SEISMIC ANALYSIS OF CUBIC BURIED TANKS REGARDING SOIL STRUCTURE INTERACTION

Yasin Moradi

PhD. Student, School of Civil Engineering, College of Engineering, University of Tehran, Iran

Prof. Khosrow Bargi

Professors, School of Civil Engineering, College of Engineering, University of Tehran, Iran

Reza Dezvareh

PhD. Student, School of Civil Engineering, College of Engineering, University of Tehran, Iran

ABSTRACT

Behavior of buried tanks during and after the earthquake is very important. This has led the attention of many researchers due to the seismic behavior of tanks that are buried in the soil. Dynamic analysis of such structures because of the interaction between soil and structure during an earthquake is very important that must be considered. In this paper, According to the interaction effect of soils and structures, under the time history record, seismic behavior of concrete cubic buried tanks has been analyzed with the finite element software (Abaqus). In this process according to depth of burial, for soil structure interaction modeling and wave propagation phenomena is used direct solution method and viscous absorbing boundary. Finally, the impact of changes in important parameters such as soil parameters and burial depth on stress and deformation values is presented and studied.

Keywords: *Seismic analysis, Soil Structure Interaction, Buried tanks, Cubic reservoirs.*

INTRODUCTION

Long time underground structures due to the use of military issues, construction and ... considered by many developed countries and has been developing. Buried tanks are the underground structures that are for storing liquids such as water and oil and ...used and thus play a crucial role in normal and abnormal accidents have occurred. Such events can be mentioned to earthquake that the continued operation of buried tanks at the time of the earthquake and then it is important. So the earthquake force is an important factor for the design of such structures. This problem has caused in the past years, many researchers have been considered the analyzing such structures under seismic forces. Jacobson is among the first researchers that has done large studies on the dynamic behavior of water tanks in 1949[1]. After his research, Housner studied on a simple dynamical model for the buried rectangular and cylindrical tanks in1957[2]. In the same years, i.e. 1960 Lysmer proposed a theory of viscous absorbing boundary around a limited environment for modeling semi-constrained environment for analyzing buried tanks. But the main problem of absorbing boundaries is limitations to analyzing in the frequency domain. This led to Lysmer continued his research of absorbing boundaries and in 1969 Kuhlemeyer and Lysmer[3] and in 1972 Lysmer and Wass[4]provided other additional models based on the theory of absorbing boundaries. Research in this area did not stop his studies and other researchers like Kausel [5]presented research in this field. In 1992, Haroun use and expanded studies of Housner for flexible reservoirs. He offered empirical model for the reservoir according to soil structure interaction effects and were noted soil structure interaction effects with several experiments on turbulence in the water[6]. Haroun collected valuable information on soil structure interaction effects in previous researchers and their experiments. Haroun and previous research scientists in the field of Soil Structure Interaction will focus many researchers note to the importance of this issue on dynamic analysis of buried tanks. And was due to soil structure interaction effects in earthquake engineering converted a major issue for different structures[7]. Thus evaluation of soil structure interaction is considered an important factor for the analysis of buried tanks. Appropriate methods of dynamic analysis of structures with regard to interaction effects and soil structure are formed based on finite element method[8]. Finite Element Method is the most widely used numerical methods in structural analysis that includes nonlinear effects, what type of material and geometry[9]. Most research on soil and structure interaction studies based on finite element method is analyzing two-dimensional tanks models based on different software. However, in some cases three-dimensional model of the comment is taken[10-12].

In this study, seismic behavior of buried tanks considered with different parameters. These parameters include burial depth of disruption and material of surrounding soil. Analysis of these tanks in the process of three-dimensional model is used to evaluate more correctly from the tank wall parameters such as stress and deformation. To achieve these goals, Abaqus is used that has good computational capabilities based on finite element method[12]. In this model, the surrounding soil of the tank is assumed to be homogeneous. And to perform the analysis process, the model is affected by the static weight and then El Centro earthquake record of components is given. In modeling on software, Body, floors and ceilings of tank are considered reinforced concrete with a linear behavior. Finally wit drawing wall deformation and stress diagrams, considered parameters in tanks has been studied.

SEISMIC ANALYSIS OF BURIED TANKS

Seismic behavior of buried tanks is dependent on the surrounding environment. In general, because dynamic model of a complete system include the dynamic model in relation to surrounding structures, wave propagation conditions in tank environment and the interface between tanks and their surrounding environment must be considered. In other words, buried tanks and surrounding soil during an earthquake is in the interaction. This problem is very important for bulky and heavy structures such as tanks. One of the factors in the seismic analysis of buried tanks is soil structure interaction.

SOIL STRUCTURE INTERACTION

The Soil Structure Interaction is achieved due to the inability of structures in comply of soil deformation and the dynamical structure effects on the surrounding soil. Methods of analysis and evaluation of Soil Structure Interaction effects is summarized substructure, direct solution and mixed solution method. The most commonly used methods are direct solution method that is based on the finite element method formulation. The purpose of studying soil structure interaction of buried tanks in the dynamic analysis based on direct solution method is finding dynamic stiffness and how the waves travel at the border of the tank and its surrounding soil. So the force and displacement on the infinite boundary must be calculated in order to dynamic stiffness due to the following relationship is obtained.

$K(x,t) = \frac{P(x,t)}{U(x,t)}$ (1)

To achieve this purpose, the elasto-plastic model is used in dynamic analysis of buried tanks and its surrounding soil. This model includes nonlinear behavior and can consider criteria yield for the soil based on the stress - strain yield surface. In modeling has been used Drucker-Prager behavior that its relationship will be described as follows:

$F = \alpha J_1 + \sqrt{J_{2D}} - k = 0$ (2)

In the above equation, J1 is the first constant stress tensor and J2D is the second fixed stress tensor. $\alpha$and k are model parameters that are calculated based on soil cohesion and friction angle.

But the major problem in the process is modeling infinite environment and finding the limited area that caused the soil and structure interaction in seismic analysis will be defined as a boundary value problem. In other words, the soil around the tank contains an unlimited environment so waves must be propagated in unlimited environment in the modeling and analysis. Unlimited environment modeling is for prevent the waves reflected back from the reservoir in the boundary model. Because damping of materials are not considered energy dissipation in a limited model singly.

One of the methods commonly used for modeling the unlimited or semi-limited is using of energy absorbing boundaries. Thus energy dissipation is simulated due to radius damping of unlimited environment. To achieve this goal, at the lateral boundaries of a given model, in each node are used three spring- damper elements in perpendicular directions. Thus the return wave from the tank is dissipating in the side boundaries of desired model. Noteworthy point in this approach is definition and selection of an appropriate material damping parameters to be set correctly model.

DAMPING OF MATERIALS AND TIME HISTORY ANALYSIS

As was stated, Damping of tanks and their surrounding soil cannot dissipate return waves. So it must be used energy damping methodsin boundaries of model such as energy absorbing boundaries. But it must be more accurate in selection and definition of natural damping of materialsbecause of simulating between model and real structure. In time history analysis, damping is an important parameter in nonlinear parameters based on dynamic equation of system. In other words, purpose of dynamic analysis of buried tank is solve the cinematic equation (equation 3) based on equation force effect.

$[M][\ddot{U}] + [C][\dot{U}] + [K][U] = [M]\ddot{U}_g(t)$ (3)

In the above equation,$[K]$,$[M]$ and $[C]$ sequentially are stiffness, mass and damping matrix. Also$[\ddot{U}]$, $[\dot{U}]$ and $[U]$ are acceleration, velocity and displacement of system. $\ddot{U}_g(t)$is ground acceleration. Damping of materials is considered in damping matrix. Whereas in the soil structure interaction problem, damping coefficient of soil is major than damping coefficient of structure, damping matrix is considered righleh damping as followed equation:

$[C] = \alpha[M] + \beta[K] + \sum_{n=1}^{m}[CF_n]$ (4)

In the above equation, $[CF_n]$ is damping matrix of nth fluid viscose element and m is a number of fluid elements. Relation the rate of time variation between shear stress and strain based on viscose coefficient is used for derivation of fluid damping matrix. In equation 4, α and β can calculate as followed equation:

$$\begin{bmatrix}\alpha\\ \beta\end{bmatrix} = \frac{2\omega_i\omega_j}{\omega_i^2\omega_j^2}\begin{bmatrix}\omega_j & -\omega_i\\ 1/\omega_j & 1/\omega_i\end{bmatrix}\begin{bmatrix}\varepsilon_i\\ \varepsilon_j\end{bmatrix} \qquad (5)$$

In this equation, ω_i and ω_j are frequencies of two main modes of tank. $\varepsilon_i$andε_j are damping of theirs. Two equations as below obtain with selection main frequencies of modal analysis and considering constant damping percent:

$$\varepsilon = \alpha/2\omega_1 + \beta\omega_1/2 \qquad (6)$$

$$\varepsilon = \alpha/2\omega_2 + \beta\omega_2/2 \qquad (7)$$

Finally, according to solve above equations:

$$\alpha = \frac{2\varepsilon\omega_1\omega_2}{\omega_1+\omega_2} \qquad (8)$$

$$\beta = \frac{2\varepsilon}{\omega_1+\omega_2} \qquad (9)$$

The major point in above discussion and time history analysis is earthquake force to the system.

EARTHQUAKE FORCE AND ITS COMPONENTS

In general each structure which is burial in soil affected by six components of ground motion during the earthquake. These components include two lateral components, one vertical component and three torsion components. Horizontal components of ground motion make hydrodynamic pressures exertion to the parapet of tank. Hydrodynamic pressures include pendulous and traumatic pressures. Hydrodynamic pressures may cause shear forces and bending moment and convoluted axial stresses and shear stress on the parapet of tank. Seismic behavior of structure is a complicated behavior that this problem cause more accurate in modeling of buried tank seismic behavior. Thus buried tank seismic behavior analysis needs seismic risk assessment until can estimate correct evaluation of structure performance during the earthquake. Seismic risk assessment can calculate ground motion parameters and records and spectral requirements.

MODELING OF SOIL STRUCTURE INTERACTION EFFECT BASED ON FINITE ELEMENT METHOD

The important part of modeling in buried tank analysis is interaction between soil and structure. In general tow methods exist in Abaqus for contact solution. Penalty function method and kinematic contact method are two methods that are mentioned. In penalty functional method, there is no limitation for penetration two surfaces together. But in kinematic contact method, the value of penetration two surfaces together is zero. In this research kinematic contact method is used for modeling the slide between parapet of tank and soil with tangential parameter. According to this element in Abaqus can model friction between tank and soil and also nonentity endurance assumption of soil. This element has ability of considering soil and structure interaction. Homogeneous solid element is used for modeling the tank. Also homogeneous solid element is used for modeling the soil with regarding soil parameters. Solid element is six faced and eight node elements that in each node three degree of freedom exist. This model includes nonlinear behavior and can consider criteria yield for the soil based on the stress - strain yield surface. In modeling has been used Drucker-Prager behavior for soil behavior.

3D finite element models in Abaqus were presented in following figures:

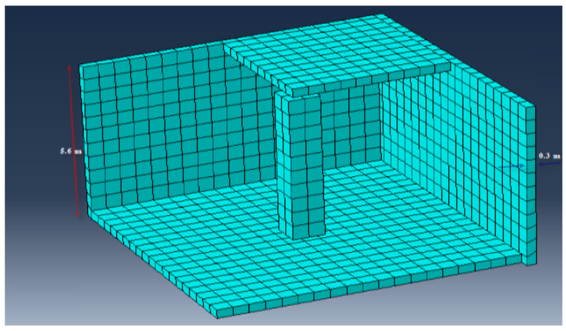

Figure – 1

Cubic tank 3D model

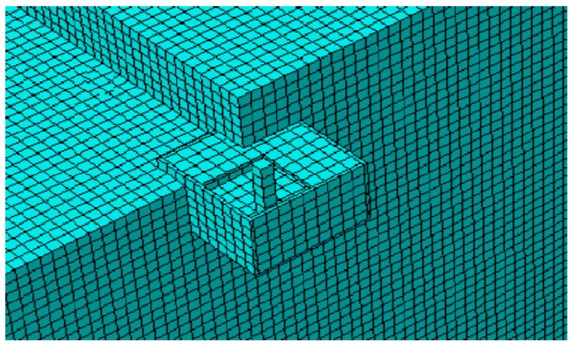

Figure – 2

Section of Cubic tank and surrounding soil

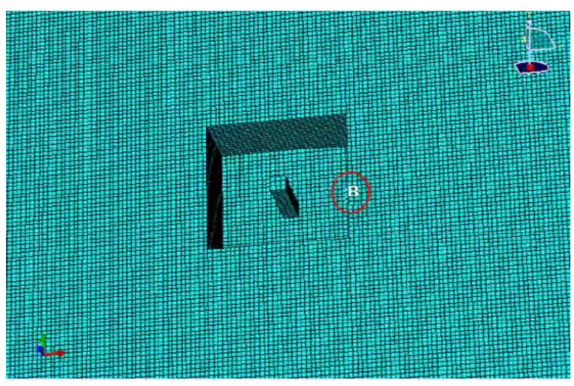

Figure – 3

Plan of Cubic tank and surrounding soil

TANK MODELS DESCRIPTION

In this paper, concrete cubic tank model is used for studying seismic analysis regarding soil structure interaction. Density of concrete is 2400 kg/m^3 and Poisson coefficient and elasticity module are .2 and 2.1e9 kg/m^2. Soil of models considered in two states soft and severe with 1900 kg/m^3 density. Characteristics of two models of soil for tank are presented in table-1.

Table – 1

Soil surrounding Characteristics

Friction Angle	Cohesion kg/m^2	elasticity module kg/m^2	Poisson coefficient	Soil Type
26	1400	1e6	0.25	Soft Soil (A)
35	0	7e6	0.35	Severe Soil (B)

Soil located on the rocky bed and the earthquake record is applied to the lower bounds of system. Record of earthquake will be imposed on the models as acceleration time history based on acceleration seismic of L-Centro. Due to the time of the analysis of large models for the calculation is used the volatility of the earthquake record. Thus, a longitudinal record of earthquakes in El - Centro over 2 seconds, the second .4 to 2.4, has been used. Figure 4 shows the acceleration records.

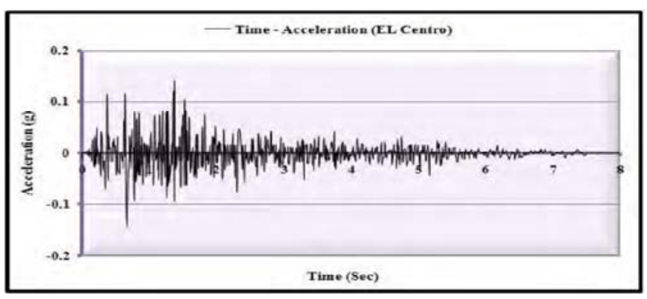

Figure – 4

El-Centro acceleration record

Four projects described in this paper which has been considered in Table- 2.

Table – 2

Specifications of tanks

Model Number	Tank Shape	Burial Depth (m)	Dimension of Tank	Soil Type	Height of Tank (m)
1	cubic	5	10 * 10	A	5.6
2	cubic	8	10 * 10	A	5.6
3	cubic	15	10 * 10	A	5.6
4	cubic	5	10 * 10	B	5.6

In all models the fluid pressure height inside the tank is considered 3 m of water. Also the middle column of tanks is considered 1 in 1 m square. Thickness of floor, wall and roof of tanks for all models is considered 0.3 m.

SEISMIC ANALYSIS OF TANKS

After the seismic analysis of presented reservoir models, the results as graphs in Figure 5 and 6 is obtained. In these diagrams have been tried Stress and deformation values at certain points in accordance with changes in the height of the tank, be evaluated. Thus, changes in parameters such as dimensions of the tank, burial depth and soil type are examined for the amount of stress and deformation of the tank wall. In the first step of research results, it has been investigated changes in wall deformation and stress of model number 1 and 4 as diagrams show in figure 5. As seen, the deformation changes in the height of the tank wall in the soft soil is more than the severe soil. For values of the stress diagrams for the soft and hard soil is almost one form but the scales are different. In other words, for both models, the values of maximum tensile stress are in the middle of the tank. However, for soft soil, stress changes than the elevation tank is much more than the hard soil and stress levels in tank elevation change in a big range. Amount of stress on the buried tank wall in soft soil is also considerably higher than the assumed model in hard soil. This is due to discuss the Soil Structure Interaction that has important effects on stress levels for the buried tanks in soft soil. In other words we can say that with the softening of the buried soil surrounding, the interaction between soil and structure increases. It is recommended that heavy structures such as tank are not built on soft soil and if this obligation, Dynamic Soil Structure Interaction

Effects on soil non-linear behavior will be considered.

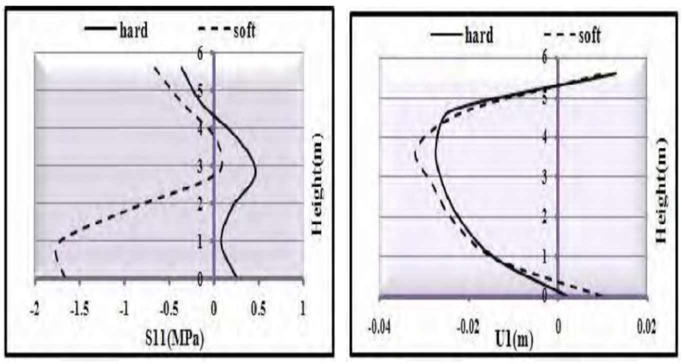

Figure – 5

Cubic graphs of deformation and stress in the tank wall according to the change of soil

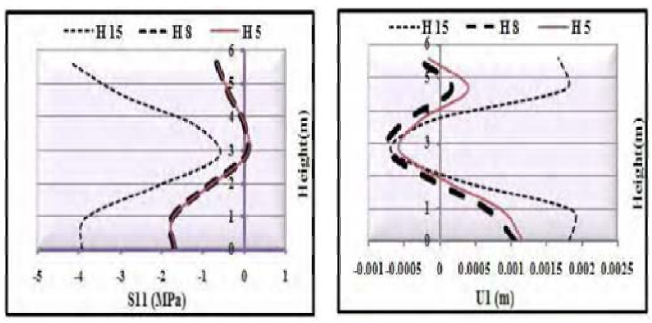

Figure – 6

Cubic graphs of deformation and stress in the tank wall according to the burial depth

Other studies in this paper are burial depth of buried tanks. For this purpose, three models were selected as the analytical samples. The results in Figure 6 are visible. As seen in this figure, changes of stress and deformation of the buried tank wall in the depths of 5 and 8 meters for the cubic tank is almost the same. But with the increase of twice that amount,the selected the parameters variations increases and the resulting graph is a lot of changes in tank elevation. It should be noted that the curves for the present model, are almost one form but with different scales. In other words, it can be stated that with increasing burial depth, the impact of the earthquake and the stress levels of the tank wall and the deformation increases.

CONCLUSIONS

- Soil type has a great effect on the Soil Structure Interaction. In other words, the soft soil against hard soil has more interaction with the structures. This increase structural stresses around the tank wall in the soft soil. On the other hand in soft soil, the stress variations in the concrete tank wall are also increasing.

- With softer the soil surrounding the tank, horizontal displacement of tank wall is increasing. On the other hand, the amount of time that tank movement decreases also increased. Thus soil around the tank is a special matter and Soil Structure Interaction is a very important problem.
- According to the obtained results, it is recommended that heavy structures such as tank are not built on soft soil and if this obligation, Dynamic Soil Structure Interaction Effects on soil non-linear behavior will be considered.
- Dynamic response of buried tank in the soil depends greatly on the site specifications and location of structures.

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