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# A review of the literature on the underground (buried) storage tanks

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# ABSTRACT

The main objective of fluid storage tanks construction is to construct safe and low-cost storage tanks which are resistant against earthquake. But in the computer design methods for the design of low cost and high performance storage tanks, little attention has been paid to development of quantities. In this study, first the underground tanks were compared to non-underground storage tanks and the results showed that underground tanks had better performance in terms of maximum displacement and stress against their wall. Afterwards, the impact of changes made in the underground tanks through the depth of underground tank, the type of soil around the tank, the distribution of dynamic pressure by different fluids, the impact of water depth on the tank frequency, and ratio of length to height on frequency of the tank, was investigated. The results of this study suggest that any increase in the tank depth leads to an increase of the tension and displacement and with softer soil around the tank more critical results will be achieved. In addition, the fluid dynamic pressure distribution is strongly linked to the specific weight of the fluid. With any rise in the water level of the tank or increase of length to height ratio, the frequency of the tank is reduced.

**KEYWORDS**: underground tanks, dynamic pressure of fluids, the depth of underground tank.

## 1. INTRODUCTION

Water has long been a determining factor in human life and its presence is one of the amenities of life. That's why people have always been trying to save water and use it in their lives. Early humans, inspired by nature, used any device for water storage. With civilization of human being and construction of elevated structures the need for water and reserving that is felt more than ever before. Considering urban constructions and lack of surface space for water storage tank, and considering that tank is a structure that plays a critical role in vital arteries, construction non-flat tanks (above or below the ground level) is one of the inevitable water storage strategies.

Tanks, in terms of their placement, are divided into 2 categories of air and land tanks. Land tanks also can be divided into three categories as follows:

## 1. buried tanks

buried concrete tanks are the tanks that are located at a proper depth under the ground and their walls and roof is covered with soil. In addition to their advantages in terms of camouflage against environmental factors, these tanks are also very suitable for heat exchange. In cold regions, buried tanks should be used to prevent freezing of water (1). Some examples of buried tanks are shown in Figure 1.

## 2- half-buried tanks

Tanks whose wall is often embanked up to half of its height and there is virtually no soil on the tank roof. These tanks are not suitable in terms of camouflage, temperature changes and the expansion and contraction of the roof slab, and according to the terms of passive defense, are not recommended for use in urban drinking water network (1). Examples of half-buried water tanks are presented in Figure 2.

#### 3. Visible tanks

These tanks are usually constructed in a visible way in terms of landscape architecture and symbolism, and also in accordance with the environment in order to organize urban, historical and tourism landscapes (1). Examples of visible water tanks are shown in Figure 3.

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Fig.1. buried concrete tank (1)



**Fig.2.** half-buried concrete tank (1)



Fig.3. visible concrete tank (1)

Use of buried and half-buried tanks for storing water, oil products, or industrial wastes, is developed increasingly. Investigation of the Seismic behavior of buried tanks in terms of the dynamic pressure distribution of the fluid inside the tank and the pressure of the surrounding soil under earthquake loading is very important (2).

Different parameters should be taken into considerations for investigation of tanks under earthquake loading. These parameters include fluid-structure interaction. It should also be noted that in the case of buried tanks, soil-structure interaction is one of the parameters.

The idea of construction of concrete tanks was first proposed in Tokyo in 1914, i.e. during the World War II against the United States of America when Japan tried to build fuel storage tanks to store ships fuel (3). The behavior of fuel tanks in earthquake conditions has been the focus of many researchers. And this is not only because of the vitality of tanks function after earthquakes but because of the simplicity of the tank structure and effectiveness of fluid - soil – structure in their behavior.

Hoskins and Jacobs (1934) published the first report according to laboratory observations and analysis of a rigid cylindrical and rectangular tanks under the horizontal movement of earthquake. In 1949, Jacobs measured the hydrodynamic pressure on the inside surface of a cylindrical tank and outside of a cylindrical pole surrounded by water, whose base was under the influence of a horizontal movement, He is the first researcher who has done extensive research on the dynamic behavior of tanks. Graham and Rodriguez (1952) introduced an analytical method for calculation of vibration and shock pressures in a rectangular tanks. Following that, Hasner (1957) carried out some studies on dynamic models of underground cylindrical and rectangular tanks. Chu et al (2001), introduced some methods for seismic and vibration analysis of tanks containing liquids where solutions of linear and non-orthogonal natural frequencies and added mass matrix provided a modified numerical method and an alternating convergent numerical method for calculating added mass matrix to perform a seismic analysis. Shirmali et al. (2002) modeled the seismic response of tanks containing liquids that were separated from the base and subjected them to two factors of Horizontal seismic excitation. In the same year, he modeled two types of above-ground tanks through conjugate nonlinear differential equations, and subjected them to bilateral earthquake excitation. Given the non-linearity of the deformation behavior of the base, the seismic response was measured through newmark's step by step method. Hvanchv et al.(2004) used a conjugate dynamic model to measure the seismic response of liquid storage tanks in the area under the effects of structure-fluid interaction. Lyvavglv and Dogangan, (2007), investigated the effects of base embedding on the seismic behavior of tank - base - soil - fluid with the structure of the case that embeds the fluid tank. Displacement of the high roof of the tank is significantly influenced by embedding in soft soil, yet this influence is less significant for harder soil types. Except the soft soil type, embedded parameters such as volatility shift does not affect the response. Except for soft soil type, embedding doesn't affect other response parameters such as volatility shift. Lyvavglv, (2008), investigated the dynamic behavior of the Rectangular fluid tanks - soil / foundation with a simple and quick method. in this method the fluid interaction of two Hanser masses for fluid and cylindrical model for soil / foundation was presented.

The results show that displacement and base shear forces generally decrease with any reduction in the hardness of the soil. However, embedding, flexibility and soil-structure interaction don't have any considerable impact on volatility shift.

Synhamahapata and Mitra, (2008) used the finite element method to simulate the impact of interaction in a concrete water storage tank, in this case, the tank foundation was considered solid. The Soil around the fluid tank was not taken into considerations for analysis of fluid contained by the tank. The results of the analysis show that the hydrodynamic pressure on the flexible wall is more than the pressure on the solid wall.

Ozdemir et al., 2010 evaluated the fluid-structure interaction through non-linear method, in order to perform a seismic analysis of anchored and non-anchored steel liquid storage tanks. Fluid motion was dominated by the *Navier* – *Stokes* equations. Both nonlinear and geometry provisions were taken into considerations for accurate determination of the stress, strain and strain distribution rate throughout the tank. The Predicted results were compared with experimental data. The results show that laboratory results are highly consistent with the predicted results.

## 2. Comparison of buried and non-buried rectangular tanks

A tank in 13.2 \* 13.2 \* 3.5, dimensions which contains 3 meters of water, has floor and walls with thickness of 30 cm and 20 cm respectively and consists of three layers of concrete and two layers of armature with non-linear behavior. The specific weight of concrete and steel is, 2400  $kg/m^3$  and 7800  $kg/m^3$  respectively Poisson's ratio for the concrete and steel is, 0.17 and 0.3 respectively. Modulus of elasticity is considered 20 *Gpa*, 200 *Gpa* and shear modulus is considered 21 *mpa* this model is evaluated by Tabas and Naghan accelerograms which were scaled as 0.4g. two records were introduced to the model along the X axis. Figure4 represents an overview of the tank model and the above mentioned Accelerograms are shown in Figure 5 (5).



Fig.4. the overview of the tank together with its roof (5)





Fig.5. Comparison of the maximum displacement of the tank roof in buried and non-buried conditions (5)

According to the proposed model, the results of the maximum displacement of tank roof under Naghan and Tabas earthquake records, in buried and non-buried conditions, are shown in Table 1.

Table 1. maximum shift of the tank roo	f for one soil type (5)

Accelerogram type	maximum displacement of the tank roof $\left(mm ight)$	
	buried	Non-buried
Tabas earthquake records	1.91	3.66
Naghan earthquake records	2.38	4.54

According to Table 1, the results of the analysis show that the Soil-structure interaction has been effective in displacement of the tank roof and significantly reduces the maximum displacement in Tabas and Naghan earthquake records, such that the results of displacement in non-buried model is almost twice the results of the buried model.

Apart from maximum displacement, the level of stress is in the tank is another factor that determines the effect of buried tanks, in addition to the maximum displacement. Therefore, the tensions in the inner and the outer wall of the tank (along the y axis) was investigated for both buried and non-buried conditions under both Naghan and Tabas earthquake conditions. The results of this investigation can be seen in Figures 6 and 7.



Fig.6. the range of tension in the outer layer of the tank wall under Naghan earthquake conditions (5)



Fig.7. the range of tension in the inner layer of the tank wall under Naghan earthquake conditions (5)

According to the results, tension in the inner and outer walls of the non-buried tank is more than that in the buried tank. It can also be seen that in both buried and non-buried conditions, the tensions in the inner walls of the tank is more than the tension in the outer walls and this could be due to hydrodynamic power of water.

#### 3. The effects of depth and soil type on a rectangular tank

In this section, cubic concrete tank Model is considered to analyze the soil-structure interaction in order to investigate the effects of depth and soil type on the tanks. The density of concrete in 2400  $kg/m^3$ , Poisson's ratio is 0.2 and modulus of elasticity is considered  $2.1*10^9 kg/m^2$ , the soil is used in both soft and hard types with the density of 1900  $kg/m^3$ , the characteristics of the soil model is presented in Table 2 (6).

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<b>Table 2.</b> Characteristics of the soft around the tank (0)						
Angle of friction	viscosity	modulus of elasticity	Poisson's ratio	Soil type		
		$kg/m^3$				
26	1400	1000000	0.25	ig(Aig) Soft soil		
35	0	7000000	0.35	$\left(B ight)$ Hard soil		

Table 2. characteristics of the soil around the tank (6)

The subject models are listed in Table 3, in all models, the tanks include 3 meters of water and the middle column of the tanks is in form of a square with an area of 1 meter. An example of this model is presented in Figure 8.

Tank height ( <i>m</i> )	Soil type	Tank dimensions ( <i>m</i> )	( <i>m</i> ) Burial depth	The form of tank	Model No
5.6	A	10*10	5	cubic	Model 1
5.6	A	10*10	8	cubic	Model 2
5.6	A	10*10	15	cubic	Model 3
5.6	В	10*10	5	cubic	Model 4



Table 3. specification of tanks (6)

Fig.8. the 3D model of the cubic tank (6)

El Centro earthquake record was applied on a bedrock in form of time history. In consideration of the entire seismic record, the volume of calculations greatly increases, therefore, to prevent an increase in the volume of calculations, only two seconds of seismic record ranging between 0.4 to 2.4 seconds is taken into considerations. El Centro earthquake record is shown in Figure 9.



Fig.9. Al Centro earthquake record (6)

After seismic analysis of the proposed models, the results were obtained in form of Figures 10 and 11. In these figures, the stress and displacement values in the set locations, are measured in accordance with changes in the height of tanks. Afterwards, parameters such as tank depth and type of soil were changed to calculate the level of stress and displacement in the tank wall. First studies on changes in wall deformation and stress models of 1 and 4, Figure 10 was drawn in order to evaluate the effect of soil type on deformation and stress in the tank wall, in addition, figure 11 was drawn to investigate the effect of the stress and deformation changes in the walls of the tank.



Fig.10. stress and deformation changes over the height according to soil type (6)



Fig.11. stress and deformation changes over the height according to the burial depth (6)

Figure 10 shows that changes of deformation over the height of the wall is more significant in soft soil compared to hard soil. And in both models, the maximum tensile stress is in the middle of the tank. In soft soil, the scope of stress change over the height, is more significant than that in hard soil. In addition, the level of tension in the soft soil is considerably more than that in hard soil types. In Figure 11 it can be seen that tanks at a depth of 5 and 8 meters have performed almost identically but with increase of depth to 15 meters, stress and displacement will increase and the diagram will change significantly.

#### 4. Comparison of different fluids in buried tanks

The Rectangular tank, with the walls connected to the rigid bottom, and a width of 6 meters and depth of 3.5 meters which is filled with a fluid up to 3 meters of its depth. The walls and floor of the tank has a thickness of 50 cm and is rigid. Examples of the above model is shown in Figure 12 (8).



Fig.12. the finite element model considered for the tank and the surrounding soil (8)

To investigate the seismic models such as the above mentioned models of Bam and Al Centro ear quake records, whose acceleration is scaled at to 0.8 g and 0.45 g respectively, these records are introduced to a soil type in  $\phi$ , c conditions, with  $0 kg/m^3$  and 35 degrees. The Concrete and soil characteristics in the tank model is presented in Table 4. In addition, different fluids used here and their specifications in this study are presented in Table 5.

Specific weight $\left(kg/m^3\right)$	Poisson's ratio	Module of elasticity $\left(kg/m^2\right)$	specifications
2400	0.2	2.1*109	concrete
1800	0.35	$7*10^{6}$	soil

Table 4	aanarata	and	coil	apagifia	tional	(Q)	۱.
1 able 4.	concrete	anu	5011	specifica	uions	0	)

Table 5. fluid specifications (8) $(kg * s/m^2)$ viscosity $(kg/m^3)$ Specific weightBulk modulus $(kg/m^2)$ specific				
1. 15* 10 <sup>-4</sup>	1000	2.1*10 <sup>8</sup>	water	
8.1*10 <sup>-3</sup>	860	1.55*10°	oil	
3.1*10⁴	680	1.03*10 <sup>8</sup>	gasoline	

After the analyses, the dynamic pressure exerted on the bottom of the fluid tank in the above-mentioned models, is as shown in Table 6

**Table 6.** dynamic pressure of the fluid exerted on the bottom of the tank  $(kg/m^2)$  (8)

El centro	Bam	Fluid/earthquake
62261.7	92542.4	water
47578.2	80866.2	oil
34278.6	60743.2	gasoline

The results of this table reflects the fact that when the fluid is in the water tank, in both earthquake records, the maximum dynamic pressure is exerted to the bottom of the tank, and gasoline exerts the minimum dynamic on the bottom of the tank. According to Table 2, this is attributed to higher specific weight of water compared to other fluids

Now, the Fluids listed in Table 2, are investigated for the push distribution of the fluid dynamic pressure caused by the *sloshing* phenomenon. The results of this analysis on the basis of maximum amount of pressure between fluid and structure, is shown in Figures 13 and 14. It should be noted that the maximum fluid dynamic pressure is exerted on the middle part of the tank wall at a distance of 1.5 to 2 meters from the fluid level.



Fig.13. Push distribution of the fluid dynamic pressure exerted on the tank wall (Bam earthquake) (8)



Fig.14. Push distribution of the fluid dynamic pressure exerted on the tank wall (El Centro earthquake) (8)

# 5. The effects of water depth and length to height ratio on the frequency of the tank

The study model, is a cuboid tank which has solid plates parallel to the x axis and flexible plates along the y axis. This model is shown in Figure 15.



Fig.15. 3D model of the proposed tank to be evaluated by the proposed analytical method (4)

The Model defined in Figure 15, is divided into 2 models in terms of the connection conditions of rigid and flexible plate, the two models are as follows:

• Model 1: a rectangular plate which is fixed on the bottom and has simple anchor on the sides and is open on the top side, this model is called ss - c - ss - f. This model is shown in figure 16:



Fig.16. boundary conditions for the plate modeled in form of ss - c - ss - f (4)

• Model 2: In this model, the top side is open and the other three sides are fixed. This model is called c - c - c - f. The model is shown in Figure 17



**Fig.17.** the boundary conditions for the plate modeled in form of c - c - c - f (4)

Earthquake record applied on these models, is the horizontal component of the North-South record in the 1940 El Centro earthquake which is shown in Figure 18



Fig.18. the horizontal component of the North-South record in the 1940 El Centro earthquake (4)

The models defined by the earthquake record which is shown in Figure 18, were evaluated using an analytical method. The natural frequency of the tank, in terms of different depths of the fluid inside the tank, was measured by the analytical method and is presented in Figure 19.



Fig.19. natural frequency changes in fluid - tank systems in terms of the fluid depth (4)

As can be seen, with increasing depth of the fluid in the tank, the natural frequency of the fluid-tank system is reduced. The Values for the main frequency at a height of 11.2 m for the 2-D, 3-D and 3-D ss - c - ss - f systems and 3-D c - c - c - f systems is 3.07 and 3.5 and 3.67 respectively. In addition, the length to height ratio of the tank and its impact on the frequency was investigated in two-dimensional and 3-dimensional ss - c - ss - f and 3-dimensional c - c - c - f models. Range of aspect ratios, is intended. The analysis, frequency values are calculated and shown in Figure 20. The range of changes in length to height ratio, was considered  $10 \le 2L_y / H_c \le 20$ . The analysis, frequency values are calculated and shown in Figure 20 (4).



Fig.20. the changes in the main frequency of the system in terms of length to height ratio of the flexible tank wall (4)

With Increase in  $(2L_y/H_c)$  levels, the main frequency values will be inclined towards the amount obtained by the analysis of two-dimensional model and in fact the three-dimensional anchor conditions will fade. For  $(2L_y/H_c) = 10$ , the main frequency will be very close to its values in the two-dimensional analysis. For  $(2L_y/H_c) \ge 10$ , the changes in  $(2L_y/H_c)$  will have no effect on the main frequency. This means that the seismic response of the systems, with not change significantly for great ratios  $(2L_y/H_c)(4)$ .

## 6. Conclusion

The presence of soil around the tank is extremely effective in reduction of Horizontal displacement and thus reduction of tension. It should be noted that due to low displacement and stress in buried tanks, Sections used in buried tanks in more delicate than Sections used in non-buried tanks (5).

Soil type has a significant impact on Soil-structure interaction. The softer soil cause greater stress around the walls of the tank. Soft soil show greater interaction compared to hard soil. Moreover, with increase in the depth of the buried tank, tension and displacement will also increase (6).

Fluid dynamic pressure exerted on the floor and walls of the tank is directly correlated to fluid specific weight. Therefore, specific fluids should be used in the process of tank designing so that reasonable and economical results may be obtained (8).

With increase in depth of the fluid in the tank, the natural frequency of the fluid-tank system involved is reduced. With increase in  $(2L_y/H_c)$  values, the values of the main frequency is reduced and will be inclined towards the values of two-dimensional model analysis. In fact, in this condition the three-dimensional anchor conditions will fade (4).

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