Numerical Simulation on the Slow-Drift Motion of a Semi-Submersible Platform Considering Mooring Effects

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1. INTRODUCTION

Regarding semi-submersible or tension leg platforms, it is known that second-order wave drift forces as well as viscous drag forces acting on the columns and pontoons have an important effect on low-frequency motion response of the platform. (Pijfer and Brink(1977), Li & Kareem (1992), Berthelsen et al.(2009)) In addition, mooring system for the position keeping is involved in the characteristics of the low-frequency horizontal motions and also causes significant mooring forces in the vertical motions when large horizontal excursion occurs. Thus, accurate estimation of the low-frequency motion of the semi-submersible platform requires a careful consideration of nonlinear and viscous fluid forces and mooring forces. In this study, time-domain numerical simulations were conducted to study the low-frequency drift motion of a semi-submersible platform. Three different mooring system were taken into account to examine the mooring effect. The numerical results were validated by comparing with the model test data and discussion is made on the effect of mooring on the low-frequency motion response of the semi-submersible platform

2. SIMULATION MODELS

In general, a semi-submersible platform exhibits not only wave-frequency motions but also low-frequency motions in high waves. In this case, the vessel dynamics is strongly coupled with the mooring dynamics which can affect the horizontal and vertical motions of the semi-submersible platform. Therefore, in order to simulate the motion of the semi-submersible platform accurately, the motion equations of the platform in Eq. (1) should consider both hydrodynamic and mooring forces.

$$([\boldsymbol{M}] + [\boldsymbol{a}(\infty)])\{\ddot{\boldsymbol{\xi}}\} + [\boldsymbol{C}]\{\xi\} = \{\boldsymbol{F}^{\boldsymbol{hydro}}\} + \{\boldsymbol{F}^{\boldsymbol{mooring}}\} \tag{1}$$

$$\{\boldsymbol{F}^{\boldsymbol{hydro}}\} = \{\boldsymbol{F}^{\boldsymbol{convol}}\} + \{\boldsymbol{F}^{\boldsymbol{exciting}}\} + \{\boldsymbol{F}^{\boldsymbol{drag}}\} + \{\boldsymbol{F}^{\boldsymbol{drift}}\} \tag{2}$$

where, $[\boldsymbol{M}]$ is the inertia matrix of the offshore structure, and $[\boldsymbol{a}(\infty)]$ is the infinite frequency added-mass matrix. $\{\xi\}$ is the displacement vector of 6 degrees of freedom of the offshore structure, and $\{\ddot{\boldsymbol{\xi}}\}$ is the acceleration vector. The hydrodynamic forces basically include the radiation forces $\{\boldsymbol{F}^{\boldsymbol{convol}}\}$ based on convolution integral and wave excitation forces $\{\boldsymbol{F}^{\boldsymbol{exciting}}\}$ obtained from the diffraction problem. $\{\boldsymbol{F}^{\boldsymbol{convol}}\}$ is a convolution forces to consider the added mass and wave damping acting on the float according to the motion of the float-body on free surface. In addition, fluid drag $\{\boldsymbol{F}^{\boldsymbol{drag}}\}$ and wave drift forces $\{\boldsymbol{F}^{\boldsymbol{drift}}\}$ should be taken into account to simulate the low-frequency slow-drift motions of the platform. In this study, the fluid drag was calculated based on the Morison equation. $\{\boldsymbol{F}^{\boldsymbol{mooring}}\}$ refers to the mooring force. In this study, the mooring force was calculated based on the static elastic catenary equation with the axial stiffness (EA_0) of the mooring line. The solution of the elastic catenary equation can be obtained by solving the nonlinear equations of Eqs. (3) and (4).

$$f_1(L_S, T_H) = 2hT_H + w(h^2 - L_S^2) + \left(\frac{wL_S^2}{2EA_0}\right)\left(\frac{w^2L_S^2}{2EA_0} - 2wh - 2T_H\right) = 0 \tag{3}$$

$$f_2(L_S, T_H) = L_s - \frac{T_H}{w} sinh\left[\frac{w\{X_T - (L_T - L_S)\}}{T_H} - \frac{wL_T}{EA_0}\right] = 0 \tag{4}$$

where, T_H and L_S are the horizontal force and suspended length of the mooring line, respectively. h is the water depth and w is the weight per unit length of the mooring line. L_T and X_T are the total length and excursion of the mooring line.

In this study, K-SEMI (KRISO SEMI-submersible platform) was considered as a target model for the present numerical simulations. Fig. 1 shows the snapshots from the model test of the K-SEMI under survival wave condition. Fig. 2 shows three numerical simulation results depending on different numerical modellings. When comparing Fig. 2(a) and (b), it can be clearly observed that the low-frequency motion significantly increased both in motion time series and its spectrum when the fluid drag force was considered. However, the numerical simulations with viscous drag only still underestimated the low-frequency motions compared to the experimental results. When the viscous drag and wave drift forces were considered at the same time, the low-frequency motion response of the simulations became closer to the model test results as shown in the Fig. 2(c). This confirmed that not only the viscous drag forces but also wave drift forces are important for the accurate prediction of the slow-drift motion of the semi-submersible platform.

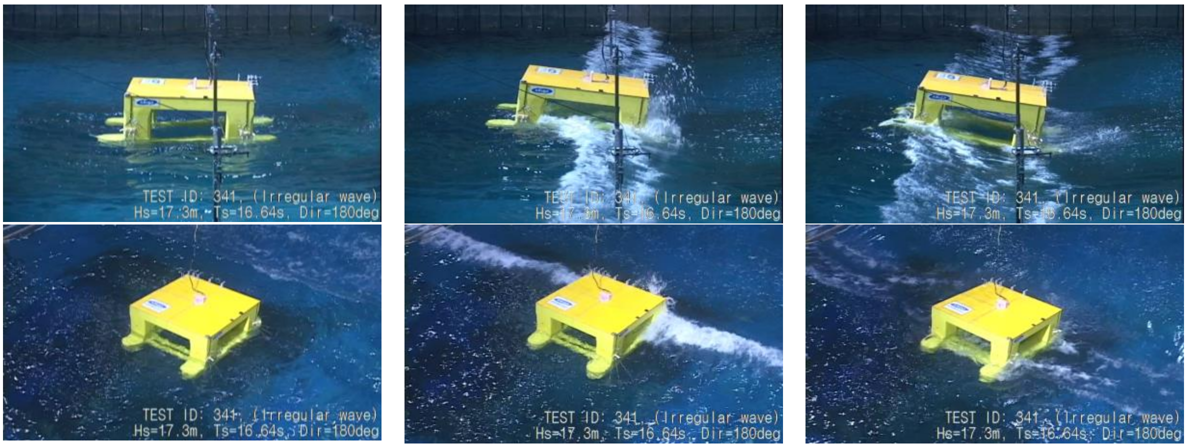
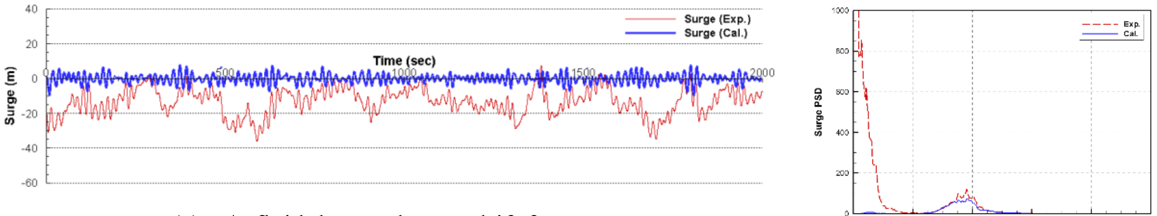
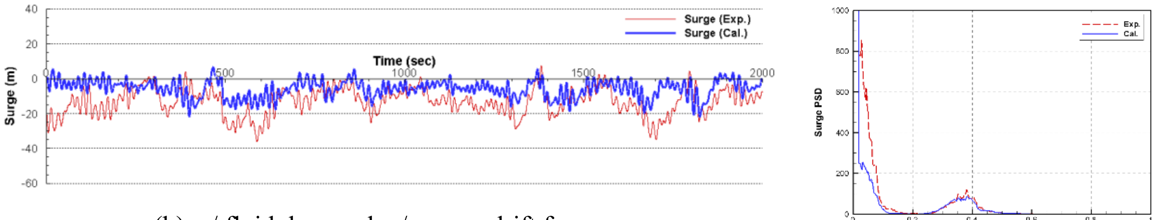


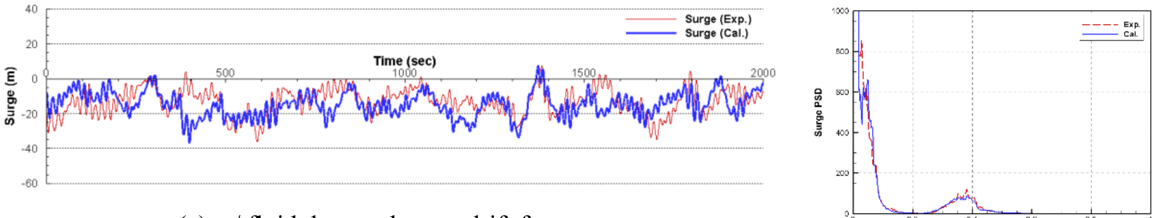
Fig. 1 Snapshots from model test of K-SEMI



(a) w/o fluid drag and wave drift forces



(b) w/ fluid drag and w/o wave drift forces

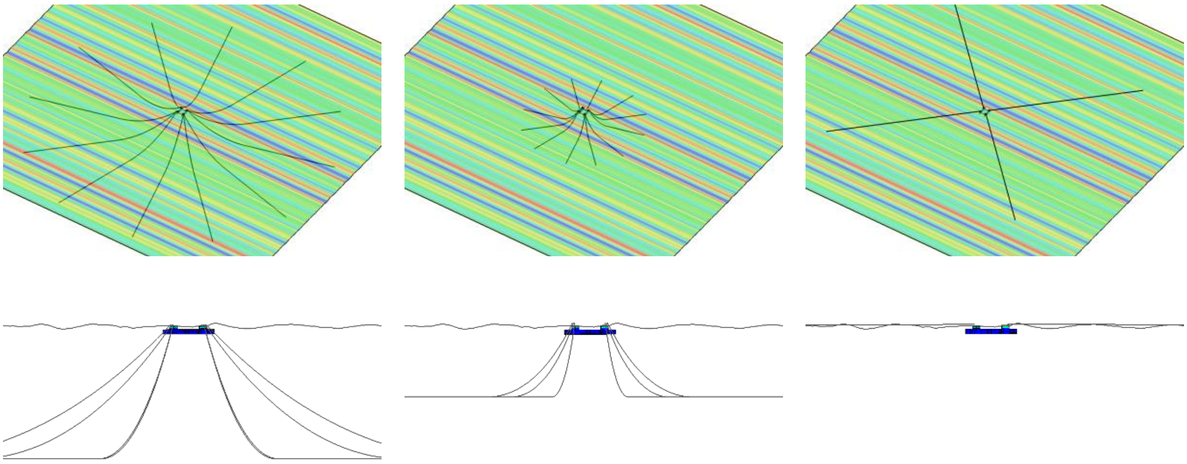


(c) w/ fluid drag and wave drift forces

Fig. 2 Motion time series and its spectra from numerical simulation (Hs=17.3m, Tp=16.64 s)

3. SIMULATION RESULTS

A series of numerical simulation studies were conducted to examine the effect of mooring on the low-frequency drift motion of the semi-submersible platform. As shown in Fig. 3, three different mooring system were taken into account. Here, Fig. 3(a) is the original catenary mooring which is designed at the water depth of 300 m. Fig. 3(b) is the truncated catenary mooring at the water depth of 160 m which was used in the model test with the scale ratio of 1/50. Lastly, Fig. 3(c) is the soft spring mooring which is frequently used for the conventional model test. In principle, if the horizontal restoring forces are considered only, various different models are possible with regard to the truncated mooring. Fig. 4 shows three possible truncation moorings with different line weights. As shown in the left graph, the optimal axial stiffness may be selected to minimize the error of the horizontal restoring forces. However, as shown in the middle and right graphs of Fig.4, the vertical mooring forces may be quite different depending on the weights of the truncated moorings although the horizontal mooring forces are within acceptable accuracy ranges. This obviously imply that the vertical motion characteristics of the semi-submersible platform can be affected by the truncated mooring modellings.



(a) Original catenary mooring (b) Truncated catenary mooring (c) Soft spring mooring

Fig. 3 Configurations of three mooring system

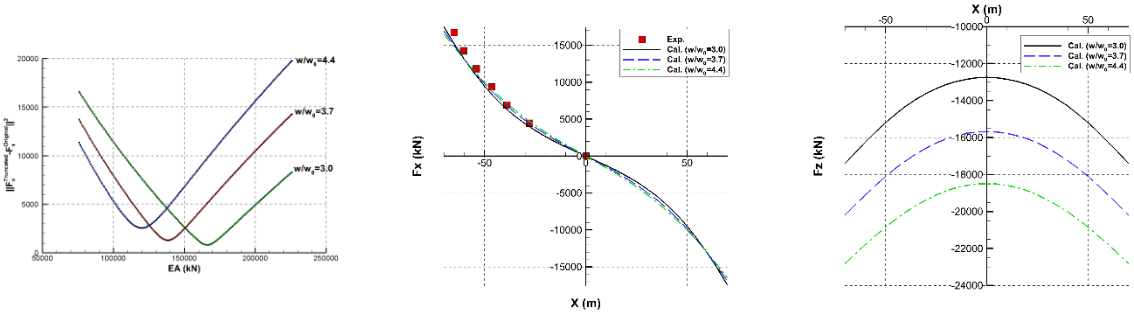


Fig. 4 Error of truncation modeling (left), horizontal & vertical force comparisons of the truncated mooring (middle & right)

Fig. 5 compares the motion time series and its response spectrum by applying three different moorings. For comparison, the model test results with a truncated mooring are plotted together. Regarding the surge motion, when the spring mooring was applied, the low-frequency slow drift motion was slightly overestimated rather than those of the catenary moorings. This is because the horizontal restoring force increases nonlinearly with the surge excursion under the catenary mooring condition, whereas it changes linearly in the spring mooring. In the case of pitch, the low-frequency motion response increased significantly only for the catenary moorings, not spring mooring. In particular, it can be observed that the numerical simulation with the truncated mooring was the closest to the model test results. These can be understood that the vertical mooring forces of the catenary moorings mainly cause the low-frequency pitch motions while the spring mooring exerts the horizontal mooring forces only. This indicates that when applying the truncated mooring system, it is important to match both horizontal and vertical mooring forces to predict the low-frequency motion responses of the semi-submersible platform.

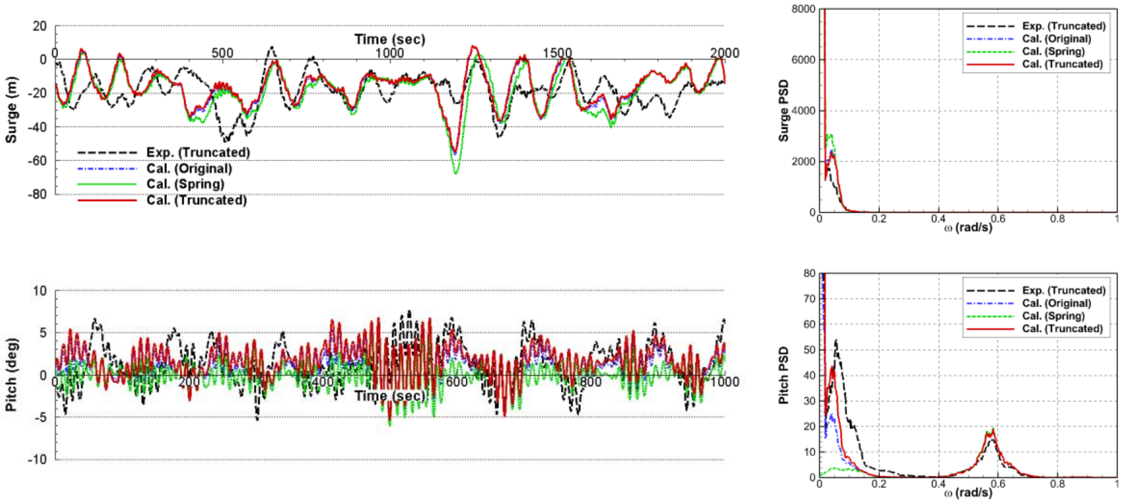


Fig. 5 Motion time series and its spectra with three different moorings (Hs=10.0 m, Tp=10.64 s)

4. CONCLUSION

In this study, the slow-drift motion of a semi-submersible platform was numerically investigated. Time-domain simulations were carried out based on general floating-body dynamics. It is confirmed that not only the viscous drag forces but also wave drift forces are important for the accurate prediction of the slow-drift motion of the semi-submersible platform. In addition, the numerical results under three mooring conditions showed how significant the mooring system have an effect on the low-frequency pitch motions of the semi-submersible platform.

ACKNOWLEDGEMENT

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