Seismic Analysis of Buried Tanks According to the Interaction of Fluid and Structure

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Abstract

Behavior of buried tanks during an earthquake, according to the application and its importance after the earthquake, the issue is a vital and important. This led to different parts of the seismic analysis of tanks has been buried by several researchers. In this paper, one of the essential and important part of the process tanks buried seismic analysis, ie the fluid and structure interaction during earthquakes has been considered To enter thus the dynamic pressure on the reservoir and its interaction effects with regard to the effect of fluid and structure interaction is evaluated. For this purpose, seismic behavior of cube shaped tanks buried in the soil according to the three-dimensional models to aid software Abaqus Is investigated. In the process fluid as a continuous medium, and Non-rotating assumed incompressible and equations of motion, based on differential equation governing the hydrodynamic waves is considered. Finally, the effect of important parameters such as the type and height of fluid in the various models under the effect of an earthquake record as a time history has been evaluated.

Key words: buried tanks, and fluid structure interaction, fluid type, fluid height, cube shaped tanks**.**

1. Introduction

Register based storage tanks and buried in various liquids is maintained for this purpose different forms such as cubic, cylindrical and ... Are produced. The first tank buried in 1914 in Tokyo was built. Then during World War II, many buried tanks to store Fuel ships were constructed. Appropriate member of such structures led to construction of reservoirs buried to date regarded in many industrialized countries, and semi-industrial gains. But the important thing in this process, design safe and economical while tanks are. Such structures during Register, subject to various risks, which are the most common and most important risks are earthquake. Considering the major seismic countries such as Iran also is important. Because such structural damage, sometimes irreparable consequences, financial and sometimes in criminal And search is the environmental. One of the major problems in process design and seismic analysis of buried tanks, fluid interaction within the reservoir and the tank wall during an earthquake is. Hydrodynamic pressure fluid reservoir tank is an important factor for the design. This case by various researchers Has been investigated that can be Jacobsan [1] and Housner [2] as the pioneers of this issue mentioned. Housner hydrodynamic pressure water to two If the pressure and impact, and oscillatory models into rigid and flexible tanks examined [3-4]. After him, giving curves Epstein Lngrhay estimate bending and reversal, research in this field improved [5]. Then Haroun and experimental results based on past research and theory, Hydraulic fluid pressure distribution in the various reservoirs was investigated [6]. Research in this area and never did not end in decades The past and continue to Researchers different finite element based on science and fluid dynamics, the interaction of fluid and structure are considered. The researchers tried to provide suitable model for simulating more realistic environment under the design earthquake force based on the interaction of fluids and structures have [7-12]. This research led to various methods such as added mass method, Lagrangian method - Euler and others, in making the interaction of fluid and

structure is presented [13]. Lagrangian systems, mesh with the deformed material is moving and no material flow between elements, will be created. One of the benefits approach
Lagrangian for this case, the production of free surface mesh is the material automatically. Meanwhile, the disadvantages that can be used to the lack of physical environment issues with large deformation levels mentioned. Euler method, a fixed mesh network and material flows in the mesh. Euler method in Direction of fluid dynamics and the best way to solve problems of large deformation flow. The advantages and disadvantages caused to research in the field of fluid and structure interaction for seismic analysis of tanks continued to be buried.

In this paper, the effect of fluid reservoirs in seismic analysis cube buried in soil, has been discussed. Thus the fluid reservoir and the buried soil in three dimensions using software ABAQUS Model and the effect of fluid and structure interaction during earthquakes based on Euler's method - Lagrangian has been considered. Using three-dimensional space due to more realistic models is that this issue affects the accuracy of results. In modeling, surrounding soil is homogeneous and to perform seismic analysis process, first under the effect of medium weight forces were static and then Elcentro components of earthquake records is given. Also in this modeling, sex body, floor and ceiling of reinforced concrete tank of the type considered linear behavior Was. Finally, draw diagrams tank wall deformation and stress, type and height of fluid has been studied.

2. Seismic analysis of buried tanks

In general, different methods for seismic analysis of buried tanks there, the two analysis are divided into static and dynamic. In static analysis, ground motion effects by an equivalent static force can be supplied. In this way, generally the force structure based on a law coefficients are obtained. Meanwhile, the analysis of dynamic forces into the structure, based on the dynamic structure reflecting the movement of earth caused by an earthquake is determined. Dynamic analysis, including spectral analysis and time history analysis method is. The dynamic spectral analysis, the effect Ground motion as acceleration reflected spectrum is determined. Meanwhile, the dynamic time history analysis, the effect of ground motion acceleration time history as a site to be determined. Therefore, time history analysis, seismic Geotechnical studies required at the site until this Ground based movement for the desired site, based on analysis of earthquake ground response should be determined. Earthquake Risk Analysis in two definite or probable is done. Based on analysis of earthquake ground motion profile can then records the required spectrum and can be calculated. The general trend process Complex and requires knowledge of different parameters are [14]. Therefore, the dynamic time history analysis process, should have economic justification is. As was expressed earlier, buried tanks to suit a wide application in different fields, have a particular importance. Therefore, the process must be analyzed And the design be done with special precision. This caused the buried tanks to seismic analysis based on dynamic time history analysis be conducted and be economically justified.

2.1 Time history analysis and damping materials

Time history analysis, giving accelerated structure of the earth as a function of time is analyzed. So in this process, some momentum mapping is needed as much as possible reflect the actual ground motion at the structure is constructed. In time history analysis and structural behavior can be linear or nonlinear model Considered. One important difference between linear and nonlinear models, damping ratio and the method is applied in the respective models. Important factor in the exercise of all damping factors based on nonlinear relationship is Dynamic system, so must define in the selection and inherent damping materials because most simulation models with reality Be accurate. Meanwhile, the dynamic analysis of buried tanks, based on equations of motion based on the relationship between (a) under the force of earthquakes is formulated.

$$[M][\ddot{U}]+[C][\dot{U}]+[K][U]=[M]\ddot{U}_g(t) \quad (1)$$

In relation to the above $[M]$ ، $[C]$ and $[K]$ Matrices respectively mass, damping and stiffness is. $[\ddot{U}]$ ، $[\dot{U}]$ and $[U]$ Respectively the acceleration, velocity and displacement are the system. Also related to (1) $\ddot{U}_g(t)$ Indicating accelerated earth. Damping system for damping materials in the matrix is [15].

The Rayleigh damping matrix as described in the general case the following relationship can be considered.

$$[C]=\alpha[M]+\beta[K]+\sum_{n=1}^{m}[CF_i] \tag{2}$$

In relation to the above $[CF_n]$ Element damping matrix n, viscous fluid and m is the number of fluid elements. Damping matrix for the extraction fluid, the relationship between strain rate and shear stress changes in time according to the viscosity coefficient is used. In relation (2) coefficients can be α and β In the general case be calculated based on the following.

$$\begin{bmatrix}\alpha\\ \beta\end{bmatrix}=\frac{2\omega_i\omega_j}{\omega_i^2\omega_j^2}\begin{bmatrix}\omega_j & -\omega_i\\ 1/\omega_j & 1/\omega_i\end{bmatrix}\begin{bmatrix}\xi_i\\ \xi_j\end{bmatrix} \tag{3}$$

In relation to the above ω_i and ω_j Two-mode frequencies, respectively, and the main reservoir ξ_i و ξ_j Damping is related to it. With a choice of two main frequencies ω_1 and ω_2 Modal of analysis and consider a fixed percentage of damping, can be related based on the following two equations (3) and obtain relations dynamic analysis:

$$\xi=\alpha/2\omega_1+\beta\omega_1/2 \tag{4}$$

$$\xi=\alpha/2\omega_2+\beta\omega_2/2 \tag{5}$$

Finally, the above equation, we will:

$$\alpha=\frac{2\xi\omega_1\omega_2}{(\omega_1+\omega_2)} \tag{6}$$

$$\beta=\frac{2\xi}{(\omega_1+\omega_2)} \tag{7}$$

Reflection point in the above discussion and analysis of time history, the earthquake force is the system.

2.2 Earthquake force and its components

In general, any structure which is within the soil, while under the effects of the six components of earthquake ground motion is placed. This component consists of two components side, a vertical component and three component torsion Coordinate is around. Horizontal component of ground acceleration caused hydrodynamic pressures applied to the tank wall is. Hydrodynamic pressures can induce shear forces and bending and thus anchor ring compression and tensile stresses and shear stresses are significant in the tank wall. Therefore, hydrodynamic pressures important factor in seismic analysis process tanks are buried.

According to research conducted [3-4], hydrodynamic pressures induced by earthquakes can be induced impact pressures and pressures can transfer into. Impact pressures due to inertia forces due to movement of the reservoir appears to be general. Directly to the power grab in the tank wall are associated. In other words related to the impact pressure of the fluid which is part of the tank wall shall swing. Meanwhile, the pressures on transitional or turbulent fluid swing, production and frequently as they enter the tank wall. In other words, the effect of vibrations caused by earthquakes, fluid level Waves appear to force the tank wall into sectors. The forces and pressures, under pressure or fluctuating transition are defined. Frequency oscillatory pressures with far smaller than the tank frequency must act, if the impact pressure, with equal frequency vibration tank act.

As can be seen that the seismic behavior of buried tanks considering fluid reservoir is Complex behavior. So should the modeling of seismic analysis of buried tanks and careful attention to the fluid reservoir and its behavior during the earthquake is. In other words, the modeling should Effects of wave propagation in fluid reservoir and the fluid interface and the tank wall according to the fluid and structure interaction phenomena are considered.

2.3 Fluid Structure Interaction

General dynamical model of a complete system always includes dynamic structural model with the environment is structural. As was expressed earlier, the fluid reservoir, as one of the environment around the reservoir due to production of the hydrodynamic pressure is very important. For this study, pressures and forces, as follows assumptions are considered:

- With small postulate, Reynolds number, the existence of turbulence in fluid flow is ignored.
- Non Rotary field is fluid and the fluid Kavytasyvn not happen.
- Reservoir fluid is ideal and is homogeneous.

However given the above assumptions, the system can be hydrodynamic equations for the fluid medium based on the equations of motion laws of survival guilt and survival be defined. Crime laws based on survival (relationship continuity) in the volume of fluid to the dimensions dx ،dy and dz And considering the amount of mass changes and fluid density acts (ρ) And fluid velocity (v_z, v_y, v_x), An equation is obtained as follows [16]:

$$\nabla^2\varphi - \frac{1}{\rho}\frac{\partial\rho}{\partial t} = 0 \tag{8}$$

These relationships, known as linkage relationship in which the fluid φ Is the potential function. However according to the laws of motion and continuity of relationship and relationship is below the low viscosity fluid is obtained:

$$\nabla^2\varphi - \frac{1}{c^2}\frac{\partial^2\varphi}{\partial t^2} = 0 \tag{9}$$

This equation, based on the vibration problems of fluid compressibility and the famous Helmholtz relationship. If the fluid regardless of the compactibility, the relationship (9) as is expressed in the Laplace equation is the same.

$$\nabla^2\varphi = 0 \tag{10}$$

For the case of Helmholtz equation governing fluid flow, with mass and survival of the laws of motion are expressed as follows [17]:

$$\nabla^2 p - \frac{1}{c^2}\frac{\partial^2 P}{\partial t^2} = 0 \tag{11}$$

In relation to the above P and c Wave propagation speed in the fluid is. For structures which are in contact with fluid, the fluid pressure is transferred to the structure and fluid displacement affects the structure, therefore in such cases the balance equation is expressed as follows:

$$\{n\}.\{\nabla P\} = -\rho\{n\}\frac{\partial^2\{u\}}{\partial t^2} \tag{12}$$

In relation to the above $\{u\}$ Displacement vector structure and level of contact $\{n\}$ Contact surface normal vector is fluid and structure. On the other hand the structural environment of the expression balance equation is as follows:

$$\sigma_{i,jj}(u) + \rho_s.\ddot{u}_i = 0 \tag{13}$$

In relation to the above $\sigma_{i,jj}$ Tension, $\ddot{u}$ Acceleration and Is the density structure. Now considering the above relations and interaction of fluid and structure and dynamic balance in relation to the contact fluid and structure, the following equations can be fluid and structure at the border be defined:

$$\begin{bmatrix} [M_e^s] & [0] \\ [M^{fsi}] & [M_e^P] \end{bmatrix} \begin{Bmatrix} \{\ddot{u}_e\} \\ \{\ddot{P}_e\} \end{Bmatrix} + \begin{bmatrix} [K_e^s] & [K^{fsi}] \\ [0] & [K_e^P] \end{bmatrix} \begin{Bmatrix} \{u_e\} \\ \{P_e\} \end{Bmatrix} = \begin{Bmatrix} \{F_e\} \\ \{0\} \end{Bmatrix} \tag{14}$$

In relation to the above $[M_e^s]$ ،$[K_e^s]$ ،$[M_e^P]$ and $[K_e^P]$ Mass and stiffness matrices respectively and structures are fluid. The matrices $[M^{fsi}]$ and $[K^{fsi}]$ In relation (14) is also defined as follows.

$$[M^{fsi}] = \rho[R_e]^T \tag{15}$$

$$\left[K^{f_{si}}\right] = -\left[R_e\right] \qquad (16)$$

In relation to the above $[R_e]$ Matrix interaction is fluid and structure and is calculated as follows:

$$\rho\left[R_e\right] = \rho\int_s \{N\}\{n\}^T \{N'\}^T ds \qquad (17)$$

In relation to the above $\{N\}$ Form and function of the pressure $\{N'\}$ Is the displacement shape function.
Finally, software components can be based on such limited ABAQUS And appropriate use of elements based software [18], and fluid structure interaction based on these relationships in terms of modeling can be. The real causes become more important given the model in seismic structural analysis and accuracy of results is improved.

2.4 Reservoir modeling and interaction of fluid and structure based on Finite

As was expressed earlier, hydrodynamic pressure under the effect of earthquake force into the wall of the tank system is hydrodynamic equations for fluid medium based on the equations of motion laws of survival guilt and survival is the expression. Based on these equations, when the dynamic numerical method Fluids due to the high volume of calculations is not cost effective, based on the finite element software such as ABAQUS Is used. The finite element method software equations of motion (Navyr Stokes) and continuity equations (mass Survival Act) and solve the problem unknowns can be calculated. Based on these equations finite element method, generally based on solving approach implicit or explicit solution method is performed. Each of these methods have Have different advantages and disadvantages, based on the type of problem and expected results are selected. Implicit set of equations in the way the system stiffness matrix method to solve directly the formation and movement of each node is calculated. Meanwhile, the explicit method of problem solving and can be as dynamic displacement of each node according to the acceleration of the node can be calculated in each step Reload [18].
In this article, and fluid in the reservoir modeling software environment ABAQUS Three-dimensional form and two separate classification has been defined and mesh. In this process, considering that hardly compared with the fluid reservoir is higher, as flexible at the reservoir is considered. Modeling in this study for eight cubic fluid elements of a particular knot, attributed to elements EOS Used. The elements for the design of surface wave phenomena and have applications within the reservoir fluid model is appropriate [18]. For the contact and interaction of fluid and reservoir fluid and reservoir of public contact algorithm is used. The algorithm most comprehensive method for modeling fluid and structure interaction, which has unique abilities [16, 19].
In current models of water and oil as the fluid reservoir modeling using the method based on the two fluid equation of state is defined. Based on the equation of state, can resist the hydrodynamic volume of a substance can be determined and thus a function of pressure in the matter density and internal energy are considered.
For reservoir modeling in this study, the overall element Solid Type Homogeneous Used. Gender setting specifications and based on the required tank (concrete) and other reservoir parameters is done. For modeling soil around the tank, the element of Solid Type Homogeneous But based on soil parameters settings are used. Element Solid A six-dimensional element is eight knot, in which each node there are three degrees of freedom. Based on these elements can be treated Elasto plastic Dragr Pragr through dynamic characteristics such as soil cohesion and soil internal friction angle, can be defined for nonlinear behavior. Thus to model the behavior, the actual behavior of the system is near.
Models of three-dimensional finite element software ABAQUS For cubic tank in the following form is provided.

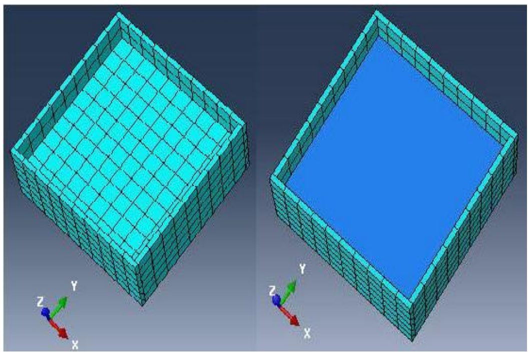

Figure 2 - Three-dimensional view of the reservoir and fluid ABAQUS

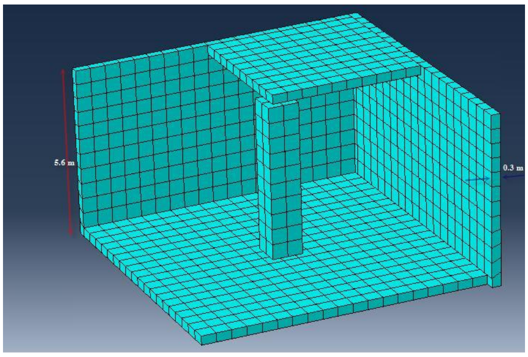

Figure 1 - Reservoir modeling element Classification in ABAQUS

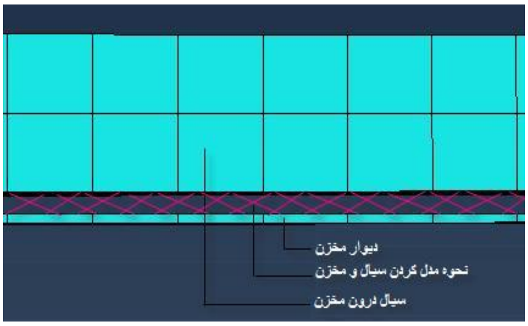

Figure 4 - magnification fluid boundaries and structure ABAQUS

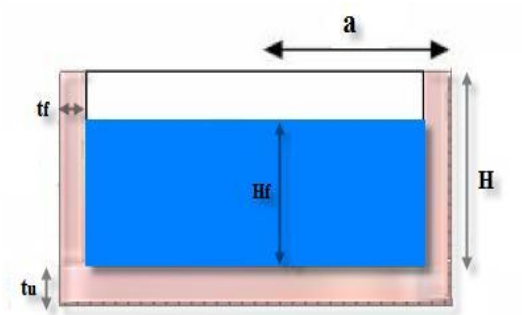

Figure 3 - Side view of the reservoir and fluid

2. Dissected specimens and model tanks

This paper models tanks made of concrete cube for seismic evaluation and analysis based on the interaction of fluid and structure are used. Specific weight of concrete used in all the models $2400 kg/m^3$ And modulus and Poisson's ratio for concrete Elastisite the model sequentially 0.2 and $2.1\times10^9 kg/m^2$ Been considered. As a single layer of soil around the tank and the length and transverse dimensions $60_m \times 60_m$ And the deep 40_m Defined that 30_m Below the floor level around the tank and almost 5_m Located on the overhead tank. The density of soil around the reservoir modeling, the $1900 kg/m^3$ Been considered. On the soil bed is rocky and earthquake records from the lower boundary is applied to the system. Earthquake acceleration time history record form based on the acceleration of earthquake records Elcentro models apply. Considering the time being, and analysis of large Being models for the calculation of the area of severe fluctuations in earthquake record is used. For this purpose, the longitudinal length of the record of earthquake Elcentro 2 Seconds, the second 0.4 To 2.4 Has been used. The damping coefficient equal to 5 percent of all models and values α and β According to calculations, respectively, against 0.13 and 0.016 Been considered. Fluid reservoir in two mechanical specifications in Table (1) are considered.

Table 1 - Profile of fluid within the reservoir

Soil type	Modol elastisite (kg/m^2)	Density (kg/m^3)	Viscosity (kg.s/m)
Water (Model A)	2.1×10^8	1000	1.15×10^{-4}
Oil (Model B)	1.55×10^8	860	8.1×10^{-3}

In this paper general design of the tanks buried five different profile descriptions (Table 2) is considered.

Table 2 - Profile of the studied reservoirs

Model Number	T-1	T-2	T-3	T-4	T-5
Fluid height	5_m	2.5_m	5_m	2.5_m	0
Fluid Type	A	A	B	B	_

All models in the tank dimensions $10_m \times 10_m$ External height 5.6_m Been considered. Middle column dimensions for all models as the square $1_m \times 1_m$ Is assumed. Thickness of floor, wall and roof of tanks for all the models 0.3_m Is considered. Thus the maximum height of fluid reservoir 5_m is.

4. Analysis of seismic vessels

After the analysis of seismic and reservoir models presented, the results charts Description forms (5), (6) and (7) has been made. The charts have been tried, stress and deformation values in specific areas appropriate to change the height and type of fluid reservoir, to be evaluated, thus changes in the type and height Fluid reservoir to the tank wall deformation and stress levels according to the interaction of fluids and structures must be examined.

For this purpose, the first step, models T1 ، T2 (Tanks containing water) and T5 Has been studied. Figure (5) charts concrete tank wall deformation and stress according to the height of the fluid reservoir shows.

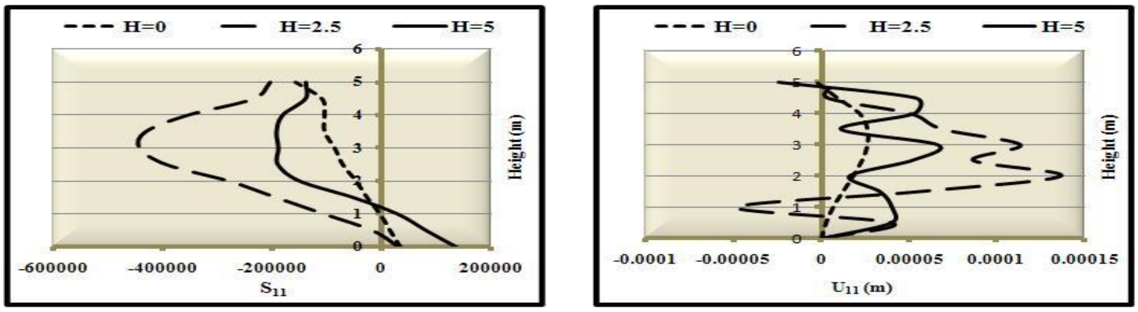

Figure 5 - Diagram deformation and stress in the wall of the tank containing water

As the chart form (5) is observed, the reservoir containing fluid (water) had more stress and deformation to the tank is empty. This system of weight gain due to the presence of fluid within the reservoir can be produced. In other words, the weight system (reservoir and the fluid) of Earthquake force the system increases. Thus, stress and deformation levels in the tank walls increases. But the increased amount of fluid within the reservoir and the direct relationship is not linear. In other words, as in Figure (5) can be seen, stress and deformation values for the height of the tank wall fluid 2.5_m Most of the models is related to altitude. Ie despite fluid weight loss due to reduced height, stress and deformation values have increased. This is due to the hydrodynamic pressure in the pre, the interpretation was discussed. The hydrodynamic pressure in the pressure mode Transition impact and pressure are defined, an important factor in seismic analysis process tanks are buried. Elevation model 2.5_m Transitional or fluctuating pressures due to surface waves that are produced, most of the tank is full mode. This increased the stress and deformation levels in case the tank wall is half full. In other words, in which case the tank is nearly full, and surface waves generated less force to the tank wall into the lot do not. Meanwhile, for the tanks half full, surface waves with more force and therefore produce more force into the tank wall sectors. This increases stress and deformation values for the tank wall mode is half full. Hydrodynamic pressures another factor for increasing amounts of wall stress and deformation in comparison with fluid containing reservoir tank is empty.

In this paper we verify the results of the seismic analysis of tanks containing water, oil tanks containing analysis and also has been investigated. Figure (6) stress and deformation diagrams containing concrete tank wall to the height of the oil 5_m ، 2.5_m And shows an empty tank.

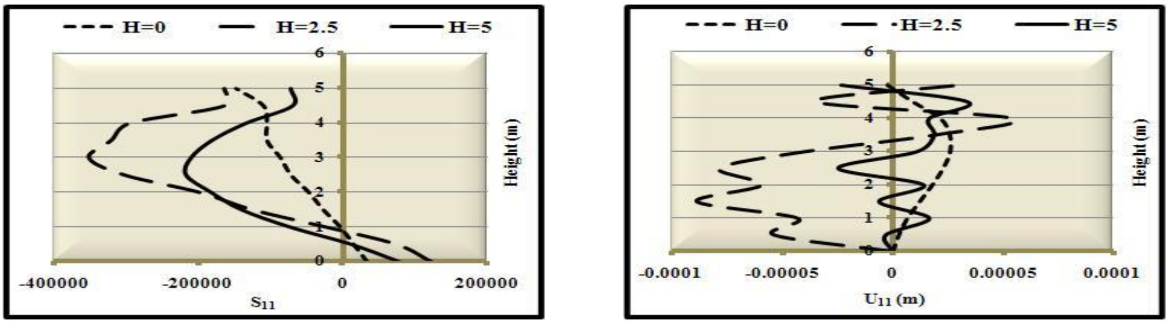

Figure 6 - Graph deformation and stress in the wall of the tank containing oil

As in Figure (6) is observed, the results for oil, water is the same. In other words, like tanks containing water, for tanks containing oil to the highest height of deformation and stress 2.5_m And lowest for the tank is empty. It is worth noting however that the stress and deformation values for reservoirs containing oil reservoirs contain less water is one of the reasons this issue is the fluid density. In other words, with decreasing fluid density, weight system (reservoir and fluid contained within it) is reduced, so the effect of earthquake force reduction and stress and deformation values of the reservoir wall Decrease. The other hand, decreased specific gravity fluid hydrodynamic pressure (impact pressure and transfer) is reduced. Thus the force on the walls of the tank containing oil tanks containing water reservoirs was lower and this also reduces stress and deformation values are the reservoir wall. Figure (7) The maximum amount of stress and deformation in the walled tanks containing oil and water shows.

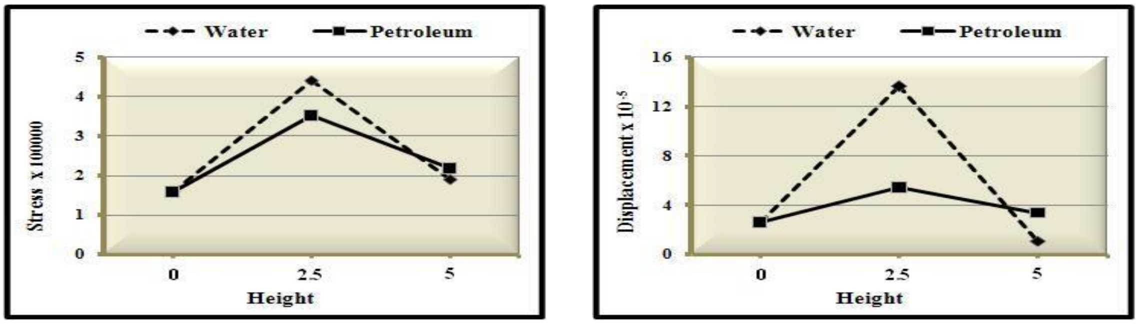

Figure 7 - Graph maximum deformation and maximum stress in the reservoir wall for fluid water and oil

5. Conclusion

- enter the hydrodynamic pressure on tank wall with the fluid density are related. Thus the design of buried tanks should specify the type of fluid to be eventually plan to ensure a safe and economical.
- pressure fluctuations and surface waves in the stress and deformation values walled tanks have an important role and therefore must be in the process of seismic analysis of this phenomenon in terms of tanks to be buried.
- Due to fluctuating pressures resulting from surface waves, stress and deformation levels in more than half full tanks are tanks that can be filled with comprehensive analysis in the field of fluid height, height of the crisis can be calculated for the design of buried tanks.
- According to the results obtained in connection with the type of fluid, is recommended in the seismic analysis of buried tanks, and fluid structure interaction effects are considered.

- According to the results and affairs related to the fluid and structure interaction and hydrodynamic pressure, it seems that other properties such as fluid viscosity, velocity of seismic wave propagation and so the stress and deformation values contribute to the tank wall. Therefore it is recommended the comprehensive analysis of earthquake records for other effects of fluid type and relevant parameters must be examined.

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