PS-9　SPH-Based Numerical Simulation of Sloshing Behavior for Moss type LNG Tank

構造安全評価系　＊馬　沖、安藤　孝弘、岡　正義

1. Introduction

With the increasing demand of LNG and growing LNG exportation from the United States, Australia and other countries, it is urgently necessary to improve the transportation efficiency especially for Japan, which has the largest demand for LNG in the world and consumes approximately one-third of total global LNG production. Pursuing new concept of LNG tank with higher storage efficiency and sufficient safety performance becomes more and more important.

To overcome the shortage of the lower storage efficiency of spherical shape MOSS tank, new shape tank consisting of spheroid and cylinder is proposed. To validate the feasibility of sloshing behavior for the new shape tank, large scale model experiments are carried out for both conventional spherical shape and new shape tank with regular and irregular tank motion. The difference of sloshing force between both tanks is clarified. Also the nonlinearity of sloshing force is checked based on the regular motion test with different motion amplitude.

In this research, corresponding to the performed large-scale model tests, the relevant 3D SPH simulation is conducted for both regular and irregular tank excitation. The Response-Amplitude-Operator (RAO) of sloshing force for regular tank excitation is compared among the model test results, Star-CCM+ results and SPH results. For irregular tank excitation, the swirling observed in the model test is successfully predicted by the SPH model.

2. Model Test

The scale model tests for both conventional spherical shape tank and new shape tank were carried out[1] in National Maritime Research Institute.

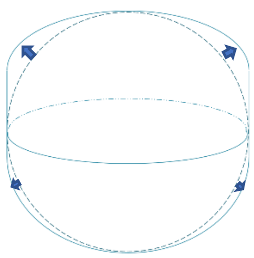


Fig. 1 Prototype of conventional spherical shape tank and new shape tank

Fig. 1 shows the prototype of conventional spherical shape tank and new shape tank. The diameter of both models is set as 1.2m. By reducing the curvature around both poles, the volume of the new shape tank is increased by 15% compared with the conventional spherical shape tank.

The filled liquid is selected as normal water with density 1000 kg/m^3 at atmospheric pressure.

Regular and irregular imposed motion tests are carry out for both tanks. For regular motion tests, the motion period and motion amplitude is set as 0.8~1.6s and 20~80mm. For irregular motion test, comparison results for the motion with significant motion amplitude 22mm and average motion period 1.14s is investigated in this research.

3. SPH Model

In this research, the open-source code DualSPHysics is used to simulate the SPH flow. DualSPHysics[2] is developed for large-scale SPH calculation by utilizing the parallel computation ability of both CPU and GPU.

The basic governing equation in SPH can be written as:

$$\frac{d\boldsymbol{v}}{dt} = -\frac{1}{\rho}\nabla P + \boldsymbol{g} \qquad \text{momentum equation} \qquad (1)$$

$$\frac{d\rho}{dt} = -\rho\nabla \cdot \boldsymbol{v} \qquad \text{continuity equation} \qquad (2)$$

$$\frac{d\boldsymbol{r}}{dt} = \boldsymbol{v} \qquad \text{trajectory equation} \qquad (3)$$

$$P = B[\left(\frac{\rho}{\rho_0}\right)^{\gamma} - 1] \qquad \text{Tait's equation} \qquad (4)$$

The spatial derivatives of particles in Eq. 1 and 2 can be solved by interpolation technique based on special kernel function as shown in Eq. 5 below:

$$A(\boldsymbol{r}) = \int A(\boldsymbol{r}')W(\boldsymbol{r} - \boldsymbol{r}', h)\, d\boldsymbol{r}' \qquad (5)$$

Table 1. Parameter of SPH model

Tank Model	spherical shape tank		new shape tank	
Particle Dimension	1cm	2cm	1cm	2cm
Particle Number	569232	86746	648980	92761

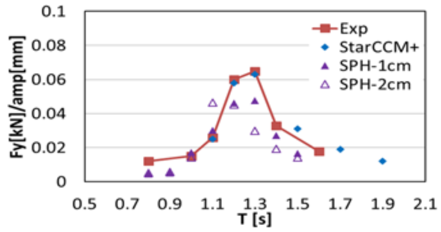
where, $\boldsymbol{r}$ is the spatial coordinates, h is the kernel smoothing length and W is the kernel function.

For SPH simulation, two models with different particle dimension, 1cm and 2cm, are established to confirm the dependency of SPH results on particle dimension (Table 1).

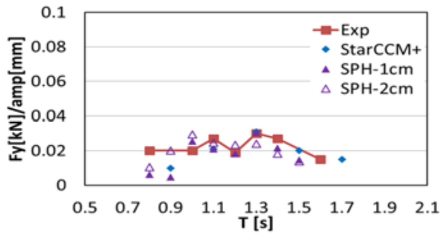
4. Results and Comparisons

Regular Motion Test

Comparisons among the model tests results, simulation results based on SPH and simulation results based on StarCCM+ are shown in Fig. 2 and 3 for Spherical Tank and New Tank relatively.

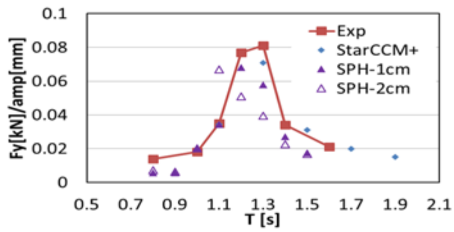


(a) Motion Amplitude 20mm

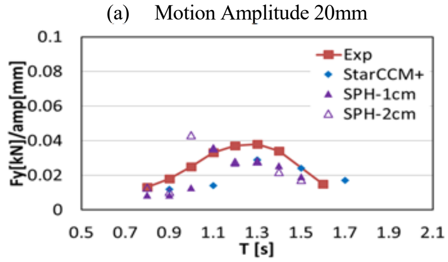


(b) Motion Amplitude 60mm

Fig. 2 Comparison of sloshing force in Y direction for Spherical Tank



(a) Motion Amplitude 20mm



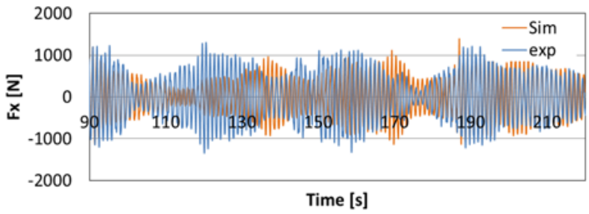
(b) Motion Amplitude 60mm

Fig. 3 Comparison of sloshing force in Y direction for New Tank

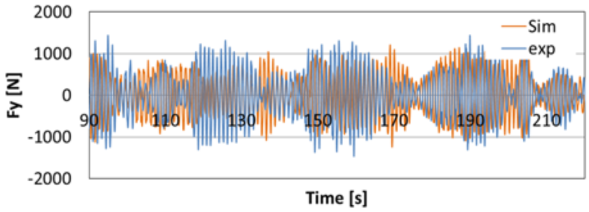
Nonlinear Sloshing force is confirmed by comparing the RAOs between different motion amplitude. The SPH model with 1cm particle shows a similar prediction capability comparing the StarCCM+.

Irregular Motion Test

As the swirling is observed during the irregular motion test, not only the sloshing force in Y direction but also the sloshing force in X direction are compared (Fig. 4 and 5).

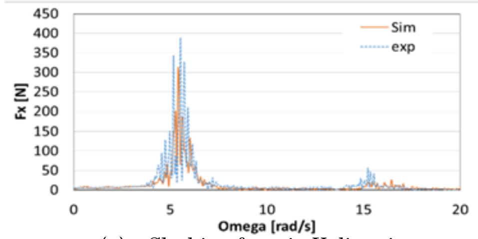


(a) Sloshing force in X direction

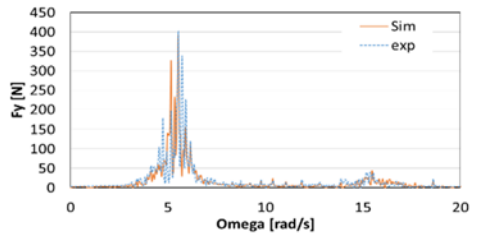


(b) Sloshing force in Y direction

Fig. 4 Comparison of sloshing force (Spherical shape tank, SPH-1cm, time domain)



(a) Sloshing force in X direction



(b) Sloshing force in Y direction

Fig. 5 Comparison of sloshing force (Spherical shape tank, SPH-1cm, frequency domain)

5. Conclusions

By checking the results of model test and numerical simulation, there is not significant difference of sloshing force observed for both conventional spherical shape tank and new shape tank. Nonlinearity of sloshing force is clearly confirmed by comparing the RAO results of regular motion test. The availability of SPH model is validated for the simulation of sloshing behavior under both regular and irregular motion.

Reference

1) Oka, M, Ando, T, Anai, Y, Tanaka, Y and Matsubara, N (2015) "A forced oscillation test of LNG tank model for safety evaluation," *The 15th Research Presentation Meeting in National Maritime Research Institute*.

2) Crespo, AJC et al. (2015). "DualSPHysics: Open-source parallel CFD solver based on Smoothed Particle Hydrodynamics (SPH) ," *Computer Physics Communication*, 187, 204-216.