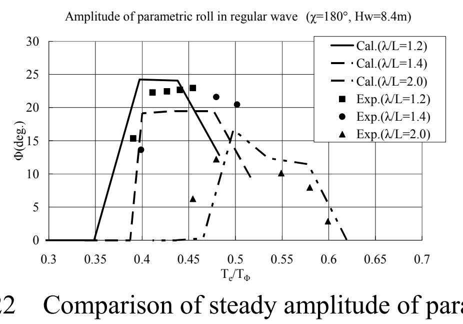

Fig. 22 Comparison of steady amplitude of parametric rolling in regular head waves with H=8.4m (Ogawa et al., 2007A)

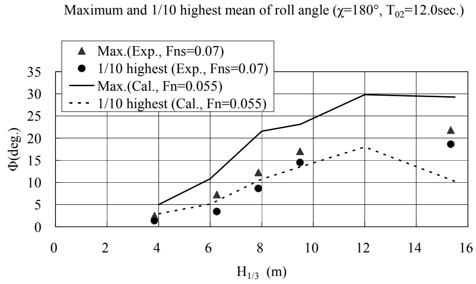

Fig. 23 Comparison of maximum roll angle of parametric rolling in long-crested irregular head waves with T_{02}=12.0sec. (Ogawa, 2007)

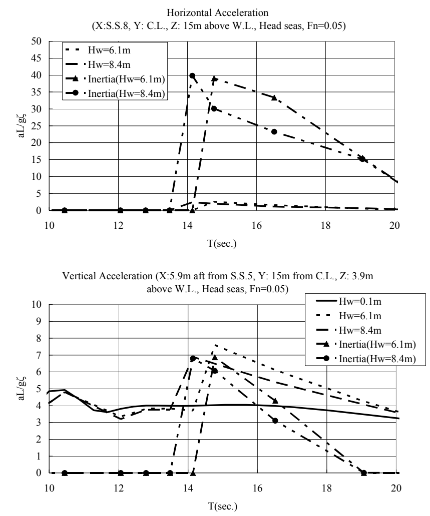

Fig. 24 Effect of wave height on the response amplitude operators of horizontal (above) and vertical (below) accelerations (Ogawa et al., 2007B)

Spectrum Analysis of Parametric Rolling

To understand the nonlinear phenomenon of parametric rolling and identify its nature in frequency domain, Iseki (2006) applied the Time-Varying coefficient Vector Auto-Regressive (TVVAR) model to the time series of parametric roll obtained by free running model experiment for the post-Panamax containership. Firstly, the relative noise contribution to roll angle during parametric rolling in regular head waves was analysed as shown in Fig. 25. From the result, the contribution of pitch to roll is negligibly small in a peak frequency of roll. Secondly a bispectrum analysis was attempted for the time series of parametric roll in short-crested irregular waves to clarify the skewness of non-Gaussian parametric rolling. Fig. 26 shows the estimated bispectra of roll and pitch motions. The peaks of roll and pitch motions appear on 45 degrees of diagonal line, which indicates the existence of nonlinearity of each motion during the parametric rolling. Finally a trispectrum analysis was attempted to identify the kurtosis of non-Gaussian parametric rolling due to third and fifth harmonic frequencies (Iseki, 2007). Fig. 27 shows the analysed trispectrum of roll motion in regular waves with fixed f_3 frequency of 0.32Hz . There are three peaks with the frequencies of 1, 3, 5 times as natural roll frequency. By applying the trispectrum analysis, kurtosis of parametric rolling due to higher order harmonic frequencies is demonstrated.

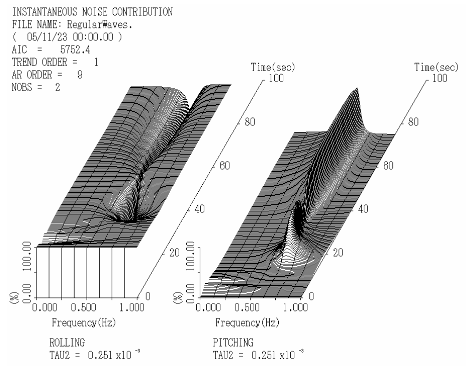

Fig. 25 Relative noise contribution to roll angle in regular head waves with H/λ=1/20, λ/L=1.6 (Iseki, 2006)

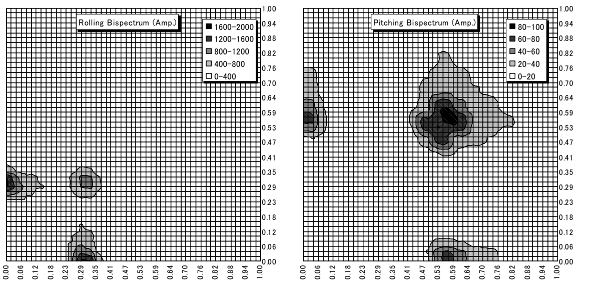

Fig. 26 Bispectra of roll and pitch motions in short-crested irregular head waves with $H_{1/3}$=0.221m and T_{01}=1.32sec. (Iseki, 2006)

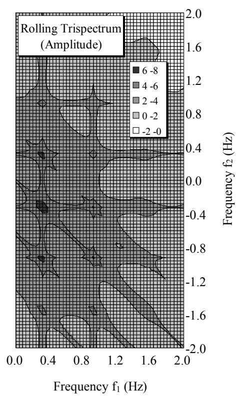

Fig. 27 Trispectrum of roll and pitch motions in regular head waves with f_3=0.32Hz, H/λ=1/20 and λ/L=1.6 (Iseki, 2007)

Prevention Devices of Parametric Rolling

For a practical purpose, it is desirable to propose preventing devices of parametric roll without any change of original hull design. Prevention of parametric rolling could be achieved by reducing the amplitude of restoring moment variation in longitudinal waves and/or to increase the roll damping. Floats attached to the ships side (sponsons) to reduce the amplitude of restoring variation and an anti-rolling tank (ART) to increase the roll damping were examined by free running model tests for the post-Panamax containership (Umeda et al., 2008). As a result, maximum roll amplitude of parametric rolling decreases by installing sponsons, and parametric rolling disappears completely by installing ART even in severe wave condition as shown in Fig. 28. Further, a cost-benefit analysis (Umeda et al., 2007) demonstrates an ART is a cost-effective option to reduce risk of container damage due to parametric rolling. However, to estimate the performance of ART, damping coefficient of water in ART is required in a numerical simulation of parametric rolling, and a scaled model test of ART is normally executed. To overcome this annoyance, Hashimoto et al. (2007B) applied the Moving Particle Semi-implicit Method (MPS method) to estimate damping effect of the tank water. As a result, the MPS method can simulate the free oscillation test and predict the natural period and damping coefficient of ART quantitatively as shown in Fig. 29. Fig. 30 shows the comparison of parametric rolling between calculations with damping coefficients obtained by the MPS method and those with a roll decay test of a physical model with ART. There is negligibly small difference between the two calculations. This comparison shows a possibility to design ART as a parametric roll prevention device without any model experiments by applying a MPS method.

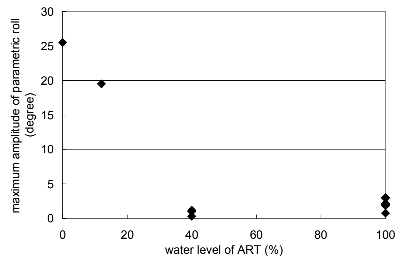

Fig. 28 Relation between water level in the ART and amplitude of parametric rolling in regular head waves at λ/L=1.3 and H/λ=0.03 (Umeda et al, 2008)

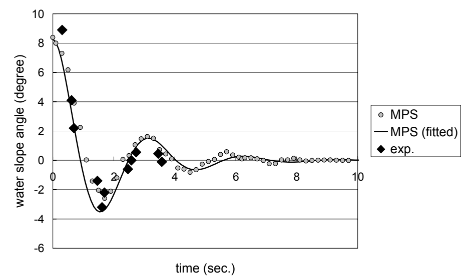

Fig. 29 Comparison of damping curve of water slope of ART between model experiment and MPS method (Hashimoto et al, 2007B)

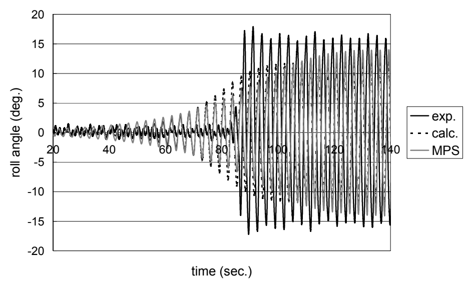

Fig. 30 Comparison of roll motion between model experiment and calculations in regular head waves λ/L=1.6 and H/λ=0.033 (Hashimoto et al, 2007B)

RECOMMENDATION FOR IMO PERFORMANCE-BASED CRITERIA

The IMO requests both the vulnerability criterion and the direct assessment for parametric rolling, by following the framework proposed by Japan, the Netherlands and the United States (2007). Responding to this requirement, the SCAPE committee recommends the following draft criteria.

Vulnerability criterion

It is important that a vulnerability criterion should be simple but should guarantee conservative safety level with a non-empirical approach. Occurrence of parametric rolling can be predicted by Mathieu's instability curve under the assumption of uncoupled linear roll equation. Based on this knowledge, occurrence of parametric rolling can be predicted with a ratio between linear roll damping and amplitude of GM variation, which is proportional to roll angle. In addition, amplitude of the parametric rolling can be estimated with approximated analytical methods with nonlinear restoring moment in still water and GM variation due to waves. If we can calculate GM variation in longitudinal regular waves, occurrence and magnitude of parametric rolling can be analytically estimated (ITTC, 2005). For simplicity sake, we can assume that the wavelength is equal to ship length and the representative wave height can be determined with Grim's effective wave concept under the relevant irregular waves.

Direct assessment

If a ship design fails to comply with the vulnerability criterion, it is expected to apply direct stability assessment. Here it is necessary to evaluate probability of parametric rolling with its maximum roll angle exceeding a critical angle in irregular waves. For this purpose, a coupled mathematical model is required including roll, heave and pitch motions in minimum for head seas and an uncoupled roll model is done for following seas. The roll restoring variation in waves and nonlinear roll damping should be accurately modelled experimentally or/and theoretically. Monte Carlo simulation must be run for adequate time duration and be repeated with sufficient number of realisations because of the possible, in certain conditions, practical non-ergodicity of parametric rolling.

CONCLUSIONS

The activity of the SCAPE committee for parametric rolling provides the following conclusions:

1. Influences of wave height, wave period, encounter angle, ship speed, wave irregularity and initial steady angle on parametric rolling are examined by free running model experiments.
2. Roll restoring variation in regular and irregular head waves are measured and compared with numerical estimations based on potential theories in amplitude and in mean.
3. Numerical prediction methods of parametric rolling are investigated to develop quantitative prediction for realising the performance-based criteria. As a result, estimation of roll restoring variation taking hydrodynamic effects into account is desirable, and ensemble mean is recommended to avoid the difficulty of possible, in certain conditions, practical non-ergodicity for the assessment of parametric rolling in irregular waves.
4. Effectiveness of the devices for preventing parametric rolling is validated by model experiments, and application of the MPS method to the design of anti-rolling tank as a parametric roll prevention device is proposed.

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