SLOSHING RESPONSE OF THE CYLINDRICAL ELEVATED TANKS WITH FRAME STAGING SYSTEM ON DIFFERENT SOIL CONDITIONS

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ABSTRACT

The aim of this paper is to investigate how the soil-structure interaction affects sloshing response of the elevated tanks with frame staging system on different soil conditions. For this purpose, the elevated tanks with frame staging system which are built on six different soil profiles are analyzed for both embedded and surface foundation cases. Thus, considering these six different profiles described in well-known earthquake codes as supporting medium, a series of transient analysis have been performed to assess the effect of both fluid sloshing and soil-structure interaction. Fluid-Elevated Tank-Soil/Foundation systems are modeled with the finite element (FE) technique. In these models fluid-structure interaction is taken into account by implementing Lagrangian fluid FE approximation into the general purpose structural analysis computer code ANSYS. A 3-D FE model with viscous boundary is used in the analyses of elevated tanks-soil/foundation interaction. Formed models are analyzed for embedment and no embedment cases. Finally results from analyses showed that the soil-structure interaction for the elevated tanks affected the sloshing response of the fluid inside the vessel.

1. INTRODUCTION

Elevated tanks are critical and strategic structures and damage of these structures during earthquakes may endanger drinking water supply, cause to fail in preventing large fires and substantial economical loss. i.e. This type of upsetting experiences was shown by the damage to the staging of elevated tanks or failed fire resistance in Chile 1960 (Steinbrugge and Rodrigo, 1960), 1978 İzu-Oshima and Miyagi earthquakes (Minowa 1980) and 1971 San Fernando, 1987 Whittier earthquakes (Knoy, 1995). Since the elevated tanks are frequently used in seismically active regions, seismic behavior of them has to be investigated in depth. Historically, shear stress does not appear as a significant contribution to tank damage. In contrast, overturning moment appears to have been of critical importance in tanks damaged during earthquakes (Taniguchi 2004). Therefore, estimation of the structural response to lateral forces has been mainly investigated. Moreover, an excessive liquid sloshing may cause the structural failure or/and the manipulation loss, and which frequently leads to the tremendous loss of human, economic and environmental resources (Cho and Lee, 2004). For this purpose, effects of the soil-structure interaction and fluid-structure interaction on the behavior are the issues that researcher should focus on.

Numerous studies in the dynamic behavior of the fluid storage tanks have been carried out and most of them have a connection with the ground level cylindrical tanks. Contrary to this, very few studies are related to the underground (Goto and Shirasuna, 1980), the rectangular (Doğangün and Livaoğlu, 2004) and the elevated tanks (Livaoğlu and Doğangün 2006) in which fixed-base assumption is mostly made. Therefore, concentration is focused on the dynamic behavior of the fluid. How the soil/foundation systems affect the sloshing response of the elevated tanks have not been generally discussed in these studies. Because of the indefiniteness on elevated tanks about this subject, this study aims at investigating whether the soil-structure interaction affects the fluid sloshing in these tanks or not.

2. MODELING OF FLUID-ELEVATED TANK-SOIL/FOUNDATIONS SYSTEM

There are different methods and/or approaches in modeling the soil and fluid medium interacting with structures. In this paper the methods that can be implemented into FEM are selected. For this purpose the soil domain was discredited using 3-D finite elements with viscous boundaries in order to take soil-structure interaction effects into account and Lagrangian fluid finite elements are selected for the fluid-structure interaction. These approaches and the whole the Fluid-Elevated Tank-Soil/Foundation model are subtitled as follows.

2.1 Fluid-Structure Interaction

Fluid-structure interaction problems can be investigated by using different approaches such as added mass, Lagrangian, Eulerian, and Lagrangian-Eulerian in FEM and Smoothed Particle Hydrodynamic (SPH) methods (Anghileri et.al. 2005) or by using the analytical methods like Housner's two mass representations (Amabili 1996), multi mass presentations of Bauer (1964) and Eurocode 8 (2004) etc. Among these, displacement based Lagrangian approach is selected to model fluid-elevated tank interaction. The fluid elements are defined by eight nodes having three degree-of-freedom at each node; translation in the nodal x, y, and z directions. Brick fluid element also includes special surface effects, which may be thought as gravity springs used to hold the surface in place. This is performed by adding springs to each node, with the spring constants being positive on the top of the element. Gravity effects must be included if a free surface exists. For an interior node, the positive and negative effects cancel out (Ansys 1994). The positive spring stiffness can be expressed below .

$$K_s = \rho A_f \left(g_x C_x + g_y C_y + g_z C_z \right) \tag{1}$$

Where ρ is the mass density, A_f the area of the element face, g_i and C_i are the acceleration and damping in the i direction and i^{th} normal to the face component of the element, respectively. In addition expressions for mass and rigidity matrices for fluid element are given below;

$$\boldsymbol{M}_f = \rho \int_v \boldsymbol{Q}^T \boldsymbol{Q}\, dV \rightarrow \boldsymbol{M}_f = \rho \sum_i \sum_j \sum_k \eta_i \eta_j \eta_k \boldsymbol{Q}_{ijk}^T \boldsymbol{Q}_{ijk} \det \boldsymbol{J}_{ijk} \tag{2}$$

$$\boldsymbol{K}_f = \int_v \boldsymbol{B}^T \boldsymbol{E}\, \boldsymbol{B}\, dV \rightarrow \boldsymbol{K}_f = \sum_i \sum_j \sum_k \eta_i \eta_j \eta_k \boldsymbol{B}_{ijk}^T \boldsymbol{E}\, \boldsymbol{B}_{ijk} \det \boldsymbol{J}_{ijk} \tag{3}$$

where $\boldsymbol{J}$ is the Jacobian matrix, $\boldsymbol{Q_{ijk}}$ is the interpolation function, η_i, η_j and η_k are weighting functions, $\mathbf{B}$ is the strain-displacement matrix obtained from $\boldsymbol{\varepsilon}=\mathbf{B}\,\mathbf{u}$ expression. If the expressions for the kinetic and potential energies are substituted into Lagrange equation, which is

$$\frac{d}{dt}\left(\frac{\partial T}{\partial \dot{u}_j}\right) - \frac{\partial T}{\partial u_j} + \frac{\partial U}{\partial u_j} = F_j \tag{4}$$

where u_j is the j^{th} displacement component and F_j is the applied external load, the governing equation can be written as:

$$\boldsymbol{M}_f\, \ddot{u} + (\boldsymbol{K}_f + \boldsymbol{K}_s)\, u = \boldsymbol{R} \tag{5}$$

where $\ddot{u}$ is the acceleration and $\boldsymbol{R}$ is a general time varying load vector.

2.2 Soil/Foundation-Structure Interaction

The simulation of the infinite medium in the numerical method is a very important topic in the dynamic soil-structure interaction problems. The general method treating of this problem is to divide the infinite medium into the near field (truncated layer), which includes the irregularity as well as the non-homogeneity of the foundation, and the far field, which is simplified as an isotropic homogeneous elastic medium (Wolf and Song, 1995). The near field is modeled using finite elements and the far field is treated by adding some special artificial boundaries or connecting some special elements. The soil is in most cases a semi-infinite medium, and this domain should be enlarged so extent that the simultaneous modeling together with the structure may be impractical. In a dynamic problem, it may be insufficient to prescribe a zero displacement at a large distance from the structure, as is routinely done in static (Nofal, 1998). But sufficiently large soil model may prescribe the soil structure interaction as is performed in some studies (Livaoğlu, 2005; Wilson , 2002). Mathematical background of all above mentioned procedures can be viewed from the study by Livaoğlu and Doğangün (2007).

2.3 Considered Fluid-Structure Soil/Foundation Interaction Model

To model the fluid-elevated tanks-soil/foundation system, finite element method is used as shown in Figure 1. Columns and beams are modeled with frame elements (six degree-of-freedom per node) container walls and truncated cone with quadrilateral shell element (four-node six degree-of-freedom per node). Lagrangian FEM (brick shaped), intze-type is idealized as a cylindrical vessel that has same capacity with it.

On the soil-structure interaction surface, foundation is also modeled using shell elements. For no-embedded case, in other words ratio of embedment height to foundation radius is zero, foundation is set up to solid soil model, but embedded cases, it is modeled using very stiff elements, by means of that, flexible motion is ignored for foundation's itself and foundation embedment ratio is selected as 1, which means that foundation embedment (e) is equal to foundation radius (r_0). In order to realize fluid-elevated tank-soil/foundation model and characterize the seismic behavior of the systems, transient dynamic analyses were carried out using the ANSYS. All elements mentioned above are available in ANSYS. Fluid elements particularly formulated to model fluid contained within vessel having no net flow rate.

Modeling details of fluid and the soil/foundation system are explained under the following title.

2.3.1 *Details of Analyzed Models*

A reinforced concrete elevated tanks on six different soil types with a container capacity of 900 m^3 are considered in seismic analyses. The elevated tanks with a frame supporting system in which columns are connected by the circumferential beams at regular interval at 7 m and 14 m elevations. . Since the intze type tank container has an optimal load balancing shape, it is widely preferred (Rai, 2002). It is also used in the tanks modeled in this study. The elevated tanks with frame supporting structure have been used as a typical project in Turkey up to recent years. Young's modulus and the weight of concrete per unit volume are selected as 32,000 MPa and 25 kN/m^3, respectively. The container is also filled with the water density of 1,000 kg/m^3.

In the seismic analysis, it is assumed that tanks are subjected to North-South component of the August 17, 1999 Kocaeli Earthquake in Turkey. Approximately first twenty seconds of ground acceleration of North-South component of this earthquake was taken into consideration. To evaluate variations of the dynamic parameters in the elevated tanks depending on different soil conditions, six soil types as shown in Table 1 were considered.

Soil conditions recommended in the literature are taken into account in the selection of the soil types and their properties (Bardet, 1997; Coduto, 2001). For two different supporting structures and six different soil types, seismic analysis of the elevated tank and soil systems were carried out in cases of no embedment (e/r_o=0) and embedment (e/r_o 1).

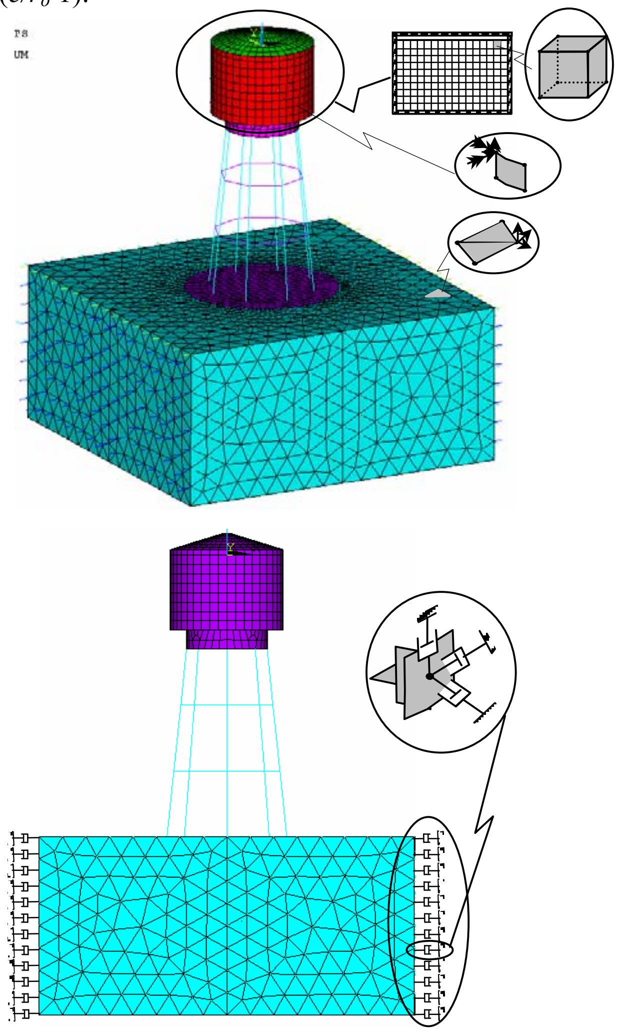

Figure 1: *Considered FE model of the fluid-elevated tank-soil/foundations in this study*

Soil types	ζ_g	E (kN/m^2)	G (kN/m^2)	E_c (kN/m^3)	γ (kg/m^3)	υ	v_s (m/s)	v_p (m/s)
S1	5.00	7000000	2692310	9423077	2000	0.30	1149.1	2149.89
S2	5.00	2000000	769230	2692308	2000	0.30	614.25	1149.16
S3	5.00	500000	192310	673077	1900	0.35	309.22	643.68
S4	5.00	150000	57690	201923	1900	0.35	169.36	352.56
S5	5.00	75000	26790	160714	1800	0.40	120.82	295.95
S6	5.00	35000	12500	75000	1800	0.40	82.54	202.18

Table 1: Properties of the considered soil types

3. DISCUSSION OF THE ANALYSIS RESULTS

The obtained peak values and their times of the maximum sloshing displacements (u_{smax}), according to the six soil conditions and two embedment ratios from the different 12 models are given in Table 2, respectively.

Frame Supporting System

Soil Type	S1		S2		S3		S4		S5		S6	
	t (s)	u_s(m)	t (s)	u_s(m)	t (s)	u_s(m)	t (s)	u_s(m)	t (s)	u_s(m)	t (s)	u_s(m)
$e/r_0=0$	10.10	-1.96	10.10	-1.98	10.15	-2.02	10.15	-2.14	10.20	-2.26	10.35	-2.42
$e/r_0=1$	10.10	-1.96	10.10	-1.97	10.10	-1.99	10.15	-2.08	10.15	-2.15	10.25	-2.31

Table 2: Results of sloshing displacement of the fluid obtained from all seismic analysis

3.1 Effects of the Soil/foundation condition

From analyses of twelve different conditions, almost same result are obtained that Soil/foundation system changes the maximum sloshing response of the fluid inside the vessel of the elevated tanks. From all, results of maximum sloshing displacement obtained from the elevated tanks with frame supporting system in case of embedded and no embedment cases are illustrated in Figure 2.

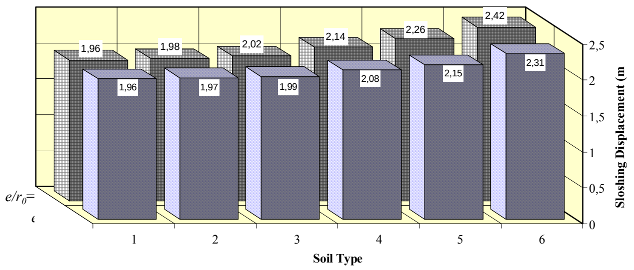

Figure 2: *According to the soil type the deviations of the maximum sloshing displacement obtained from the elevated tanks with frame supporting system in case of embedment and no embedment*

This illustration supports that the interaction is effective on the sloshing in the elevated tank. When the soil gets softer, increases in the maximum sloshing response can be seen in the figure. This increase is more severe for no embedment cases than embedded case. For example, sloshing response for frame supporting system reach 2.42 m for S6 soil type in case of no embedment but for the shaft supporting system this can only reach 2.32 m. When same comparisons are made for the effect of embedment it can be seen that the maximum fall in the value of sloshing displacement is 0.34 m in S6 soil type underlying the tank with shaft supporting system.

The calculated sloshing displacements variation in time for S1 to S3 soils were illustrated in Figure 3 indicating the case of embedment (a) and no-embedment (b). It is seen that the maximum displacement practically occurs at the same time (t =10,1 s~10,3s) for all systems. Also from the results it is seen that the variation in the sloshing for stiff soil type like S1 to S3 is small. But for softer soil type variations is comparatively larger. Since the soil type deviations are investigated, the tendency between S1 to S3 is almost same for both embedment and no embedment. This phenomenon is different for the comparison about Deviations of the sloshing displacements in time between S1 to S6. So the sloshing displacement increases 18% between S1 to S6 in embedded case and no embedment for frame supporting system. Furthermore, this variation is noted as 33% in case of no embedment (see Table 2.).

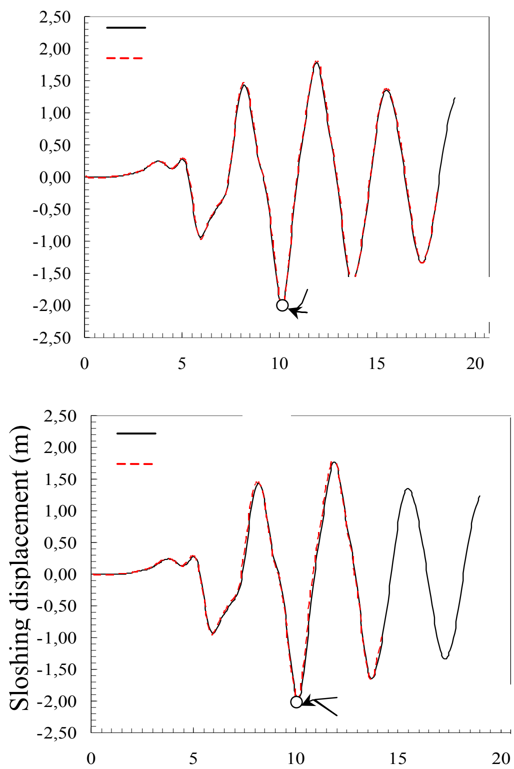

Figure 3:*Deviations of the sloshing displacements in time between S1 to S3 (a) in case of no embedment and (b) in case of embedment*

Amplitude wise, sloshing deviations show that response is different from each other. Especially, soil/foundation interaction effects on sloshing response are shown clearly from the result of all analyses. Negligible effects of foundation embedment on the results for frame supporting system are obtained, in which the value of fall reaches 5% maximally for S6.

4. CONCLUSION

Following conclusions are drawn from the performed study.

Although, it is stated in the literature that soil-structure interaction cannot considerably affect the sloshing response of the ground level cylindrical tanks, as a consequence of this study it is found out that the sloshing response of the elevated tanks is affected by the soil-structure interaction. But this interaction effect should be taken in design of the elevated tanks into consideration in the design especially these effects should be encountered in the roof design of the elevated tanks.

The other conclusion can be drawn from the study is that the sloshing response is affected from the embedment more in case of soft soil than the stiff soil. In other words, when the soil gets softer, the effect of the embedment on sloshing response becomes more visible.

5. ACKNOWLEDGEMENTS

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