Seismic Isolation of a Condensate Storage Tank using the Friction Pendulum System

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1. Introduction

In this study, the isolation of a Condensate Storage Tank (CST) is considered. The CST is one of the important structures in a nuclear power plant because the CST stores the cooling water. The purpose of this study is not only for the decrease of the seismic force of the CST, but in the sequel decrease of the CDF. For the investigation of the isolated CST, a numerical analysis is performed. In order to construct the governing equation of the whole system, finite elements for a structure and boundary elements for a fluid region are coupled using the equilibrium and compatibility conditions. The isolator is simulated by an equation proposed in 3D Basis Me. The target structure of this study is the CST of Ulchin 5,6 unit. The dimension of CST is tabulated in Table 1.

Table 1 Dimension of Condensate Storage Tank [1]

Item			Dimension
Height			11.430m
Diameter			15.240m
Maximum Depth of Water			9.906m
Thickness of Plate	Shell		15mm
	Roof	Knuckle Part	15mm
		Crown Part	13mm
	Bottom		7mm

2. Numerical Modeling of Condensate Storage Tank

2.1 Modeling of a fluid region

In this study, for simplicity, the contained liquid is assumed to be inviscid and incompressible, resulting in an irrotational flow field. In view of these assumptions, the governing equation of the liquid motion is represented as follows

$$\nabla^2 \phi(\mathbf{x}, t) = 0 \tag{1}$$

where ϕ is the velocity potential and $\mathbf{x} = (x, y, z)$ is the position vector. Eq. (1) is the Laplace equation and the boundary integral equation derived from the Lagrange-Green Identity can be written as [2]

$$c(\xi, t)\phi(\xi, t) = \int_\Gamma \phi^*(\xi, \mathbf{x}, t)\frac{\partial \phi(\xi, t)}{\partial \mathbf{n}} d\Gamma - \int_\Gamma \frac{\partial \phi^*(\xi, \mathbf{x}, t)}{\partial \mathbf{n}} \phi(\xi, t) d\Gamma \tag{2}$$

where Γ is the boundary of a fluid region, $\mathbf{n}$ is a normal vector, ξ is the source point, $\mathbf{x}$ is the receiving point and $\phi^*(\xi, \mathbf{x}, t)$ is the fundamental solution of the Laplace equation or Green function.

2.2 Modeling of the structure region

The structure domain is modeled using 9-noded degenerated shell elements with five degrees of freedom per node. The discretized form of the governing equation of a motion subjected to a seismic ground excitation for the liquid-structure system is written as

$$\mathbf{M}^s \ddot{\mathbf{u}} + \mathbf{C}^s \dot{\mathbf{u}} + \mathbf{K}^s \mathbf{u} = \mathbf{R}(t) \tag{3}$$

where $\mathbf{M}^s$, $\mathbf{C}^s$ and $\mathbf{K}^s$ are the mass matrices, the Rayleigh damping matrices and the stiffness matrices of the structure, respectively. Also, $\ddot{\mathbf{u}}$, $\dot{\mathbf{u}}$, and $\mathbf{u}$ are the nodal accelerations, velocities, and displacements of the structure, respectively. Superscript s denotes the matrix for a structure region. $\mathbf{R}(t)$ is the force vector for a seismic ground excitation and for the fluid-structure interaction system.

2.2 Modeling of the Base Isolation System

The base isolation system, presented by Tsopelas, P.C., et. al. [3], is applied in this study. For the numerical modeling of the FPS, the following equation is used.

$$F = \frac{W}{R}u + \mu W Z \tag{4}$$

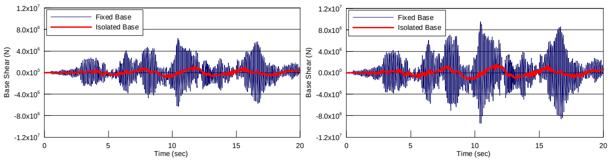
where W is the weight of a super structure, R is the radiation of a curvature, μ is the friction coefficient and the Z is the dimensionless parameter.

3. Seismic Response Analysis

For the seismic response analysis, the US NRC 1.60

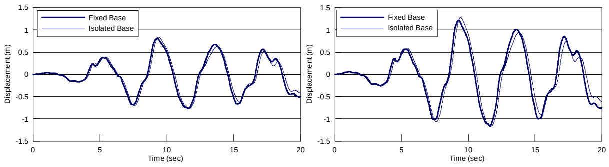
design earthquake is used. The PGA level is 0.2g and 0.3g. The base shear and sloshing height are compared between the fixed and isolated cases. The base shear of the CST is shown in Figure 1. As shown in the Figure 1, the base shear is dramatically decreased using the FPS. The decreasing rate is not really affected by the PGA level. The maximum shear of the fixed and isolated cases is 6.3MN, 1.1MN respectively, in the case of the 0.2g. For the 0.3g case, the maximum shear of 9.5MN in a fixed case decreased to 1.6MN in the isolated case.

On the other hand, the sloshing height is slightly increased as shown in Figure 2. This is because the sloshing height is associated with the displacement.



(a) 0.2g (b) 0.3g

Figure 1. Base Shear of CST as Isolation



(a) 0.2g (b) 0.3g

Figure 2. Sloshing Height of CST as Isolation

4. Decrease of CDF

The decrease of the CDF as the decrease of the seismic force is shown in Figure 3. The results are following the probabilistic safety assessment. As shown in Figure 3, over 50% of the seismic force decreases doesn't influence on the CDF. The decrease of the CDF has a convergence to some special value. This means that over 50% of the decrease of the seismic force by using the isolation system doesn't have a meaning for the point of a CDF. The results of this analysis are summarized in Table 2. As shown in Table 2, decreases of the CDF according to the decrease of the seismic forces are about 18%.

Table 2. Decrease of CDF as Decrease of Seismic Forces

PGA	Maximum Base Shear		Decrease of Seismic Force	Decrease of CDF
	Fixed	Isolated		
0.2g	6.329	1.143	82.0%	16.2%
0.3g	9.493	1.592	83.2%	16.2%

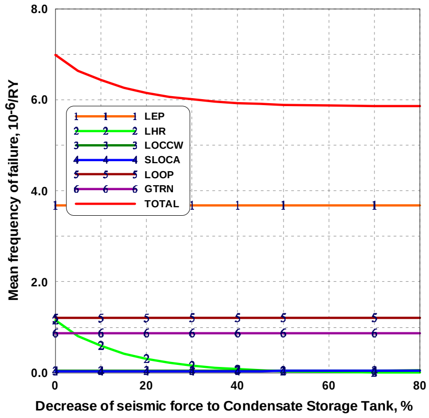


Figure 3. Variation of CDF According to the Decrease of Seismic Forces

5. Conclusion

In this study, the isolation of a Condensate Storage Tank is considered. For the investigation of the isolated CST, a numerical analysis is performed. For a consideration of a isolated fluid storage tank like a CST the whole system is divided into four parts, so called the fluid, structure, isolation part and ground which is an infinite half space. The fluid part is modeled by boundary element, the structure and isolation systems are modeled by finite element and finally the boundary method is used for a modeling of the ground. As a result, the FPS can successfully decrease the seismic force by 83% and the CDF is 16.2%.

ACKNOWLEDGEMENT

This research was supported by the Electric Power Industry Technology Evaluation & Planning Program of the Ministry of Commerce, Industry and Energy, Korea.

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