Large Parametric Rolling of a Large Passenger Ship in Beam Seas and Role of Bilge Keel in Its Restraint

Yoshiho Ikeda*, Abdul Munif**, Toru Katayama* and Tomo Fujiwara*
*Department of Marine System Engineering, Osaka Prefecture University
**Department of Marine Engineering, Sepuluh Nopember Institute of Technology (ITS) Surabaya (currently is visiting researcher at Osaka Prefecture University)

Abstract

Captive model experiments of a scale model of a large passenger ship without bilge keels in beam seas demonstrate that parametric roll resonance with roll amplitude can reach more than 25 degrees occurs in the range of short wave. It is identified that the change of wave height affects the change of metacentric height in waves so that it affects the occurrence of the parametric rolling in beam seas. It is experimentally confirmed that the designed bilge keels for the ship can restrain such parametric rolling. Moreover, the experiments with various sizes of bilge keels show that they can affect the occurrence of parametric rolling in beam seas.

Introduction

Parametric roll resonance is considered one of dangerous motions in waves that could lead to ship capsize. It is identified by the roll period is almost twice of the encounter period. This resonance usually occurs for the ratio of wave length to ship length is of 1 to 1.5. This resonance is reported many times occurred in following and quartering seas that could lead to capsize, as the results of model experiments of Paulling et al.(1972), Oakley et al. (1975), Tsuchiya et al. (1977), Kan et al. (1994), Umeda et al. (1995) and Hamamoto et al. (1996). The International Maritime Organization (IMO) also pointed out this problem in MSC Circular 707 (1995), to guide ship masters to avoid dangerous motions, including the parametric resonance in following and quartering seas.

This resonance is also reported frequently occurred in head seas as the works of Neves et al. (1999, 2002, 2004) Umeda et al.(2002, 2004), France et al.(2003) and Palmquist and Nigren (2004) and Bulian et al.(2004). As the results of those works, Sub-Committee on Stability (SLF) of the International Maritime Organization (IMO) discussed some capsizing scenarios, and considered parametric rolling in following and quartering seas and parametric rolling in head seas should be also considered in the

future intact stability criteria, besides pure loss of stability in wave crest in following and quartering seas, bow submergence in following and quartering seas, breaking waves, surf-riding and broaching in following and quartering seas (2003).
However, when we are dealing with dangerous motions in waves to be considered in building future stability criteria, we should consider more wide ranges, from following-quartering-beam-bow and head seas, and we should confirm that the ship can safe from dangerous motions in those ranges. In this paper we present significant results of our captive model experiments of a large passenger ship in beam seas. We identified a phenomenon of parametric resonance of the model ship in beam seas in short wave length with rolling amplitude can reach more than 25 degrees, which is usually under estimated by many researchers before.

Captive Model Experiment on Ship Motions in Beam Waves

Several model experiments were conducted in the towing tank of Osaka Prefecture University, which is 100 meters in long, 3 meters in wide and 1.5 meters in deep. The model of a large passenger ship with the scale of 1/125.32 was used. The principal particulars of the ship and its model are given in Table 1 and the body plan of the ship is shown in Figure 1.

Table 1. Principal particulars of large passenger ship

Items	ship	model
Length overall	290m	2.2m
Length between perpendiculars	242.24 m	1.933 m
Breadth	36.0 m	0.287 m
Depth to main deck	20.0 m	0.16 m
Draft	8.4 m	0.067 m
Metacentric height	1.579 m	0.0126 m
Block coefficient	0.709	0.709
Natural roll period	23 sec.	2.05sec.
Displacement	53140.412 ton	27 kg
Scale	1/1	1/125.32
Bilge keel: width	1.1m	0.0088m
Bilge keel: location	s.s.3.0-5.0, s.s. 5.25-6.0	

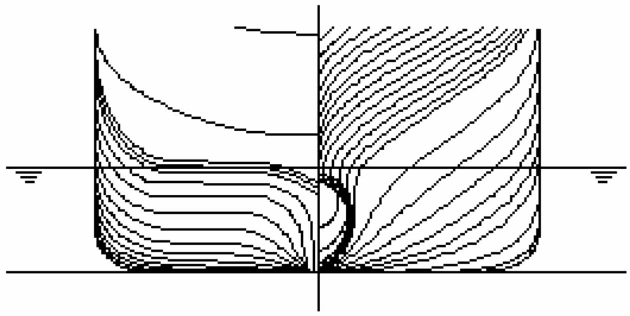

Figure 1. Body plan of ship

The model was attached to a towing carriage but free in heave, pitch, sway and roll. These motions were recorded by analog to digital converter, the time series of the motions are then identified by the Fourier expansion to determine the periods or frequencies and their amplitudes in the steady conditions. This expansion was also used to determine the wave period or frequency and its amplitude.

The captive model experiments in beam seas were carried out in conditions as in Table 2.

Table 2. Measured conditions

	Model	Ship
Wave period	0.6 – 2.2sec	6.7 – 24.6sec
Wave length	0.56 – 7.55m	70 – 944m
Wave height	0.04m	5m
Bilge keel	without, front, aft, full	

More than 100 model experiments were conducted. Types of the conducted experiments are as follows:

- Roll decay model experiments
- Captive model experiments without bilge keels
- Captive model experiments with designed bilge keels
- Captive model experiments with reduction bilge keels area from the designed ones

Parametric Resonance in Beam Waves

From the above captive model experiments, we identify significant results of parametric rolling that occurred in limited range of short wave. Figure 2 shows the roll amplitudes of ship motions in beam seas of the model ship without bilge keels, for the ratio of wave length to ship length 0.291 to 3.91 and constant wave height of 0.04m. The parametric resonance occurs in the short wave ranges, from λ / Lpp of 0.34 to 0.654. It does not occur for very short wave length, λ / Lpp is 0.291 and lower, and for long wave length, as λ / Lpp is of 0.7 or larger.

When the parametric happens, the roll amplitude can reach more than 25 degrees. The lowest roll amplitude recorded is 14.5 degrees at λ / Lpp is 0.341 and the peak roll amplitude is 26.81 degrees, occurs when λ / Lpp is 0.466. When the ship is away from the parametric rolling, the roll amplitudes are not more than 7 degrees. These results prove the danger of parametric rolling in beam waves at relative short waves, which is usually underestimated by many researchers before.

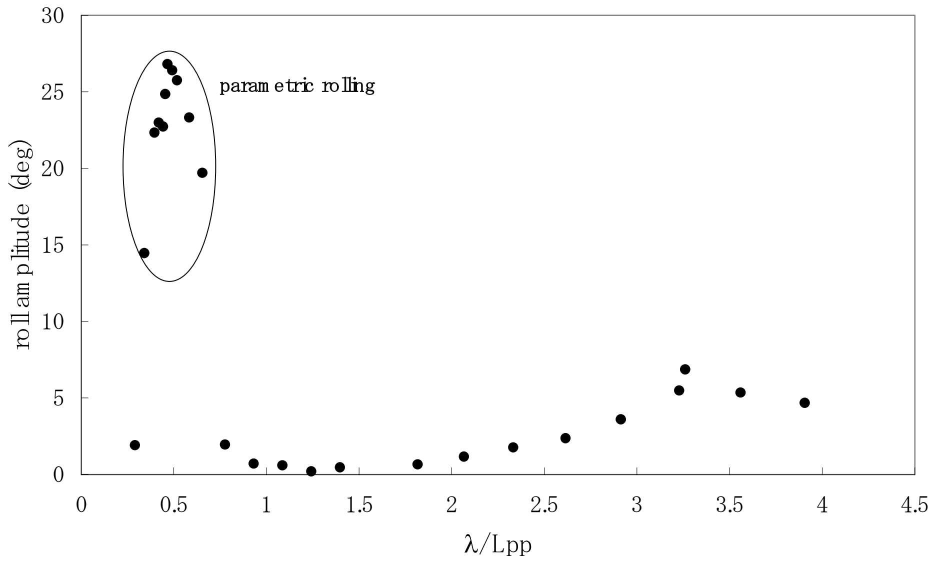

Figure 2. Roll amplitude of ship motions in beam seas for various wave length

Figure 3 shows the roll frequency and encounter frequency from the experiments. When the parametric occurs, the encounter frequency is almost twice of the roll frequency. The parametric rolling occurs in the range of encounter frequency is from 0.597 to 0.757 rad/sec, which corresponds to roll frequency 0.294 to 0.378 rad/sec.

The natural roll period in ship scale resulted from the roll decay test is 23 sec. or the natural roll period is 0.2732 rad/sec. From the results of captive model experiments, it is identified that the parametric rolling occurs when the rolling period is shorter than the natural roll period. This could be due to the effects of drift motions in beam waves, as shown in Figure 4. When the parametric occurs, the frequency of the wave is not equal to the encounter period. The drift speed increases as the wave frequency increases. This could be interesting topic in the future to investigate the effects of drift motions to parametric rolling in beam waves.

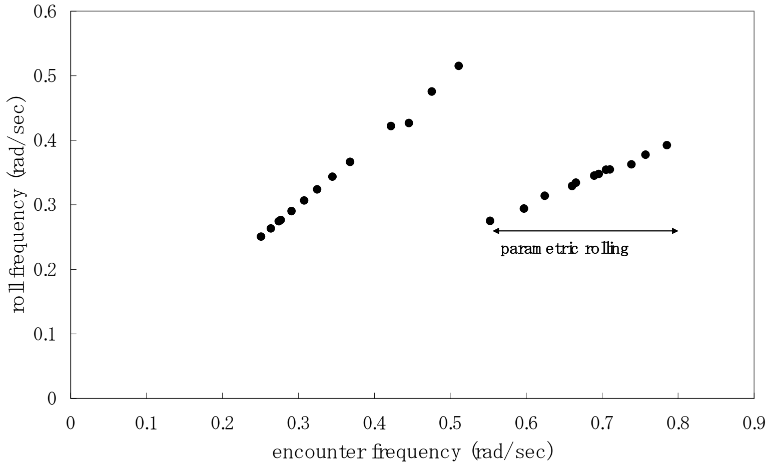

Figure 3. Relations between roll frequency and encounter frequency from model experiments

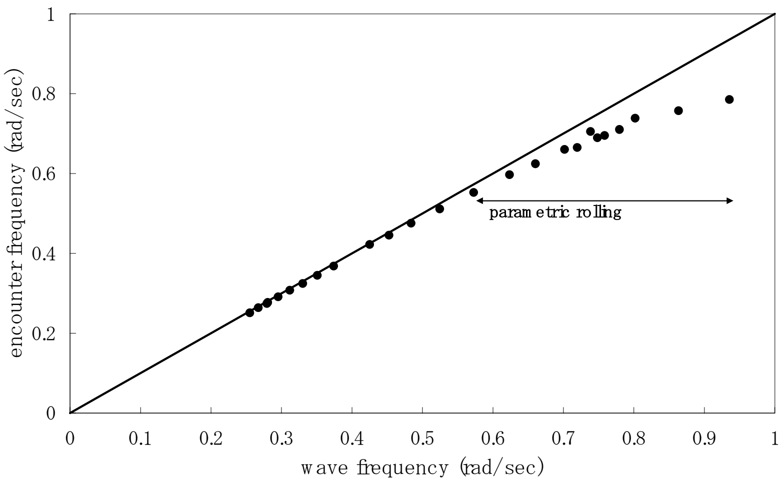

Figure 4. Relations between encounter frequency and wave frequency from model experiments

Some of the time series of ship motions recorded from the model experiments, in the ship scale, are presented in Figures 5-7. Figures 5 and 6 show the parametric resonance phenomenon, where the rolling period is almost twice of the encounter period. When the waves start attacking the ship hull, the heave displacement increases then the ship start rolling with small angle, after that parametric amplification happens due to the change of restoring moment. This phenomenon is clearly identified in those figures. But when the parametric resonance does not occur, the ship only heaves up and down, without significant change of the restoring moment. The pitch effects to the parametric resonance in beam seas, resulted from these model experiments, could be neglected.

The pitch angles are almost zero when the resonance occurs or does not.

This parametric resonance is considered due to the change of restoring moments in waves, i.e. the change of metacentric height. This phenomenon can be further clarified by the next chapter.

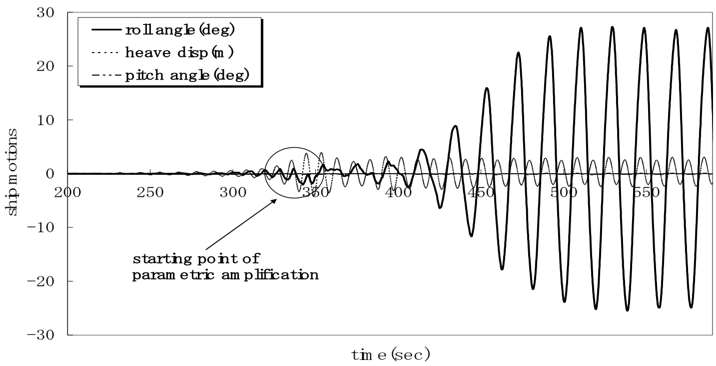

Figure 5. Time history of roll, heave and pitch motions for λ / Lpp is of 0.5165 and H / λ is of 0.04

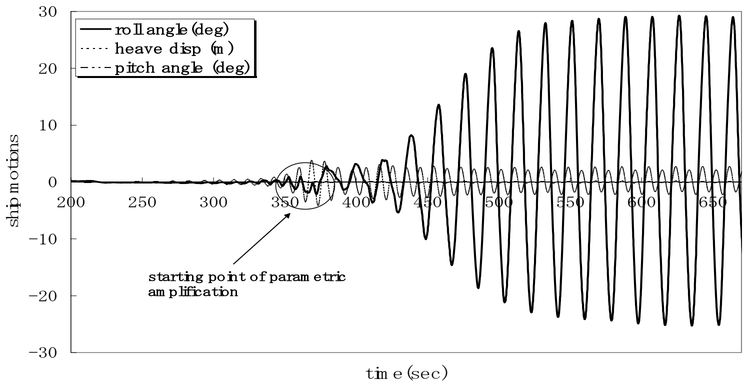

Figure 6. Time history of roll, heave and pitch motions for λ / Lpp is of 0.491 and H / λ is of 0.042

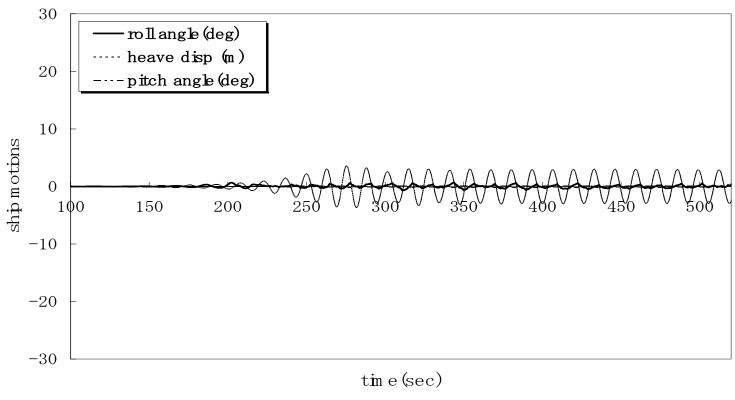

Figure 7. Time history of roll, heave and pitch motions for λ / Lpp is of 1.086 and H / λ is of 0.02

Effects of wave height

It is widely accepted that GM of a ship depends on a relative position of ship to waves and wave height. The significant change of the metacentric height becomes one of the causes of the parametric resonance. To investigate the effects of wave height to the occurrence of parametric rolling, some model experiments were conducted for constant wave length λ / Lpp is of 0.466. The results are shown in Figure 8, where the parametric resonance occurs when the steepness is 0.38 or higher. For lower steepness it does not occur.

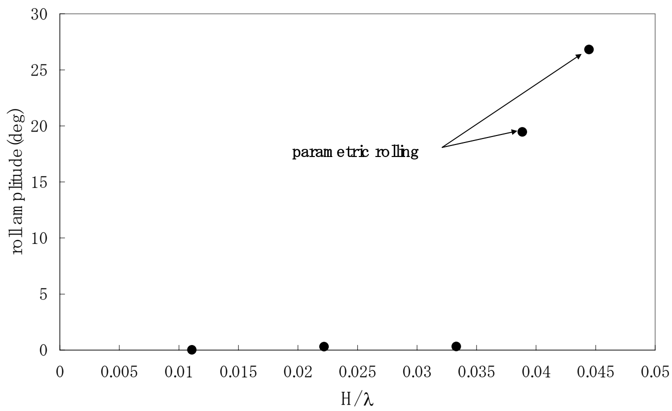

Figure 8. Roll amplitudes resulted from model experiments for various wave height

Theoretically, the change of roll restoring moment in waves can be calculated by Froude-Krylov assumption. Following this assumption, the metacentric height change, i.e. ΔGM, of this ship for λ / Lpp is of 0.466, is shown in Figure 9. Here ΔGM is defined by $\Delta GM = GM_{wavecrest} - GM_{wavetrough}$. The GM when the wave crest is at midship section is larger than that when the wave trough is at midship section, as shown in Figure 10.

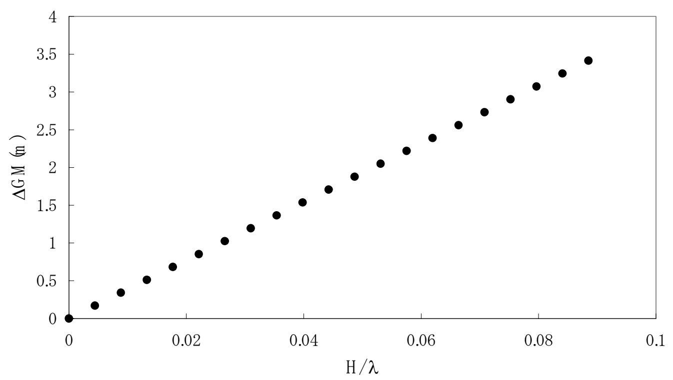

Figure 9. Change of ΔGM as function of wave steepness

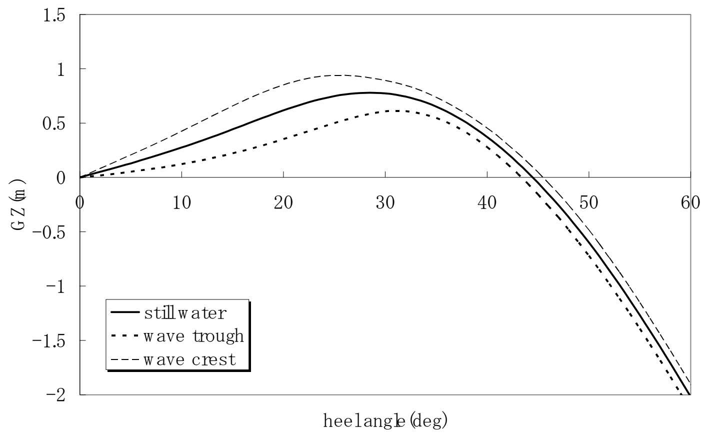

Figure 10. GZ curves in still water and in waves of λ / Lpp is 0.47 and H / λ is 0.04

Effects of Bilge Keels

Bilge keel is one of the means to restraint roll motion by increasing the roll damping. In this research, the effects of the bilge keel are investigated. At first, the design bilge keels of model scale, which consist of long and short parts are mounted in the keel lines in the locations of section s.s 3.0-5.0 in the front and s.s.5.25-6.0 in the aft. Then reduction of the bilge keels' areas was done by mounting only long parts in the front (s.s. 3.0-5.0). Further reduction was done by mounting only the short part in the aft (s.s.5.25-6.0). Results of captive model experiments with the bilge keels are shown in Figure 11.

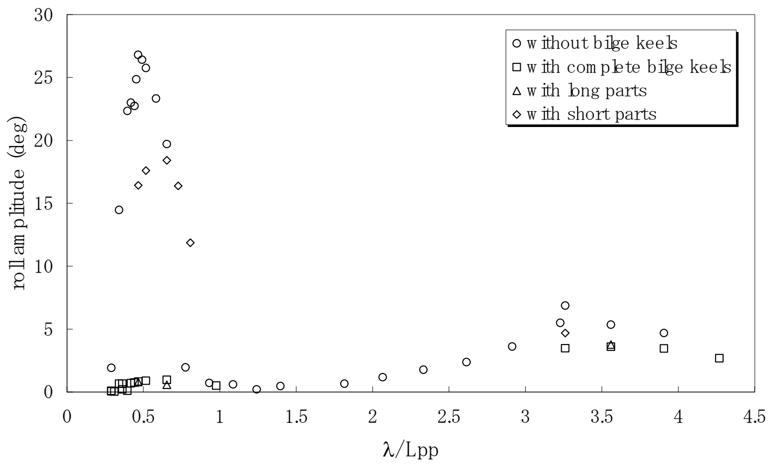

Figure 11. Effects of bilge keels to the roll amplitudes resulted from model experiments

The mounting of the designed bilge keels can reduce significantly the roll amplitudes, thus the parametric resonance can be avoided. The mounting of only long parts of the bilge keels can also reduce the roll amplitude significantly. However, when only the short parts are mounted the reduction of the roll amplitude is not so significant. In this case the parametric can not be avoided. These results show that the size of bilge keels is significant for avoiding the parametric rolling in beam seas.

Concluding Remarks

Model experiments on ship motions in beam waves of a large passenger ship were conducted. Some significant results are drawn as follows:

- It is emphasized that the parametric resonance of a ship can also occur at short waves or higher frequency in beam seas.
- The roll amplitude of the model ship could reach more than 25 degrees when the parametric resonance occurs.
- It is confirmed that the wave height can affect the occurrence of the parametric resonance.
- It is identified that the size or the area of the bilge keels can affect the occurrence of the parametric resonance in beam seas
- When considering the future intact stability criteria, the potential danger of parametric rolling in beam seas and in short waves should also be taken into account.

Acknowledgements

This work is a part of the second author's post-doctoral research supported by the Grant-in-Aid of the Japan Society for the Promotion of Science (JSPS). The authors would like to express their gratitude to the above organization.

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