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Investigation of natural frequency variation of partially filled rectangular container by external excitation

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1. Introduction

Linear sloshing frequencies of partially filled rectangular container are dominantly affected by ratio of free surface height to lateral length of a container. The fundamental sloshing frequency of a partially filled container is able to result in overflow phenomena than any other resonance sloshing frequencies. Although the ratio of free surface height to lateral length of a rectangular container are same, the fundamental frequency is varying with a lateral length of a rectangular container. The varying fundamental frequency of a rectangular container with regard to a lateral length should be considered before trying to do scale-down sloshing experiment.

Linearly scaled down experiment model can be considered properly from the structural point a view, but with regard to fluid sloshing phenomena in a rectangular container, external excitation condition should be carefully adjusted to demonstrate same sloshing phenomena of full-model.

In this study, at particular ratio of free surface height to lateral length of a rectangular container, variation of fundamental linear sloshing frequency casing overflow phenomena was investigated with variation of lateral length of rectangular container.

2. Methods and Results

Fundamental frequency of a partially filled liquid container is derived from linear potential flow theory and the ratio of free surface height to lateral length of a rectangular container is assumed to 1.173 in accordance with nuclear industry application of spent fuel storage rack. Numerical simulation was performed by OpenFOAM v5 (Open Source Field Operation and Manipulation) with interDyMFoam solver. Interface capturing method was applied with VOF(Volume of Fluid) method.

2.1 Theoretical background of fundamental sloshing frequency

Odd M. Faltinsen[2] derived linear sloshing frequency from fluid velocity potential at partially filled rectangular container with below coordinate system (Fig.1). Two dimensional linear sloshing frequency for rad/s is (1) and three dimensional linear sloshing frequency is (2).

$$\sigma_i = \sqrt{g\frac{\pi i}{l}\tanh\left(\frac{\pi i}{l}h\right)} \quad i = 1,2,\ldots \qquad (1)$$

$$\sigma_{i,j} = \sqrt{g\,k_{i,j}\tanh(k_{i,j}h)},$$

$$k_{i,j} = \pi\sqrt{(i/L_i)^2 + (j/L_j)^2}, \quad i + j \neq 0 \qquad (2)$$

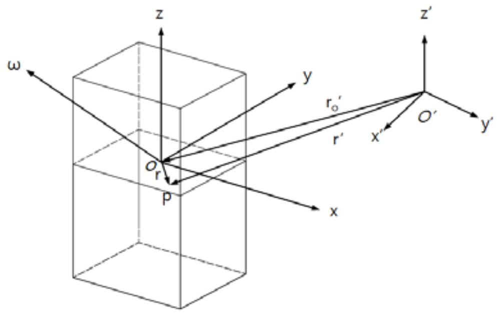

Fig. 1. Coordinate systems of a partially filled rectangular container.

In equations of linear sloshing frequency (1) and (2), h is free surface height and l is lateral length of a rectangular container. L_i and L_j are depth and width in three dimensional coordinate system. (2) is shown that linear sloshing frequency of three dimensional coordinate system is normalized orthogonal sloshing frequency of each lateral coordinates.

1st fundamental linear sloshing frequency of a two dimensional rectangular container is shown at Fig.2 that the variation rate in accordance with lateral length of a rectangular container decreases as the lateral length becomes longer.

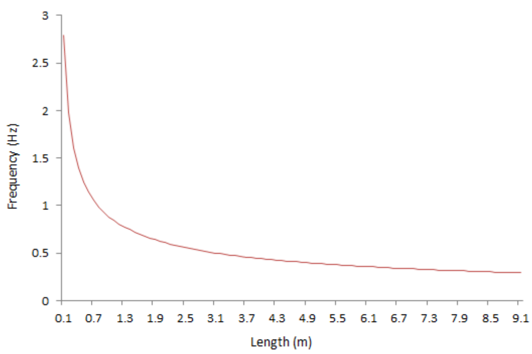

Fig. 2. 1st fundamental linear sloshing frequency (Hz) variation of a partially filled liquid 2D rectangular container in accordance with lateral length at h/l = 1.173.

In Fig.2, 1st fundamental linear sloshing frequency is varying from 0.31 at 8m of lateral length to 0.88 at 1m of lateral length. If we do experiment with 1/8 scaled down model, the effect of fundamental frequency variation should be considered and applied. Convective motion of upper part of fluid by sloshing in a container may cause such problems as overflow, slamming and damage of objects inside by 1st resonant external frequency. With same excitation frequency applied to full scale model, the external excitation at scaled down model may not cause slosh motion of fluid as full scale model. In equation (1), at same h/l ratio, squared scaled resonance frequencies are inversely proportional to ratio of full scale length to scaled length of a containers.

Therefore, it is concluded that adjust fundamental frequency at scaled down model may have same effect of full scale model.

2.2 Numerical simulation

With regard to scaled down effect, four scale-down model were investigated at adjusted 1st fundamental frequency by numerical simulation.

Lateral length of base model is 1.3m and ratio of scaled model to base model are 0.25, 0.5 and 2 respectively. 1st fundamental linear sloshing frequency of base model is 4.86 rad/s. Fig.3 shows results of sloshed free surfaces induced by adjusted frequencies.

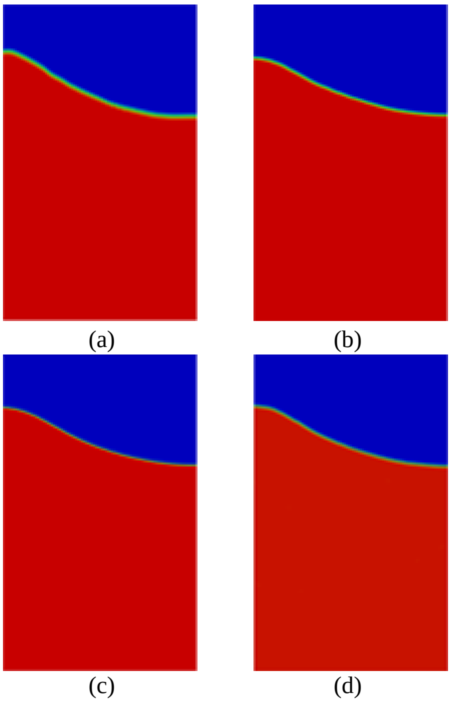

Fig. 3. Sloshed free surfaces of a partially filled rectangular container with adjusted 1st linear sloshing frequencies, (a) 1/4 scaled-down, (b) 1/2 scaled-down, (c) base, (d) 2 scaled-up.

3. Conclusions

With regard to sloshing phenomena, scale-down effect causes resonant sloshing frequency variation. From the equation (1), derived adjusted resonant frequencies (Fig.2) were applied to scaled models. Results of numerical simulation of scaled models show 1st linear sloshing mode shapes. From Fig.3, free surface shapes with adjusted resonant frequencies for scaled models show same result. Therefore, scaled down effect for doing sloshing experiment and adjusted external excitation need to be considered for reproducing same effect of full scale model result.

Acknowledgement

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REFERENCES

[1] ODD M. Faltinsen and Alexander N. Timokha, Sloshing, CAMBRIDGE., pp.122-131, 2009.