Parametric Roll Resonance of a Large Passenger Ship in Dead Ship Condition in All Heading Angles

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ABSTRACT

Although it has been widely believed that a ship in dead ship condition has the largest roll motion at resonance condition, the authors found that, because of parametric roll resonance, a kind of ships has significant heavy rolling in beam waves with slightly smaller period of the half value of its natural roll period if the roll damping is small. In the present paper, model experiments to measure ship motions of a large passenger ship in waves with various heading angle are carried out to confirm the region of heading angles where large parametric rolling appears. The results demonstrate that parametric rolling appears at wide region of heading angles and disappears in certain heading angles.

Keywords: *Parametric rolling, Head sea, Beam sea, Large passenger ship*

1. INTRODUCTION

As well known, occurrence of small parametric rolling of ships in beam seas has been pointed out by many researchers. In the previous paper proposed by Ikeda et. al. (2005), however, the authors found experimentally that heavy roll motion with much larger angle than that in resonance appears for a large passenger ship with flat stern and large bow flare in heavy beam seas due to parametric rolling. The measured results demonstrated that the large parametric rolling appears only when the ship has no bilge keel or smaller one. As wave height increases, the parametric rolling suddenly appears at higher wave height than a certain value. The authors also did a simulation of roll motion, and confirmed that similar parametric rolling appears for the ship in beam waves (Munif et. al. 2005).

In the present study, some additional experimental works to clarify effects of wave height, size of bilge keels and heading angles of waves on occurrence of large parametric rolling are carried out to reveal the characteristics of the parametric rolling.

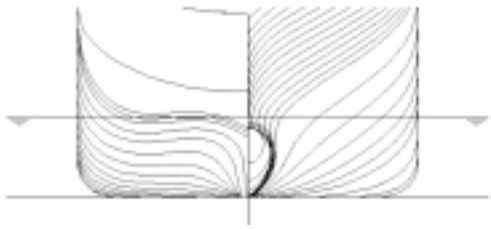

Figure 1 Body plan of the ship.

2. EXPERIMENTAL SETUP

The ship used in the experiments is the

110,000GT passenger ship designed by Fincantieri for an international cooperated research on damage stability of large passenger ships in IMO. The body plan and the principal particulars are shown in Figure 1 and Table 1, respectively. The bilge keels designed for the ship are divided into two parts, short forward one and long aft one. The roll damping can be changed by selecting these bilge keels.

Table 1 Principle particulars.

	Full Scale	Model
Scale	1/1	1/125.32
L_{OA}	290 m	2.200 m
L_{PP}	242.24 m	1.933 m
Breadth	36 m	0.287 m
Draft	8.4 m	0.067 m
Displacement	53,010 ton	26.98 kg
GM	1.579 m	0.0126 m
T_{roll}	23 sec	2.05 sec
Bilge keel : width	1.1 m	0.0088 m
Bilge keel : location	s.s.3.0－5.0, s.s.5.25－6.0	

In the previous study, a scale-model of the large passenger ship was located in transverse direction in the towing tank of Osaka Prefecture University, and the ship motions, roll, heave, pitch, sway and drift motions, were measured in regular beam waves. In the experiment, yaw and surge motions were fixed.

In the present study, the same model is located in regular waves for freely yawing conditions or various fixed heading angles for incident waves. Only transverse motion of the model is fixed by a guide. This means that drift motion in incident-wave direction is free but the motion perpendicular to it is fixed. The experimental conditions are shown in Table 2.

Table 2 Experimental conditions.

	Full scale	Model
Wave period	6.7 – 24.6 sec	0.6 – 2.2 sec
Wave length	70 – 944 m	0.56 – 7.55 m
Wave height	1.25 – 10 m	0.01 – 0.08 m
Bilge keel	without , full (front + aft) , front , aft	

3. EXPERIMENTAL RESULTS

As mentioned before, in the previous paper, the authors experimentally showed that the effect of wave height on parametric rolling in regular beam waves. To confirm the results in wider wave height region, parametric rolling of the ship without bilge keels is measured for various wave heights. The maximum amplitude of the parametric rolling at each wave height is shown in Figure 2. The results demonstrate that the parametric rolling appears just over 30mm of wave height, rapidly increases with wave height, and reaches the maximum amplitude that is about 27 degree. It should be noted that the roll amplitude does not proportionately increase with increasing the wave height but seems to saturate to the maximum one.

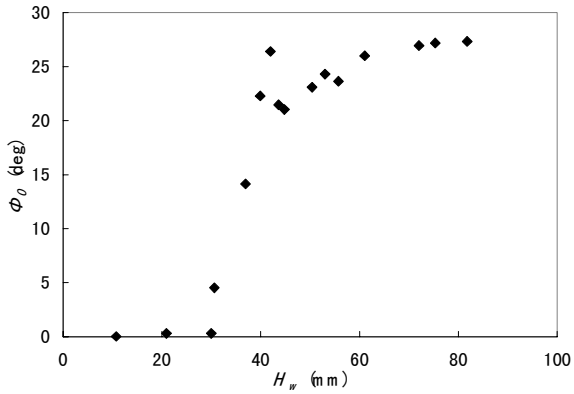

Figure 2 Effect of wave height on maximum amplitude of parametric rolling of the ship in regular beam seas

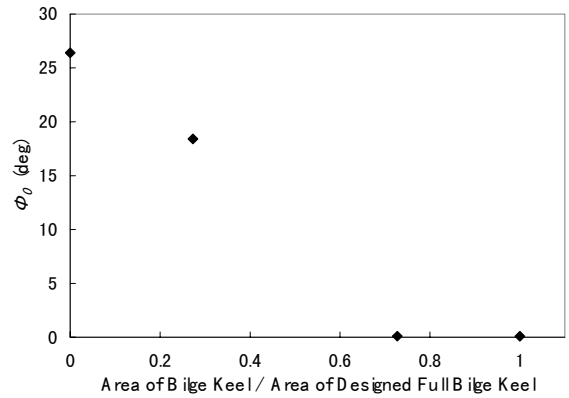

Figure 3 Effect of area of bilge keels on maximum amplitude of parametric rolling in regular beam seas.

In Figure 3, effect of area of bilge keels on maximum amplitude of parametric rolling is shown. This results demonstrate that the parametric rolling significantly depend on area of bilge keels. It is safely said that large bilge keels can completely erase parametric rolling in beam seas.

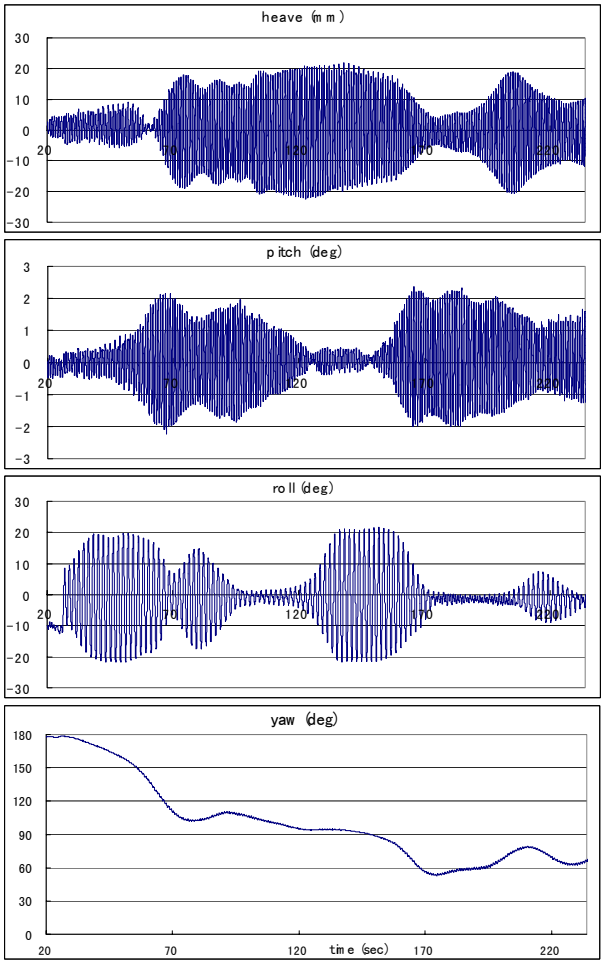

Figure 4 Time histories of motions of the ship without bilge keel released from head sea condition in regular waves at T_w=0.95sec and H_w= 0.04m.

To investigate the effect of heading angle on the parametric rolling of the dead ship, the model are released in head wave condition (χ=180°) or following wave condition (χ=0°) in regular waves with 0.04m of wave height and 0.95 second of wave period which is the period when the large parametric rolling in beam seas appears. The time histories of the heave, pitch, roll and yaw motions are measured and showed in Figures 4 and 5. The model has no bilge keel in these measurements. From the time histories of the yaw angles, we can see that, in both cases, the heading angle of the ship slowly changes to beam sea condition. The time histories of roll motion in these figures show that the period of the roll motion is twice of the heave and pitch motions. The results demonstrate that the parametric rolling occurs in wide heading angles as well as in beam seas.

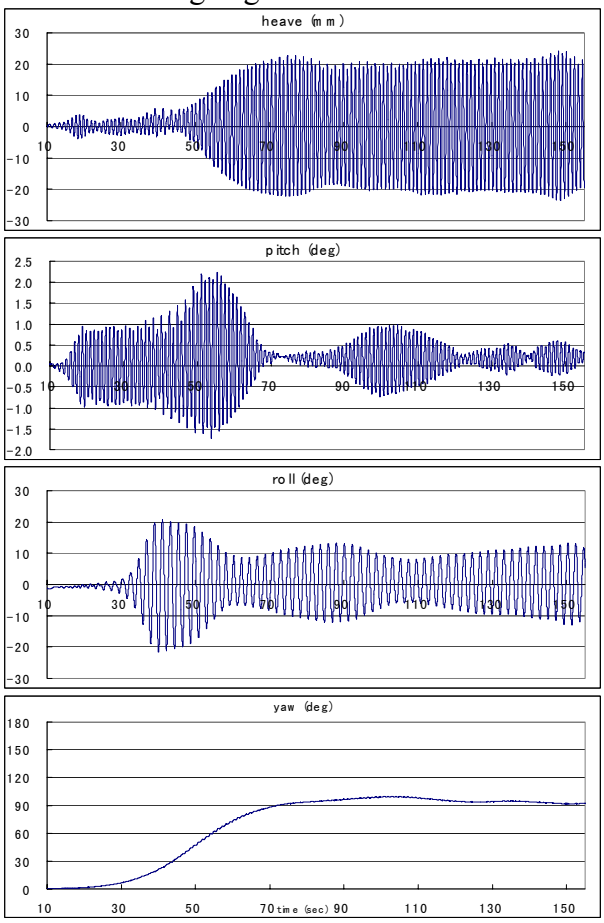

Figure 5 Time histories of motions of the ship without bilge keel released from following wave condition in regular waves at T_w= 0.95sec and H_w= 0.04m.

Since it may take time to lead to the parametric rolling and reach its steady condition, a measurement of roll motion at some fixed heading angle; 0, 90, 180 degree are carried out. And using the results of above-mentioned measurement and of previous ones shown in Figures 4 and 5, the roll amplitude of the parametric rolling for each heading angle is plotted in a polar diagram as shown in Figure 6. The results show that amplitudes of the parametric rolling is significant in following

and head seas as well as beam seas when no bilge keel is attached.

Figures 7 and 8 show variation of *GZ*-curves of the ship on the basis of Froude-Krylov assumption in heading and beam seas, respectively. We can see the *GZ*-curves significantly vary between wave crest and wave trough in head and beam waves. These large variations of the *GZ*-curve create the large amplitude of parametric rolling.

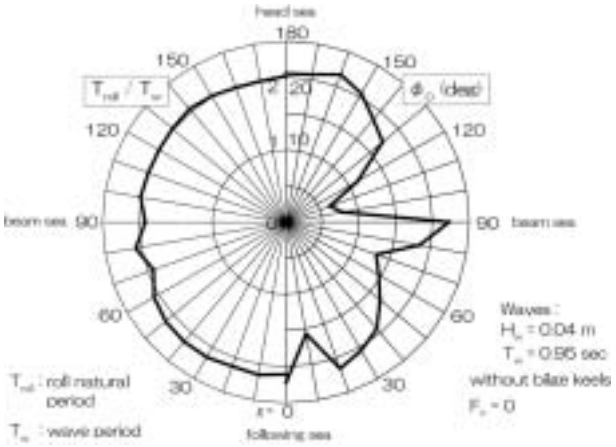

Figure 6 Effect of wave direction on amplitude of parametric rolling of the ship without bilge keel in regular waves.

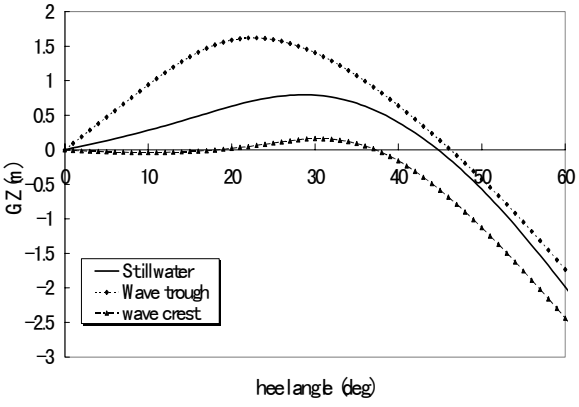

Figure 7 Variation of GZ curves in head waves of λ/L=1.5 and Hw/λ=0.033.

To investigate the effect of roll damping on occurrence of parametric rolling in various heading angles, motions of the model with bilge keels are measured in regular waves (H_w = 0.08m, T_w = 0.95 sec). In Figure 9 the time histories of motions of the ship with smaller front bilge keels released from following wave condition in the regular waves are shown. Smaller parametric rolling occurs in all heading angles of waves. When larger aft bilge keels or full bilge keels are attached, no parametric rolling appears as shown in Figures 10 and 11.

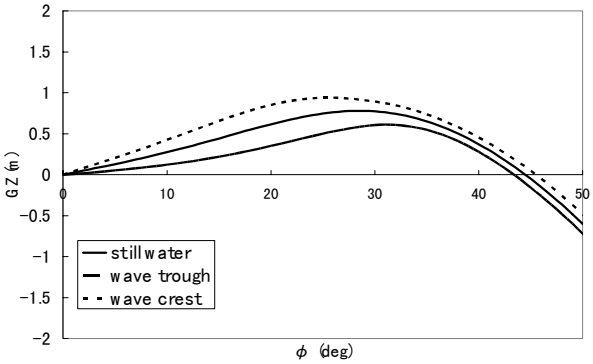

Figure 8 Variation of *GZ* curves in beam waves of λ/L= 0.47 and H_w/λ=0.04.

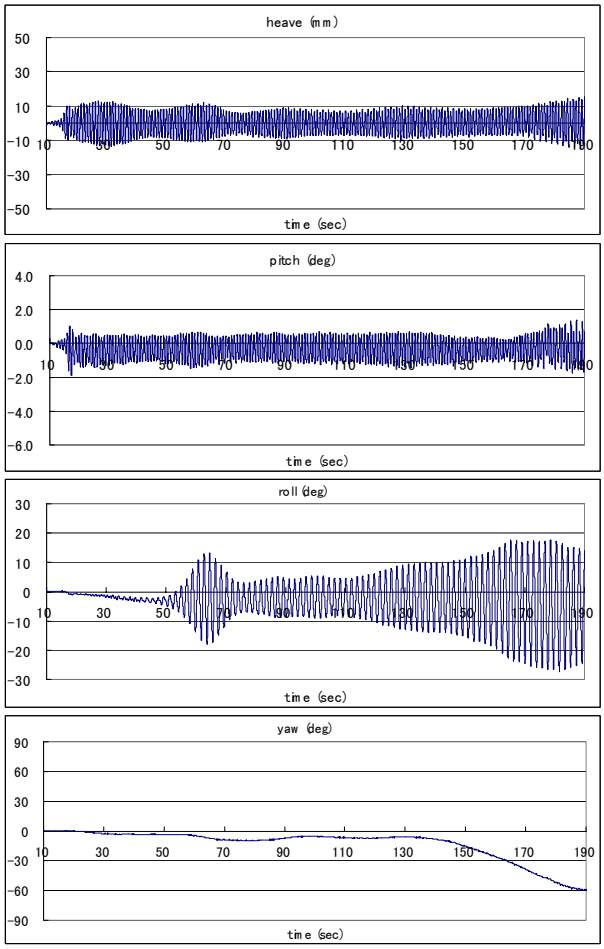

Figure 9 Time histories of motions of the ship with short (front) bilge keels released from following wave condition at T_w=0.95sec and H_w= 0.08m.

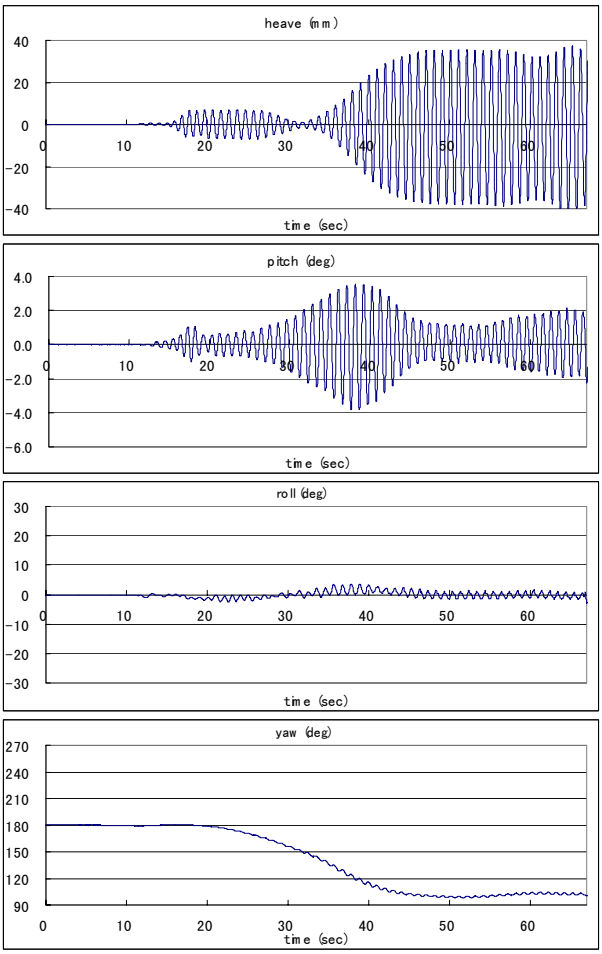

Figure 10 Time histories of motions of the ship with long (aft) bilge keels released from head wave condition at T_w= 0.95sec and H_w= 0.08m.

To search the possibility of occurrence of parametric rolling of the ship with bilge keels in head waves, measurements of ship motions of the model with full bilge keels in fixed yaw condition are carried out in regular head waves with 0.08m of wave height and various wave periods. The results are shown in Figure 12. The results suggest that parametric rolling with about 10 degree can occur for the ship with full bilge keels in head waves at 1.2 second of wave period, which is longer by 26% than that when parametric rolling in beam seas occurs. In Figure 13, the time histories of motions of the case that the maximum parametric rolling occurs are shown. It should be noted it takes long time to develop parametric rolling. In Figure 14, the effect of heading angle on parametric rolling of the ship with full bilge keels in head waves is shown in a polar diagram. We can see that in heading angles of ±20 degrees in head and following waves parametric rolling occurs even if size of bilge keels is enough to erase it in beam seas.

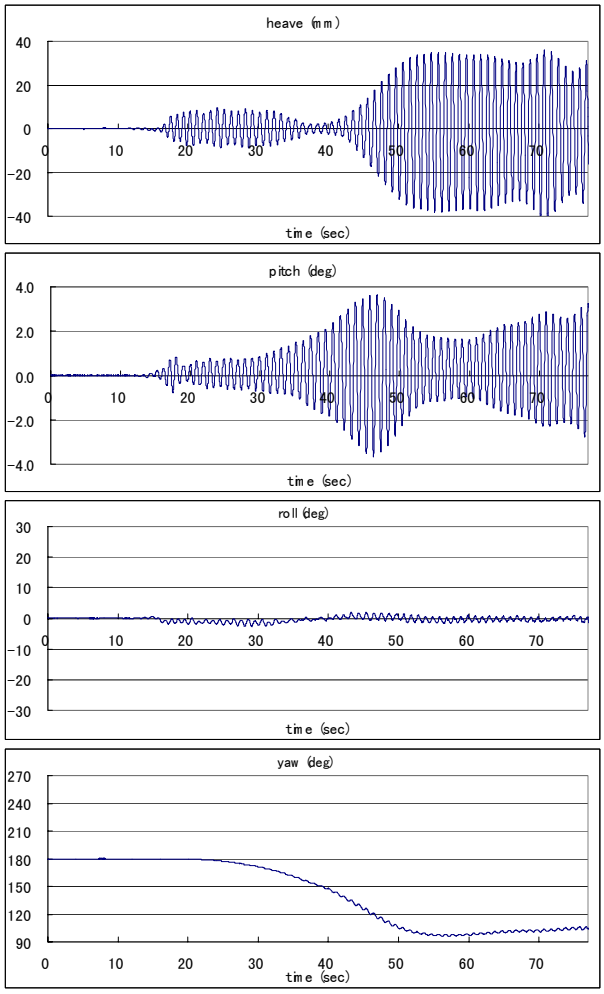

Figure 11 Time histories of motions of the ship with full (front and aft) bilge keels released from head wave condition at T_w=0.95sec and H_w= 0.08m.

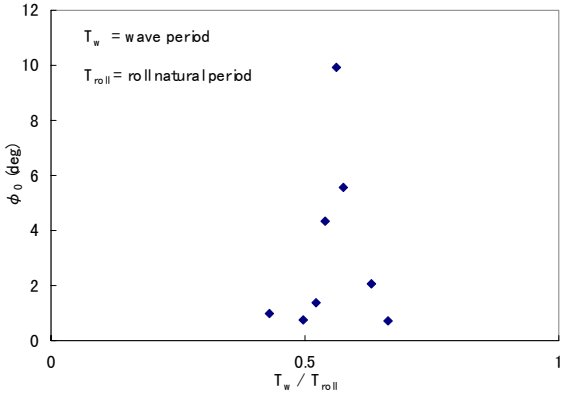

Figure 12 Parametric rolling of the ship with full bilge keels in regular head waves with T_w= 1.2sec and H_w= 0.08m.

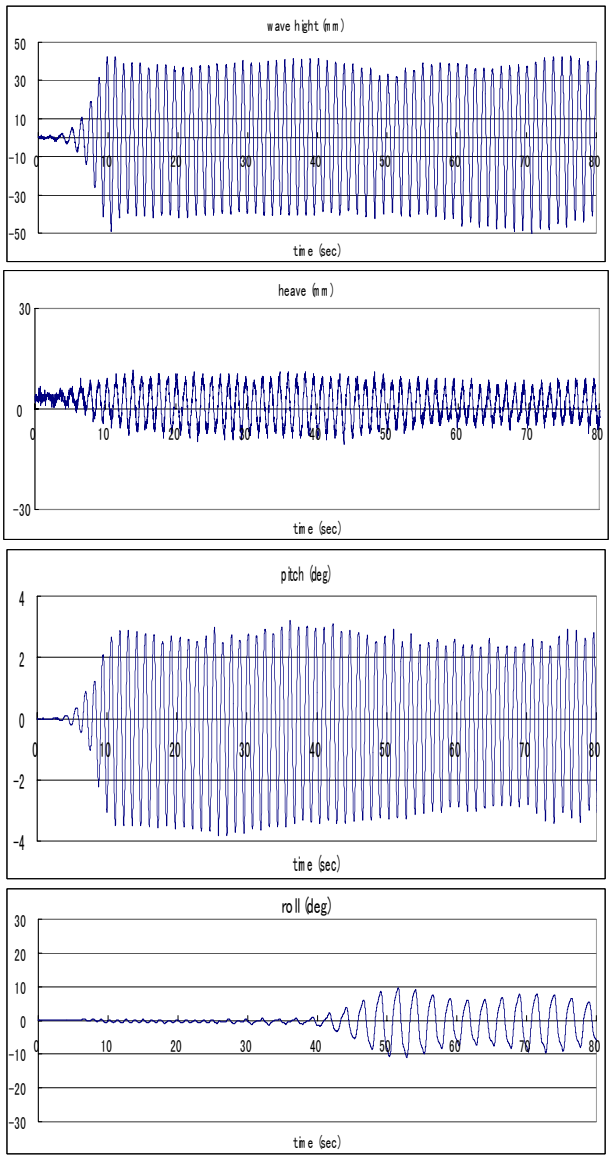

Figure 13 Time histories of motions of the ship with full bilge keels released from head wave condition in regular waves with T_w= 1.2sec and H_w= 0.08m.

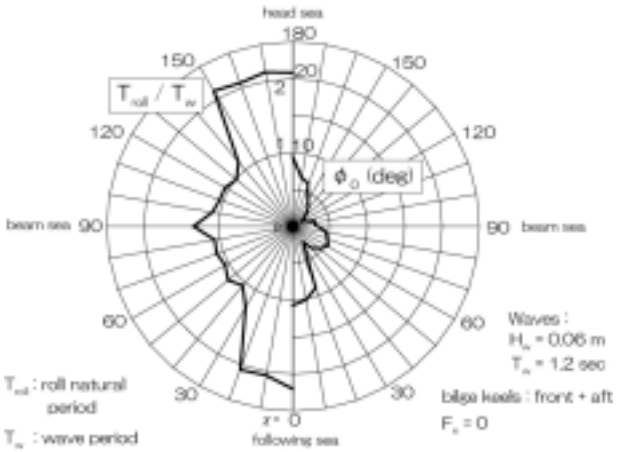

Figure 14 Effect of wave direction on amplitudes of rolling and its period of the ship with full bilge keels in regular waves.

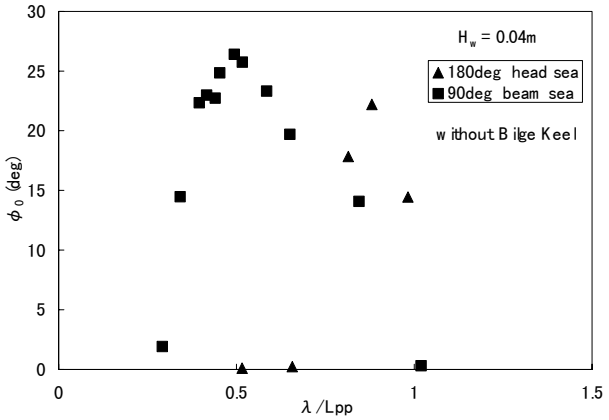

Figure 15 Difference of wave periods for which parametric rolling appears in beam and head waves.

In Figure 15, difference of wave periods for which parametric rolling appears in beam and head waves. The ship has no bilge keels and wave height is 0.04m. The results suggest that parametric rolling appears in different wave period in beam and head waves. This may be because of differences of drift speed and amplitude of stability variation in beam and head waves.

4. CONCLUSIONS

Following the previous paper of the authors in which large parametric rolling in beam seas is confirmed for a large passenger ship with a flat and shallow stern-bottom and large flare in bow in no bilge keel condition, parametric rolling in all heading angles of the same ship is experimentally investigated. Following conclusions are obtained.

When the ship has no bilge keels, parametric rolling occurs in wide heading angles including head and following seas as well as beam seas. Large variation of GZ value in waves due to a flat and shallow stern-bottom and large flare in bow induces the parametric rolling.

The effect of bilge keels on occurrence of large parametric rolling is significant. Large bilge keels can completely erase parametric rolling of the large passenger ship in dead ship condition in any heading angles of waves except head and following waves.

Parametric rolling of the ship in head seas can occur even if large bilge keels enough to erase it in beam seas are attached.

Wave periods when parametric rolling occurs in beam and head waves are different.

5. ACKNOWLEDGEMENT

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6. REFERENCES

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