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Effect of Vertical Component of Earthquake on Concrete Storage Tanks with Flexible Walls Using Coupled Finite Element and Smoothed Particle Hydrodynamics Method

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ABSTRACT: In this research, the Seismic behavior of concrete rectangular fluid tanks has been studied and the importance of the effect of the earthquake's vertical component investigated. The structure of tank and medium of the water has been modeled using finite element and smoothed particle hydrodynamics methods respectively. The smooth particle hydrodynamics which is a meshfree method, has many advantages over other traditional grid-based methods. For verification purposes, the modeling accuracy compared with the available experimental and numerical results. The analysis ran under horizontal records with predominant periods in different ranges, once considering vertical component and another time without it. Afterward, the parameters of sloshing height base shear, force in unit width and displacement of the wall have been obtained for comparison. The results show that consideration of vertical component in analysis has a negligible effect on sloshing response but it is significant on structure's response. Meanwhile, the maximum sloshing occurs in analysis under horizontal record with high predominant period. Tanks with different thicknesses or in other words, different flexibilities of walls, show completely different sloshing and structure response. Also considering walls that are parallel to direction of earthquake as flexible, has significant effect on response of the structure. As a result, the effect of vertical component and flexibility of walls must be considered in seismic analysis of tanks.

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1. INTRODUCTION

The dynamic response of flexible storage tanks can have very different characteristics from corresponding rigid tanks. This issue has been widely studied in the seismic design of cylindrical tanks. However, studies on the seismic response of rectangular tanks are very small. Also, in most studies on rectangular tanks, the structure is assumed to be rigid. Chen and Kianoush presented a simplified method using the generalized single degree of freedom system for seismic analysis and design of concrete rectangular liquid storage tanks. Their results were in good agreement with finite element methods (FEM) [1]; subsequently, they presented a design procedure for rectangular concrete tanks using this method [2]. Kianoush and Chen studied the effect of vertical acceleration on the response of concrete rectangular liquid storage tanks and proposed the combination of added mass and sequential methods. In their study, the walls parallel to the direction of the horizontal ground motion are assumed to be rigid, the response of the tank due to horizontal and vertical acceleration was obtained Separately, and finally, the direct sum and SRSS methods (ACI 350.3.01 procedure [3]) have been compared to combine responses.

The main idea of the smoothed particle hydrodynamics (SPH) method was independently proposed by Lucy [4] and Gingold & Monaghan [5] in 1977 to solve particular astrophysical problems. Monaghan applied the SPH method to free-surface flows [6]. The latest researches done on simulating the sloshing using SPH method is carried out by Green and Peiro. They proposed an SPH method for a long duration of sloshing simulations in tanks with a low fill ratio, which was following experimental results [7].

In the present study, the 3D modeling was performed, in which the flexibility of all tank's walls was considered. To investigate the effects of walls flexibility on fluid sloshing and the response of the main structure, two tanks with 1 m and 0.5 m wall thickness were modeled. To determine the different responses of structure and sloshing, three records were chosen in such a way that their horizontal component had a predominant period in different ranges. Then, to consider the effects of the vertical component of the earthquake, the model was analyzed under selected records one time without considering the vertical component and again by simultaneous consideration of the horizontal and vertical components. In this paper, the structure of the tank and fluid medium are modeled by finite element method and SPH method respectively in ABAQUS. Using the results of this research, a better understanding of the effect of the vertical component and the flexibility of the walls on the seismic response of the tanks can be obtained.

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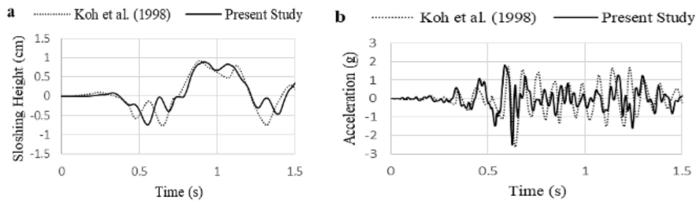

Fig. 1. Comparison of (a) sloshing height (b) acceleration time histories at the middle cross-section of the long sidewall

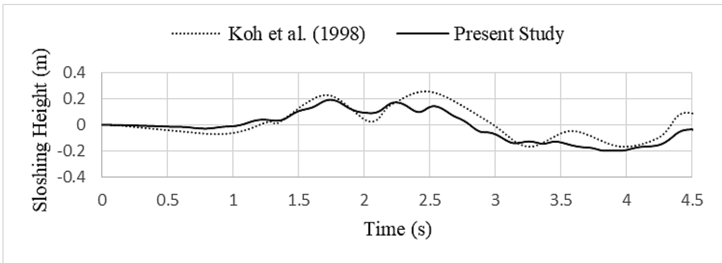

Fig. 2. Comparison of sloshing height time history at the middle cross-section of the long sidewall

2. METHODOLOGY

The SPH method is based on an interpolation technique, which allows the value of any function to be obtained at a given point, using its values at a number of neighboring points. In this method, each arbitrary function and its gradient are estimated by formulas 3 and 4, respectively

$$f_i(\vec{r}) = \sum_j f_j \frac{m_j}{\rho_j} W(\vec{r}_i - \vec{r}_j, h), \tag{3}$$

$$\nabla f_i(\vec{r}) = \sum_j f_j \frac{m_j}{\rho_j} \nabla W(\vec{r}_i - \vec{r}_j, h), \tag{4}$$

Where m_j and ρ_j are the jth particle mass and density, respectively; $f_i(\vec{r})$ is the approximated value of the function f at the point defined by the radius vector and h is a smoothing radius, which is a key parameter in the SPH approximation; It defines the distance within which particles interact with each other.

In the present study, at first, both tank's structure and water medium have meshed with 8-node, linear brick, reduced integration elements (C3D8R). Then, for water elements, a time-based criterion is used to trigger the conversion from C3D8R elements to SPH particles (PC3D elements) at the beginning of the analysis.

3. RESULTS AND DISCUSSION

For verification purposes, numerical modeling responses were compared with both shaking-table tests and numerical modeling of Koh et al. [8], which are shown in Figs. 1 and 2, respectively.

After confirming the validation through these examples, the seismic behavior of tanks and effect of walls flexibility were investigated; two tanks with wall thicknesses of 0.5 m and 1 m were modeled and analyzed in two conditions, with considering vertical component and without it. Records of 1983 Coalinga, 1994 Northridge, and 1989 Loma Prieta earthquakes were selected for analysis. Horizontal and vertical acceleration records were scaled to 0.35 g and 0.25 g respectively. Sloshing height, longwall displacement, base shear and force per unit width were calculated to compare the behavior of the tanks.

4. CONCLUSIONS

In this article, the FEM-SPH method is used to model a rectangular tank to investigate the effects of the vertical component of earthquake and tank's wall thickness. The results indicate the independent behavior of water sloshing from the tank's structure. In summary, the following results are obtained:

1. The sloshing caused by the vertical acceleration occurs by the vibration of the walls, the amount of which is negligible for both models, and with the increased horizontal predominant periods, the sloshing height increases.

2. By changing the thickness of the walls from 1m to 0.5 m the maximum relative change in sloshing is 70% (from-to 2.1 cm) which occurs in the analysis under the Coalinga earthquake record, without considering the vertical component; and the absolute maximum change is 26% (from-to 42.3 cm) which occurs in the analysis under the Loma Prieta earthquake without considering the vertical component. It should be noted that if the walls were assumed to be rigid, the responses would be the same.

3. Considering the vertical component of earthquake can also reduce the range of base shear changes, which has higher value on the model with 1 m wall thickness; the highest decrease in the maximum absolute value of the base shear occurs in the analysis under the Northridge earthquake record (33%) and the highest increase occurs in the analysis under the Coalinga record (42%). Therefore, the vertical component of the earthquake should be considered in the analysis of fluid storage tanks.

4. Considering the flexibility of the walls parallel to the direction of the horizontal ground motion effects the behavior of orthogonal walls. The amount of this effect is larger in the edges, so that by reducing the thickness of the walls from 1 m to 0.5 m in the analysis under The Loma Prieta earthquake record, the force per unit width increases either with considering the vertical component (5%), or without considering it (8%), while this change reduces the base shear in both cases, taking into account the vertical component (19%) and without considering it (20%).

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