

Effects of Sloshing on the Motion Response of LNG-FPSO in Waves

Bo-Woo Nam⁽¹⁾, Yonghwan Kim⁽²⁾

⁽¹⁾Maritime and Ocean Engineering Research Institute (MOERI), Daejeon, Korea, bwnam@moeri.re.kr

⁽²⁾Seoul National University, Seoul, Korea, yhwankim@snu.ac.kr

Introduction

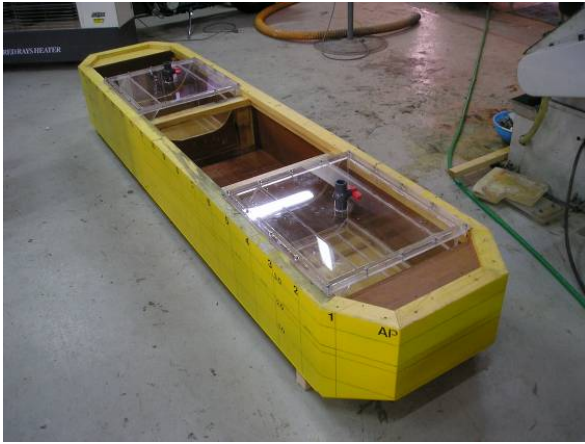
This study considers the motion responses of a LNG-FPSO in waves, coupled with sloshing in cargo. When a floating body with liquid cargo is under excitation in ocean waves, its ship motion is affected by both external wave excitation and internal sloshing-induced forces and moments. The seakeeping problem coupled with sloshing has been actively studied for the design of anti-rolling tank a few decades ago, and recently the demand of such coupled analysis becomes high particularly for the design of LNG carriers and LNG-production offshore structures, e.g. LNG-FPSO and LNG-FSRU.

Recent analyses on the couple problem can be categorized into two groups: frequency-domain (e.g. Malenica et al, 2003, Newman, 2005) and time-domain approaches (e.g. Kim, 2001, Rognibakke and Faltinsen, 2003). In particular, Kim (2001) introduced the analysis results of linear ship motion solved by LAMP and coupled full 3D sloshing flows. Moreover, the computational results using an impulsive-response-function(IRF) approach for ship motion panel method has been introduced last year in the Workshop (Nam, Kim, and Kim, 2006), showing faster computation than time-domain 3D panel method but without losing the accuracy of ship motion.

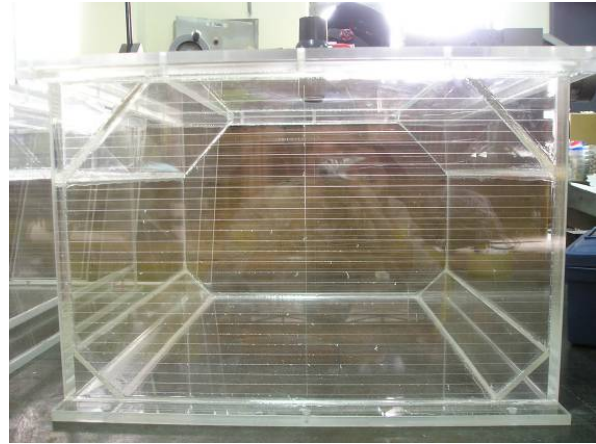
In the present study, a series of experiment have been carried out to validate the numerical scheme introduced last year. The experimental model is a LNG-FPSO with two tanks. The motion responses in regular waves have been measured in a range of frequency at different filling conditions and wave amplitudes. The measured motion RAOs are compared with computational results, and a fair agreement is found.

Experimental Study

Motion responses in regular waves have been observed for 1/100-scale model of a LNG-FPSO with two prismatic tanks. The dimensions of the LNG-FPSO are 285m(L)x63m(B)x13m(T), and the natural period of roll motion is 13 sec. Fig.1 shows the model ship and one tank installed into the body. The model ship was made of wood and the tanks were made using acrylic plate. Bilge keels were also attached at both sides of the model ship. The experiments have been carried out at 110-m towing tank of Seoul National University. Regular waves have been generated by a wave-maker with 20 flaps, and wave height was fixed to 0.025 m with an error tolerance of 0.005m. Wave height and 3-DOF motion (heave, pitch, roll) were measured by wave probe and motion sensors.



(a) Model ship



(b) Model tank

Fig.1 Model ship and tank

Numerical Methods

In the present computation, the impulse-response-function approach has been applied for ship motion. Adopting retardation function for radiation forces, the equation of motion takes the following form:

$$\sum_{j=1}^6 \left[(m_{ij} + a_{ij}(\infty)) \ddot{\xi}_j(t) + \int_0^t R_{ij}(t-\tau) \dot{\xi}_j(\tau) d\tau + c_{ij} \dot{\xi}_j(t) \right] = F_i^{ext}(t) + F_i^{slosh}(t) \quad (1)$$

where m_{ij} and c_{ij} represent the total ship mass including fluid mass in the tank, and linear hydrostatic coefficient. $a_{ij}(\infty)$ is the infinite-frequency added mass, and $R_{ij}(t)$ is the retardation function. $F_i^{ext}(t)$ is the wave excitation force acting externally on hull, while $F_i^{slosh}(t)$ is the sloshing-induced force acting internally on liquid cargo. The retardation function can be obtained using either added mass and damping coefficient, and the present study takes the latter. Including a correction term for truncation error, the retardation function can be written as follows:

$$R_{ij}(t) = \frac{2}{\pi} \int_0^{\Omega} b_{ij}(\omega) \cos(\omega t) d\omega + \varepsilon_{ij}(t) \quad (2)$$

where

$$\varepsilon_{ij}(t) \equiv \frac{2}{\pi} \int_{\Omega}^{\infty} b_{ij}(\omega) \cos(\omega t) d\omega \approx -\frac{2}{\pi} R'_{ij}(0) \frac{\cos(\Omega t) + \Omega t \operatorname{si}(\Omega t)}{\Omega} \quad (3)$$

Fully nonlinear sloshing-induced force and moment has been obtained by simulating actual fluid motions inside tanks. In this study, the numerical method introduced by Kim (2001, 2004) has been applied.

Results and Discussion

For validation purpose, the ship motions without coupling with sloshing (i.e. empty tanks) are predicted, and the results are compared with experimental measurement. Fig.2 plots the motion RAOs of heave at 180deg heading and roll at 90deg heading, showing fair agreement.

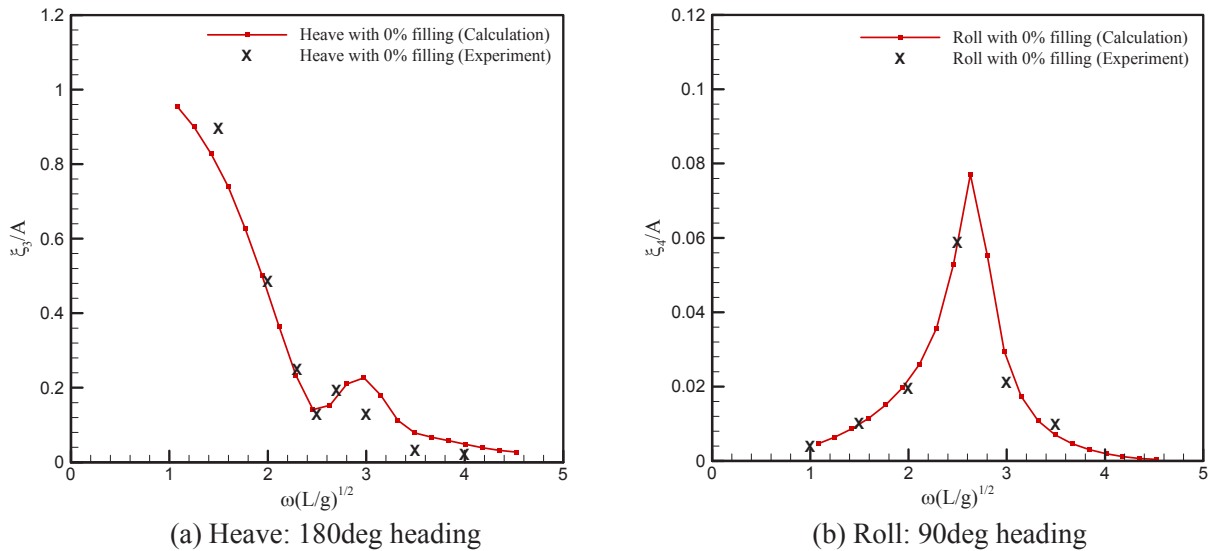


Fig.2 Comparison of motion RAOs at no filling condition

The present LNG-FPSO model has sloshing mode resonant with ship motion at low filling condition, particularly at high frequencies. Therefore, the experiment was focused on low filling conditions. Fig.3 shows the heave and roll RAOs at 180deg and 90deg headings at 30%-30% filling condition. Not much difference of the motion RAOs can be found in heave and pitch (no shown here), but the roll RAOs show significant differences. Particularly, computational results show an impressive agreement with the experimental data. This is a strong case to validate the present numerical method.

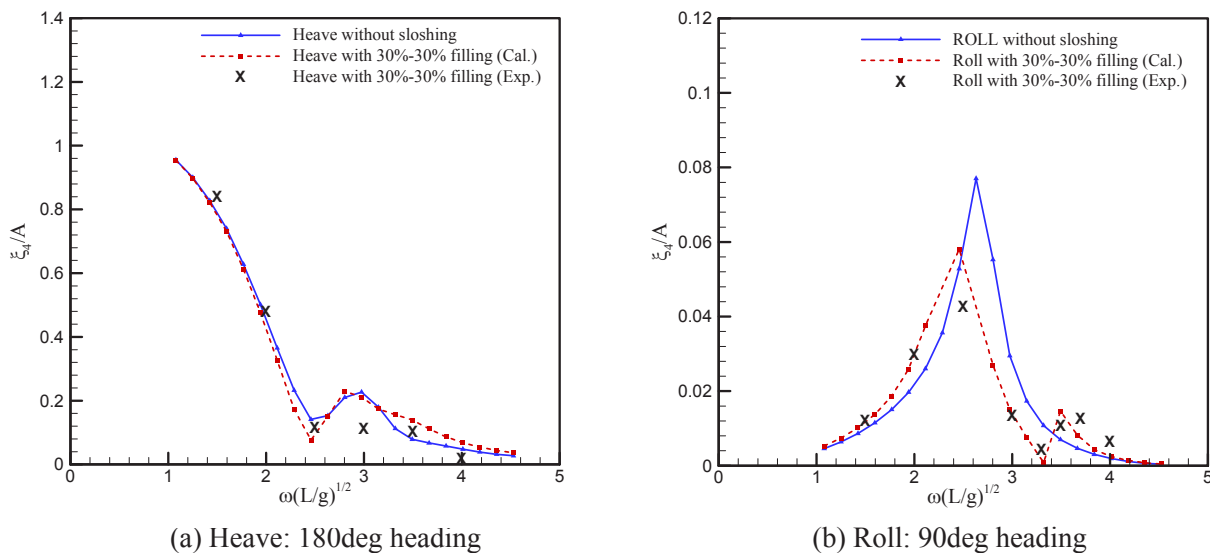


Fig.3 Comparison of motion RAOs at 30%-30% filling condition

In actual design problem of cargo structure, sloshing-induced impact loads are of great importance. Fig. 4 shows a comparison of time-histories at three locations on tank wall: bottom corner (001), knuckle point between bottom hopper and side wall, and knuckle point between top hopper and side wall. In this

specific case, the occurrence of large impact at upper knuckle point is obvious in the coupled case, showing clearly the importance of the coupled analysis. However, the coupling effects do not always result in the increase of sloshing-induced pressure. The increase or decrease of pressure is dependent on resonant condition.

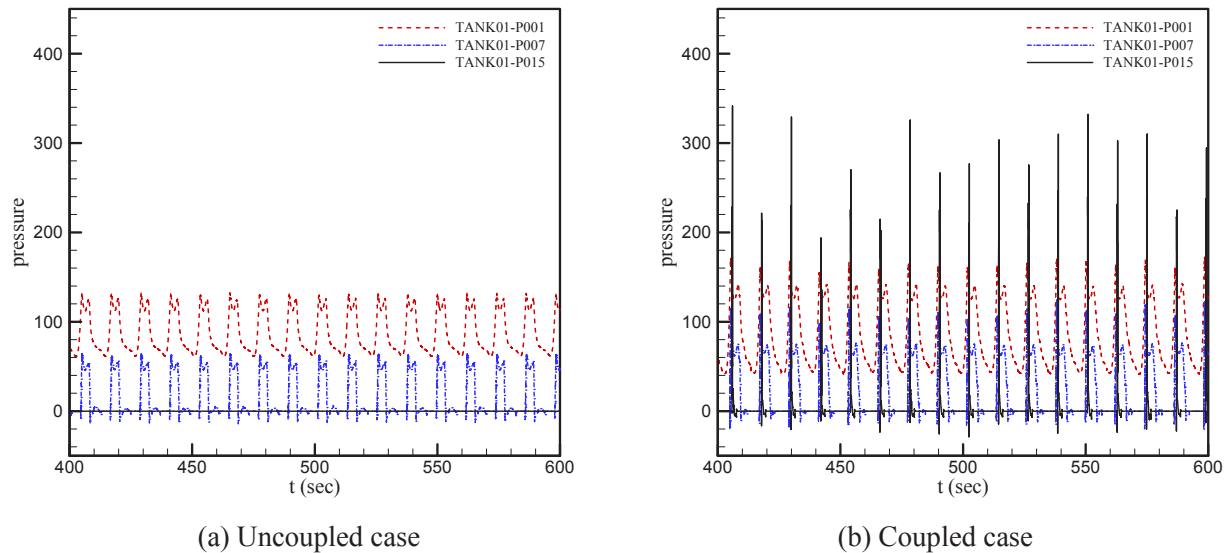


Fig.4 Comparison of pressure history on the tank walls with and without sloshing coupling: 90 degree heading, 30%-30% filling, $\omega(L/g)^{1/2} = 2.80$

References

- Kim, Y., "Numerical simulation of sloshing flows with impact load," Applied Ocean Research, 23, 2001.
- Kim, Y., Shin, Y.S., Lee, K.H., "Numerical study on slosh-induced impact pressures on three-dimensional prismatic tanks," Applied Ocean Research 26, 2004.
- Malenica, Š., Zalar, M. & Chen, X.B. "Dynamic coupling of seakeeping and sloshing," 13th ISOPE, Honolulu, USA, 2003.
- Nam, B.W., Kim, Y., Kim, D.W., "Nonlinear Effects of Sloshing Flows on Ship Motion," IWWF, Loughborough, UK, 2006.
- Newman, J.N., "Wave effects on vessels with internal tanks," 20th Workshop on Water Waves and Floating Bodies, Spitsbergen, Norway, 2005.
- Rognebakke, O.F., Faltinsen, O.M., "Coupling of sloshing and ship motions," Journal of Ship Research 47, 2003.