Enhancement of Uplift Displacement of the tank bottom plate Due to The Out-Of-Round Deformation of Cylindrical Shell

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1. Introduction

Uplift of unanchored tanks is inevitable when the tanks are subjected to strong earthquake motions. Many analytical and experimental studies have been made to date (e.g. [1-3]). However, a dynamical system that describes uplift of the tanks is still under investigation. In this research, effects of out-of-round deformation of cylindrical shell on uplift displacement of tank bottom plate and uplift width are investigated.

2. Numerical Tank Model

In this study, a cylindrical shell flat-bottom tank without a roof is examined. The tank is a broad configuration and unanchored with respect to the foundation. The mechanical properties of the tank and contained liquid are illustrated in Table 1. For evaluating effects of out-of-round deformation on uplift of the tank, this study uses three tank models that have the same cylindrical shell but different rigidity of stiffeners (See Table2). A Model-1 has the multistage rigid stiffeners that are modeled by a rigid element with an interval of 600.5 mm. A Model-2 has the multistage elastic stiffeners with an interval of 600.5 mm. Each elastic stiffener is a 700-mm-width, 15-mm-thickness and a 70000-N/mm2-elastic modulus. A Model-3 has fewer multistage elastic stiffeners comparing to the Model-2 in order to increase out-of-round deformation of the cylindrical shell by removing three stiffeners for four from the Model-2.

Symmetry in the behavior of the tanks with respect to the x-z plane enables to use a half-part of the tank model. The cylindrical shell and bottom plate are modelled by shell elements consisting of 21,639 nodes and 21,640 elements. The tank stores liquefied natural gas (LNG). In order to model fluid-structure interaction, the Arbitrary Lagrangian Eulerian (ALE) approach is employed in this study. A fluid part is modelled by Eulerian elements consisting of 301,168 nodes and 301,400 elements. The tank is supported by a foundation made of concrete, which is modelled by solid elements consisting of 15,651 nodes and 10,640 elements. The properties of the foundation are shown in Table 3. Each numerical model of the tank is assumed to have 1% of the structural damping ratio.

The first natural period of the tank bulging motion is 0.4 seconds. To differentiate fundamental behavior of the tank rock motion with/without effects of the bending stiffness of the tank bottom plate and out-of-round deformation of the cylindrical shell, the horizontal sinusoidal base acceleration whose driving period is identical with the first natural period of the tank bulging motion (0.4s) and amplitude is set as 10000 mm/s^2. Employing the explicit finite element analysis procedure, a time-history of the uplift displacement and out-of-round deformation of each tank is computed.

Table 1 Mechanical property of tank and contained liquid

Diameter of the tank (m)	51.5
Height of the tank (m)	31.44
Thickness of the cylindrical shell plate (mm)	16 to 54.5
Thickness of the tank bottom plate (mm)	6.0
Young's modulus of aluminum alloy (N/mm^2)	70000
Poisson's ratio of aluminum alloy	0.3
Density of the aluminum alloy (kg/mm^3)	2.670x10^{-9}
Density of the contained liquid (LNG) (t/m^3)	0.48
Depth of the contained liquid (LNG) (m)	28.824
Viscosity of the contained liquid (LNG)	1.00x10^{-20}

Table 2 Combination of the property of tank shell

Model Number	Tank shell	
	Rigidity of stiffener	Interval between stiffeners (mm)
1	**Rigid**	600.5
2	Elastic	600.5
3	Elastic	**2402.0**

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Table 3 Mechanical property of foundation

Diameter of the foundation (m)	71.50
Thickness of the foundation (m)	10
Density of the foundation (kg/mm^3)	7.700x10^{-9}
Young's modulus of the foundation (N/mm^2)	30000
Poisson's ratio of the foundation	0.3

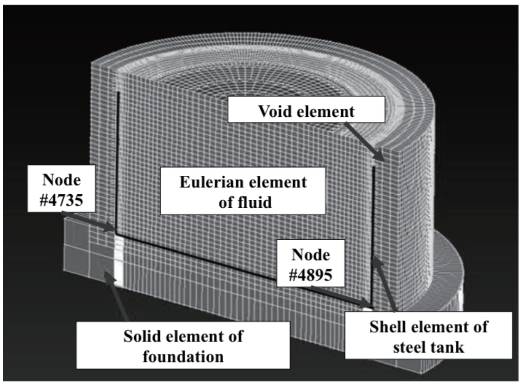

Figure 1 Numerical tank model

3. Results and Discussion

For examining synchronization between the out-of-round deformation of the cylindrical shell and the uplift displacement of the tank bottom plate, their time histories are superimposed on Figure 2. The outward deformation of the cylindrical shell of Model-2 and Model-3, i.e. 58.7mm and 189mm, are about 0.1% and 0.4% of the diameter of the cylindrical shell (See black circle on Fig.2). Then, the uplift displacements of Model-2 and Model-3 are about 0.85 times and 0.61 times as large as the uplift displacement of Model-1. Uplift widths of Model-2 and Model-3 are also shorter than uplift width of Model-1 (See Fig. 3a).

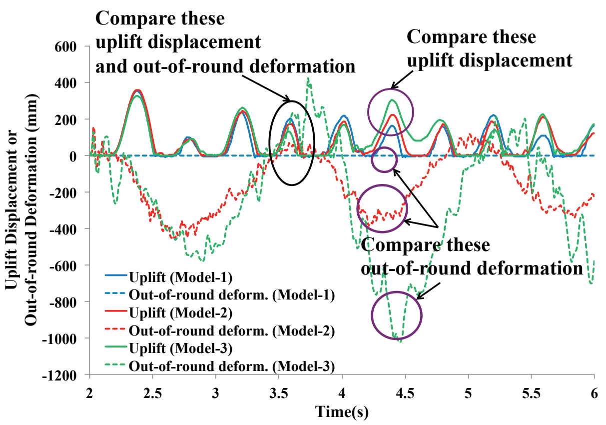

Figure 2 Synchronization of between out-of-round deformation of cylindrical shell and uplift

On the other hand, the inward deformation of the cylindrical shell of Model-2 and Model-3, i.e. 354mm and 965mm, are about 0.69% and 1.87% of the diameter of the cylindrical shell (See purple circle on Fig.2). Then, the uplift displacement of Model-2 and Model-3 is about 1.34 and 1.84 times as large as the uplift displacement of Model-1. Uplift widths of Model-2 and Model-3 are also longer than uplift width of Model-1 (See Fig. 3b).

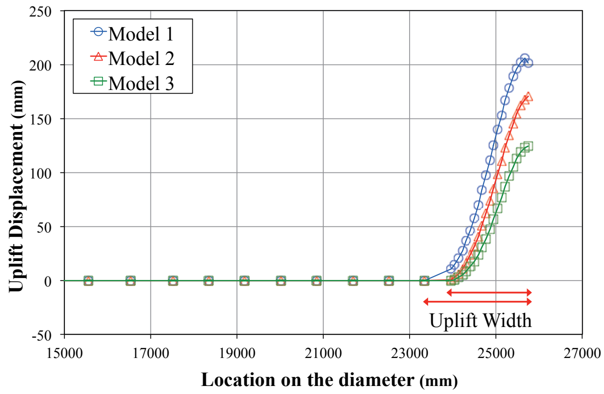

Figure 3a Uplift width of the right bottom side (3.59s)

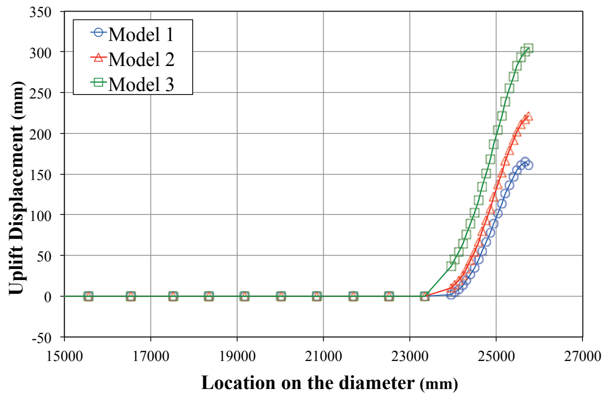

Figure 3b Uplift width of the right bottom side (4.40s)

4. Conclusion

Out-of-round deformation of the cylindrical shell has significant influence on the uplift displacement of the tank bottom plate. Especially, the inward deformation of the cylindrical shell enhances the uplift displacement of tank bottom plate and uplift width. It indicates mistreatment of out-of-round deformation of the cylindrical shell yields significant underestimation of the uplift displacement of the tank bottom plate. Therefore, quantification of influence of the out-of-round deformation of the cylindrical shell on the uplift displacement of the tank bottom plate is necessary.

5. Acknowledgements

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6. References

[1] Clough, D. P., 1977, "Experimental evaluation of seismic design methods for broad cylindrical tanks," UCB/EERC-77/10, PB-272 280.
[2] Malhotra, P. K., and Veletsos, A. S., 1994, "Uplifting Response of Unanchored Liquid-Storage Tanks," J. Struct. Div. ASCE, 120(12), pp. 3525–3547.
[3] Taniguchi, T., 2005, "Rocking dynamics of unanchored model flat-bottom cylindrical shell tanks subjected to harmonic excitation," Journal of Pressure Vessel Technologies, ASME Vol.127 No.4, pp. 373-386.