An Experimental Investigation on Reduction of List Angle of a Semi-submersible Platform in Head Sea

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Abstract: In this study, an experimental investigation has been made to investigate reduction of second-order roll motion of a semi-submersible platform in head sea condition by adding hull damping. The second-order heave drift force and roll drift moment are known as main triggers inducing the list angle (Hong et al., 2010). Hong et al. (2013) showed the possibility of reduction of list angle by changing pontoon shape and adding damping device on the hull by numerical calculations. One of their findings was that the reduction of the list angle due to increasing pontoon surface damping is significant. A series of model tests with a 1:50 scaled model of semi-submersible were carried out at the wave basin of KRISO. It was experimentally found that adding damping on hull surface is effective for suppression of list angle.

Key words: List angle, semi-submersible, model test, nonlinear roll, reduction of list angle

1. Introduction

As oil and gas exploration region has been moving to deeper and deeper water regions, the use of semi-submersible platforms is expected to increase both for drilling and production. Two new concepts of semi-submersibles can be found, the one with deeper draft and non-uniform pontoon for deep water production platform and the other one with shallow draft for deep water drilling rig.

The deep water semi-submersible with increased draft and large damping plate was devised to use dry tree. The shallow draft semi-submersible was designed for deep water drilling in relatively mild sea states. For shallow draft semi-submersible platforms, so called list angle has been reported by Voogt et al. (2002, 2007). The list angle is defined as the steady roll angle under head sea condition.

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Their model experiments revealed that the list angle occurs only for specific wave periods and the existence of current magnifies the list angle.

Hong et al. (2010) showed that the second-order heave drift force and roll drift moment are main triggers inducing the list angle. Hong et al. (2013) showed that the reduction of the list angle can be possible by changing pontoon shape and adding damping device on the hull. But their conclusions were drawn from numerical results only. One of their findings was that the reduction of the list angle by increasing pontoon surface damping is significant. This is an important design point of view since adding hull damping is relatively an easy job compared with changing hull design.

In this study an experimental investigation has been made to investigate reduction of second-order roll motion of a semi-submersible platform in head sea condition. A series of model tests with a 1:50 scaled model of semi-submersible were carried out at the KRISO Ocean Engineering Basin. The effect of adding hull surface damping on the list angle was investigated by changing hull surface roughness. The effect of plate barriers equipped to the pontoon top on the list angle was also discussed in view of suppression of trapped waves over the pontoons.

2. Model Tests

2.1 Test Set-up

The model test was carried out for a 1/50 scaled semi-submersible drilling rig with four columns and twin pontoons. Fig. 1 shows the semi-submersible model. The model test was conducted under the condition of the survival draft.

Fig. 1 Photo of Semi-submersible Model

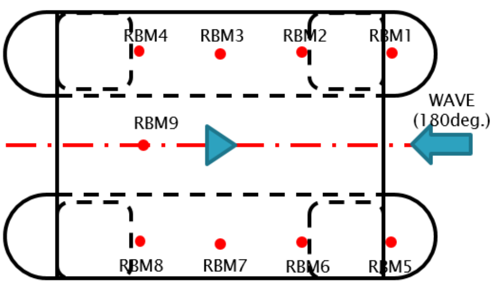


Fig. 2 Position of wave height meters (RBM)

6-DOF motions were measured with a non-contacting type motion sensor (RODYM), wave run-ups were measured for locations near front and back of columns. Fig. 2 shows the positions of wave probe (RBM). The test model was positioned with a 4-point soft spring mooring. The water depth was set to be 3.2m. Fig. 3 is a schematic view of the model setup and the model scene in the Ocean Engineering Basin is shown in Fig. 4.

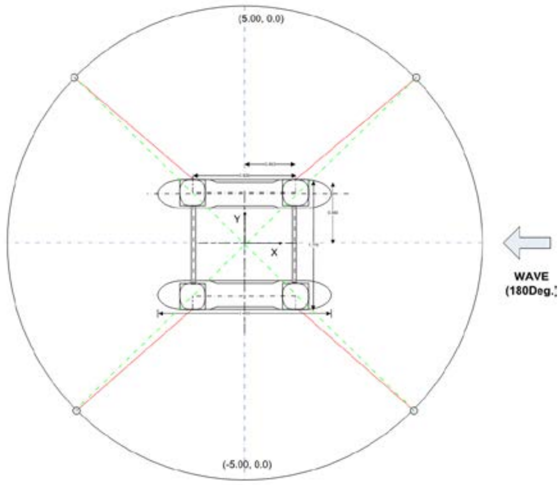


Fig. 3 Schematic View of the model setup

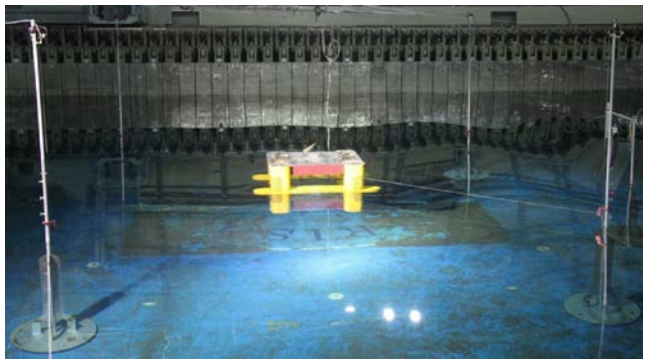


Fig. 4 Photo of Semi-submersible model setup

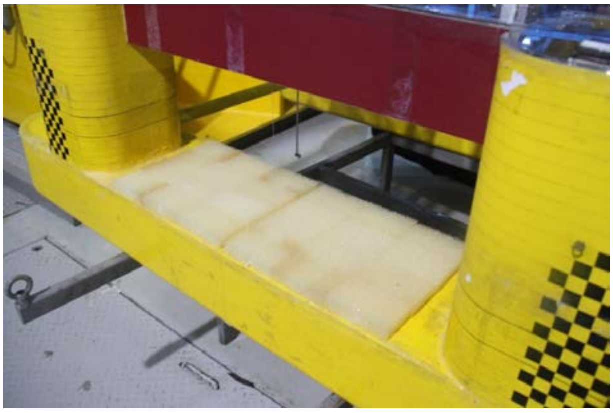
Table 1 Conditions of Experiment

Item	*Bare hull*	*w/* plates	*w/* damper
Wave height	2m, 4m, 6m	4m	4m
Wave period	6.5, 7.0, ~, 17.0, 19.0(s)	8.0, 8.5, ~, 11.0, 12.0(8)	8.0, 8.5, ~, 11.0, 12.0(8)
Draft	Survival (14.5m)	Survival (14.5m)	Survival (14.5m)

2.2 Test Conditions

The model test was conducted for three hull conditions, bare hull, pontoon with vertical barriers (plates) and pontoon with viscous damping device (sponge layer). The details are summarized in Table 1. For bare hull condition wave period ranges from 6.5 seconds to 19 seconds with 1.0 second interval. Wave heights were 2m, 4m, and 6m for each wave condition. For the hull with appendages, wave period ranges from 8.0 seconds to 12 seconds with focus on the occurrence of list angle. Fig. 5 presents the models with appendage (vertical plate) and damping layer, respectively.

(a) Vertical plated hull model



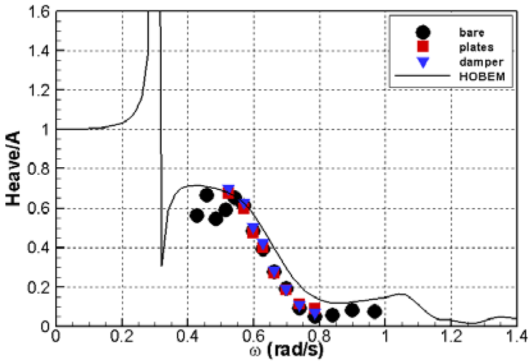
(b) Sponge layered hull model

Fig. 5 The model hull with appendages and damping layer

3. Results and Discussions

3.1 Motion Response

Heave and pitch responses in regular waves are shown in Fig. 6 for three hull shapes; bare hull, pontoon with vertical plates and hull with sponge layer on the upper surface. No noticeable response change is observed for change of hull conditions. Numerical results by using HOBEM (Higher Order Boundary Element Method) show generally good agreement with experimental values. Slight discrepancy around wave frequency 0.4 ~ 0.6 rad/s, which can be explained by shallow draft effects where nonlinear effect is not negligible.



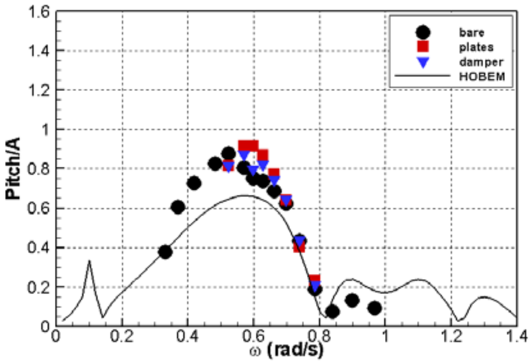
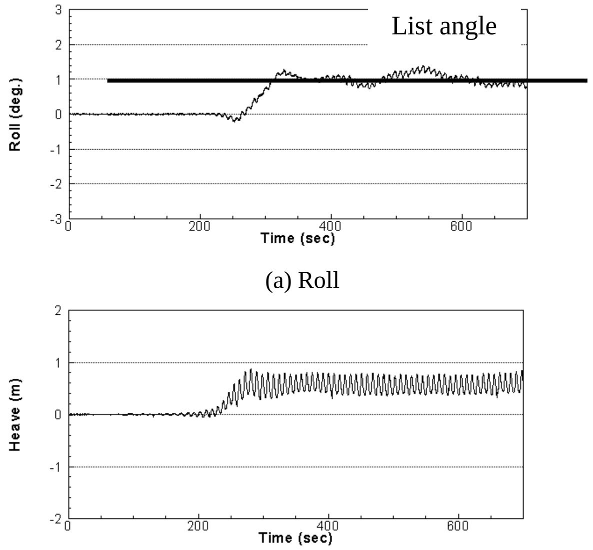


Fig. 6 Comparison of heave and pitch responses in regular waves for three hull shapes of semi-submersible

3.2 List Angle

The list angle of bare hull model was measured for wave heights of 2m, 4m and 6m, respectively. For the cases of hulls with vertical barriers and sponge layer on the pontoon top, wave height of 4m was applied. Two typical time histories of roll and heave motions are shown in Figs. 7 and 8. The case for wave height of 4m and period of 8.5s is shown in 7. It can be clearly seen that heave motion is small but mean heave motion is significant, which implies that upward heave drift force is one of important parameters of list angle. The measured list angle is about 1.0°. The other case for wave height of 4m and period of 11s is shown in Fig. 8, in which large heave motion but smaller mean value is observed. The measured list angle is about 1.8°. The survival draft is 14.5m while pontoon height is 9.6m, so the effective draft from the top of pontoon is just 4.9m which is very shallow considering wave length and wave height. Two results show that the magnitude of mean heave and amplitude of heave motion are both important in occurrence of list angle.



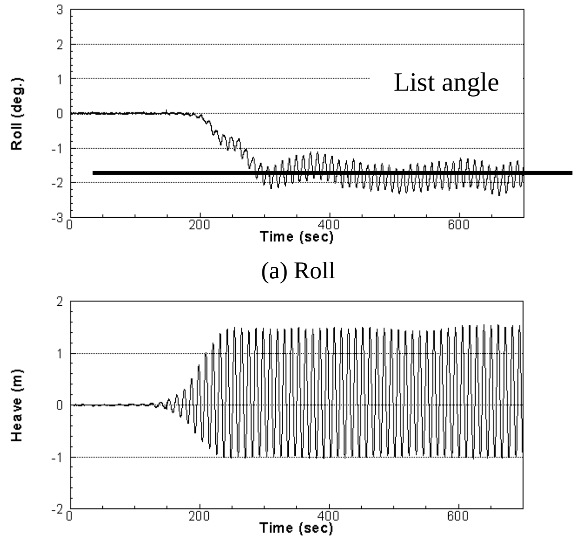
(a) Roll

(b) Heave

Fig. 8 Time histories of wave height 4m, wave period 8.5s

Fig. 10 summarizes the list angle of bare hull case for wave heights of 2, 4 and 6m. It can be seen that list angle occurrence is different for wave heights. For wave height of 2m, the list angle is noticeable for relatively high wave frequency, around 0.7~0.8 rad/s. For wave height of 4m, noticeable list angle occurs at wide wave frequency range 0.55 ~ 0.8 rad/s which corresponds to wave periods of 8.0 ~ 11seconds where upward heave drift force is dominant. It is interesting to observe list angle is not noticeable for wave height of 6m in which wave breaking was observed in the model test presumably due to shallow draft over the pontoon top.

Fig. 11 shows measured and predicted heave drift forces for the same condition as Fig. 10. The calculated value was obtained by using HOBEM, initial heeling angle 3 degrees was assumed (Hong et al., 2013). The measured value shows qualitatively and quantitatively similar trend with the calculations but the measured value shows a little bit broader distribution. This means that viscous effect should be considered in the calculation for more detailed analysis.



(a) Roll

(b) Heave

Fig. 9 Time histories of wave height 4m, wave period 11.0s

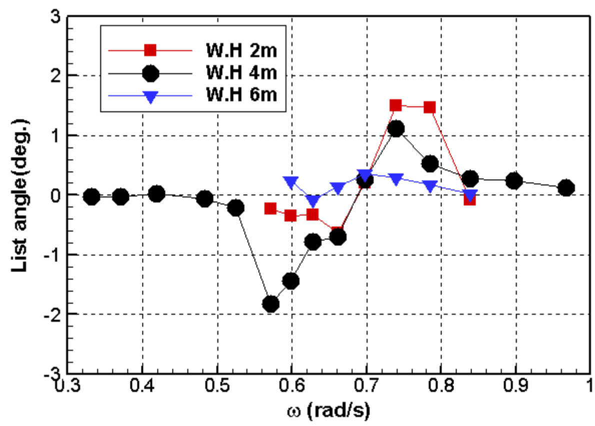


Fig. 10 List angle of bare hull, wave height 2, 4, 6m

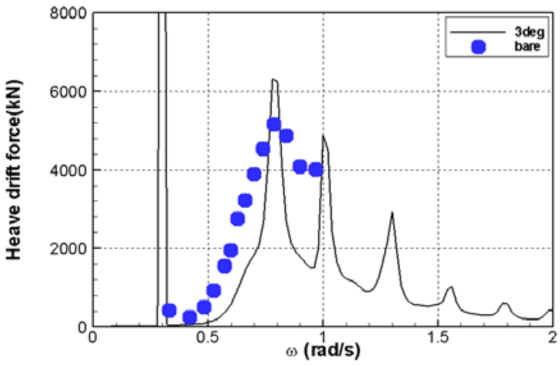


Fig. 11 Comparison of measured and calculated heave drift forces

3.3 Effect of Appendages

Two appendages were equipped as shown in Fig. 5, the vertical plate and sponge layer were devised to dissipate trapped wave energy between main columns. As shown in Fig. 12, two different types of appendages show noticeable effect on suppression of list angles. The sponge layer damping device show list angle suppression effect over wide range of wave frequencies while the vertical damping plate show the effect for specific wave frequency. This result implies that the surface damping device is more efficient for suppressing list angle in practice considering application of this kind of damping device.

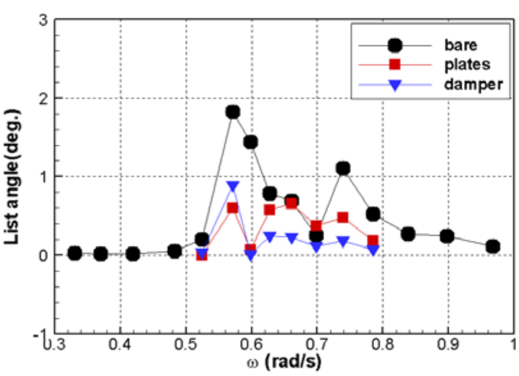
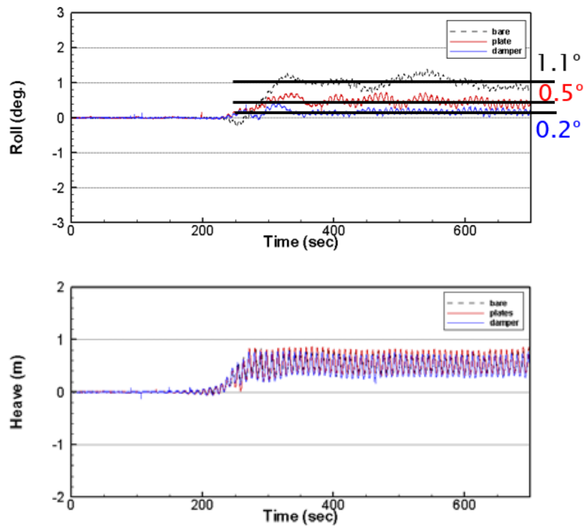
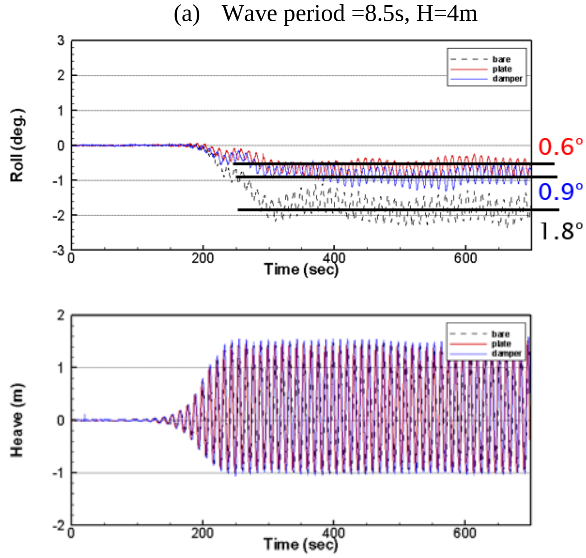


Fig. 12 Comparison of measured list angle for three different pontoon appendages

Fig. 13 shows comparison of time histories of roll and heave motions for two typical list angle occurrences. In the figure, reduction of list angle by adding damping such as vertical plates and sponge layer is significant. But it is interesting to observe that heave motion is not sensitive to adding appendages. This explains that adding damping is only effective to suppressing initial heel, not mean heave motion. This is quite reasonable because the damping does not contributes to mean value.



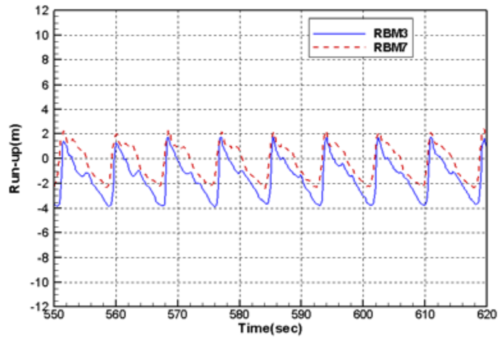
(a) Wave period =8.5s, H=4m



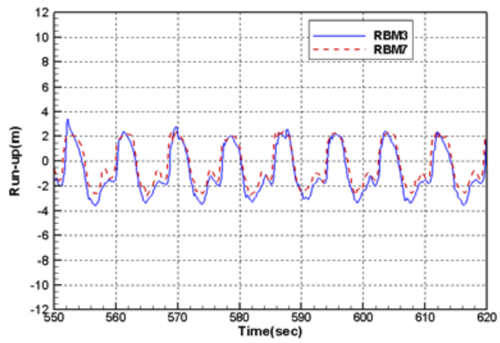
(b) Wave period =11s, H=4m

Fig. 13 Time history of roll in head sea for three different pontoon appendages

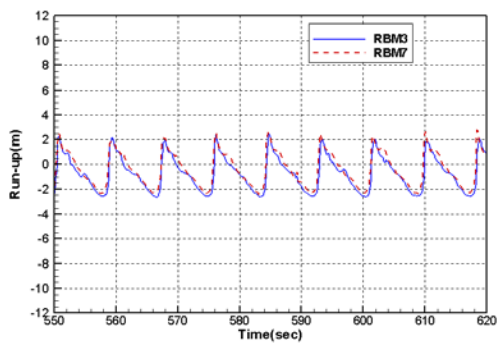
Figs. 14 and 15 compare waves measured at mid of pontoons, RBM 3 and 7 locations for wave periods of 8.5 and 11 seconds, respectively. Appendages change the patterns of trapped waves significantly. Uneven bare hull trapped waves become symmetric wave patterns to center plane by virtue of appendages. The vertical plates disturbed trapped waves more than sponge layer damper.



(a)Bare hull

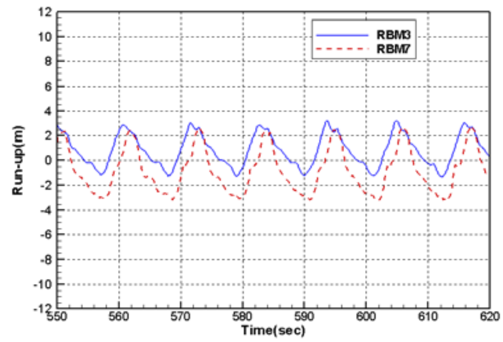


(b)Vertical plate

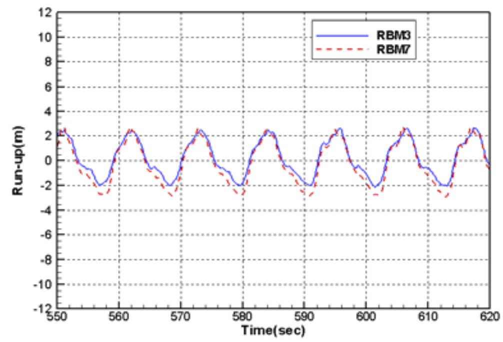


(c)Sponge damper

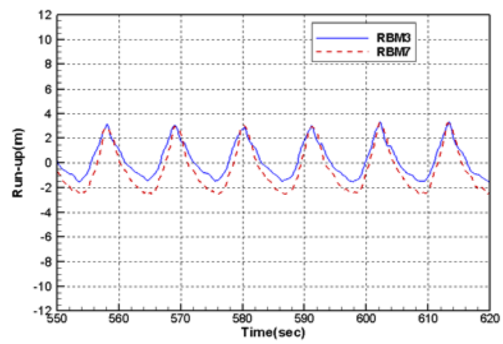
Fig. 14 Comparison of trapped wave at mid of pontoons for three different pontoon appendages (8.5 seconds)



(a)Bare hull



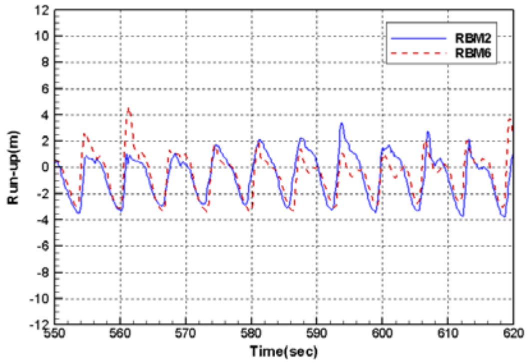
(b) Vertical plate



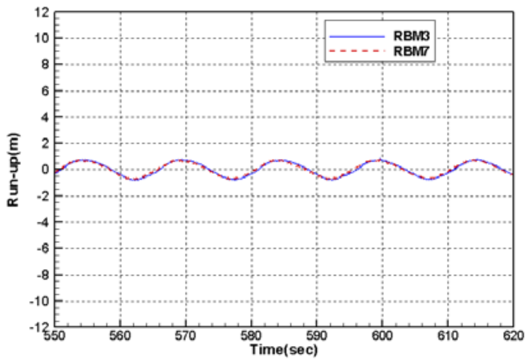
(c) Sponge damper

Fig. 15 Comparison of trapped wave at mid of pontoons for three different pontoon appendages (11 seconds)

In case of wave period of 11 seconds, similar behaviors can be observed. The area between starboard wave and portside wave can be interpreted as heeling moment. It can be seen that the area between both side waves is reduced by damping devices. Fig. 15 shows trapped wave patterns for outside of list angle occurrence wave periods, both side wave are symmetric to each other.



(a) Wave period = 6.5 seconds



(b) Wave period = 15 seconds

Fig. 15 Comparison of trapped wave at mid of pontoons for bare hull

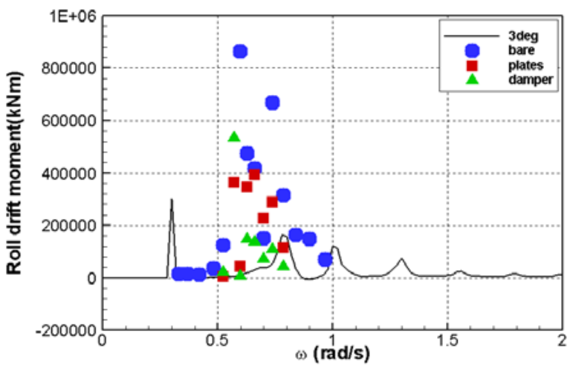


Fig. 16 Comparison of measured and calculated roll drift moments in head waves for different pontoon appendages

Fig. 16 compares roll drift moment for different hull appendages, solid line denotes calculated value by using HOBEM assuming 3 degrees initial heeling. Overall trends are similar between measured roll drift moments and calculated one but measured moment is much larger. Such discrepancy can be explained by the limited capability of potential flow model to this kind of problem.

6. Conclusions

The results of the model test for suppression of list angles of semi-submersible drilling rig were discussed. It was shown that the list angles noticeably reduced by adding appendages such as vertical barriers (plates) and viscous damping devices (sponge layer). The list angle suppressed significantly with sponge damper for wide range of wave periods, while vertical plates was only effective for specific waves, relatively longer waves. It was experimentally confirmed that adding damping on hull surface is effective for suppression of list angle, which was numerically predicted by Hong et al.(2013).

Adding damping contributes to make uneven trapped wave symmetric both side, which enhances stability to suppress initial heel due to heave motion. No noticeable changes wave observed for heave motion by adding damping to hull surface.

Acknowledgments

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