Bulletin of Environment, Pharmacology and Life Sciences
Bull. Env.Pharmacol. Life Sci., Vol 4 [Spl issue 1] 2015: 28-34

Online ISSN 2277-1808
Journal's URL:http://www.bepls.com
CODEN: BEPLAD
Global Impact Factor 0.533
Universal Impact Factor 0.9804

FULL LENGTH ARTICLE **OPEN ACCESS**

Comparative Study of the Effects of Different Types of Foundations on the Maximum and Minimum Values of Cyclic Stresses in Inhibited and Uninhibited Cylindrical Steel Tanks

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ABSTRACT
In this study we investigate the effects of different types of foundation son the maximum and minimum values of inhibited and uninhibited cyclic stresses of ground cylindrical steel tanks.For this purpose, we used two types of wide and long tank with a height to diameter ratio of 0.343 and 1.53. The finite element method was used to analyze the problem using ABAQUS software, as well as direct modeling approach for modeling fluid collection, tanks, foundations and soil. Also,three types of soil concrete, widespread concrete and concrete annular foundations to include the effects of foundations. The results showed that the maximum stress in uninhibited tanks on the concrete annular foundations nearly coincides with widespread concrete. This indicates that the use of all concrete foundation is of little advantage.
Keywords: *Cylindrical steel tanks, inhibited, uninhibited, wide, annular foundation*

INTRODUCTION

Damage to lifeline systems such as tanks can cause serious damage to the local public security, as occurred in the 1971 San Fernando earthquake and put public water supply system of the city in trouble. Therefore, more and more complete study of the behavior of these systems especially that of fluid storage tanks is essential**.**However, extensive studies have been conducted on the static and dynamic behavior of tanks, but still many aspects of the behavior of the tank needs more experimental and numerical investigations including the **w**idespread foundations impact on the overall behavior of the tanks that is the subject of this investigation**.** The first comprehensive study of the dynamic behavior of the tanks was conducted in 1934 on rigid tanks by Jacobsen & Hoskins [1]**.** It seems that due to their simplifying assumptions as the rigid wall of the tank and foundation they did not included interactions correct behavior in the model. Housner [2] in its simplified model divided the fluid mass into two parts, rigid and swinging. Thus, he divided the hydrodynamic pressure on the tank body into two components of the sloshing pressure caused by tank accelerated mass and osculating pressure caused by the surface waves. Cambra [3] in an experimental study evaluated the impact of foundation flexibility on the degree of tank floor scaling up in both static and dynamic states. The results showed that tank floor scaling up rates and tank wall stresses are less when the tank is located on a solid foundation than when the tank is located on the flexible foundation. However, in this experiment, foundation and tank are located directly on the shaking table and thus the simultaneous effect of foundation and soil has not been investigated. Godoy & Sosa [4] studied the impact of local and regional foundation subsidence on thin-walled cylindrical liquid storage tanks behavior as well as buckling and stress created in the tank walls. The results showed that the deformation of thin-walled shells made by local foundation subsidence are very different from that of caused by wind or earthquakes and most are caused by non-linear behavior of the shell. Bakhshi & Hassanikhah [5] in their paper studied the seismic behavior of fluid storage tanks in both inhibited and uninhibited states. Their results showed that axial, cyclic tensile and compressive stress of tanks' walls increases by increasing the flexibility of the soil andreducing the wall thickness.

This study attempts to use tanks used in industry, especially in the domestic industry for modeling. Tanks were modeled without ceilings, and tank walls were considered flexible. Moreover, we also considered the effects of interactions using the finite element method by ABAQUS software. We investigated different types of foundations effects in wave height in two inhabited and uninhabited wide and tall tanks.

Finite Element Modeling

Direct modeling approach is used in order to model the system finite element modeling. Thus, to fully consider the interaction of the fluid tank all in all fluid elements, tank, foundation and soil are directly modeled**.** The fundamental problem of soil mass direct modeling is the use of absorbing dampers around the soil to avoid hitting waves back to the system.

Soil modeling

Drucker-Prager yield criterion is used for soil modeling in linear mode.

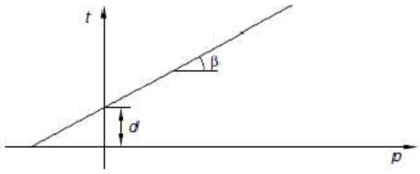


Figure 1 Drucker-Prager linear model

$$\mathbf{F = t - ptan\beta - d = 0} \qquad (1)$$

Where, β is the linear submission surface slope in stress-strain that is usually referred to as the materials friction angle, materials adhesion, p equivalent compressive stress, and t triaxial tensile stress. 8-node elements profile according to Table 1 is used to model soil.

Table 1 Behavioral characteristics of the modeled soil

d	β	$V_s\left(\frac{m}{s}\right)$	υ	$E\left(\frac{MN}{m^2}\right)$	$\rho\left(\frac{kg}{m^3}\right)$
0	**38**	**400**	**0.29**	**825.6.**	**2000**

In the table above $\upsilon$is Poisson ratio and $V_S$shear wave velocity. Also Riley damping model is used for modeling soil material damping.

$$\mathbf{(2)\ [C] = \alpha[M] + \beta[K]}$$

mass and materials stiffness. Also, the **,** In the above equations [C], [M] and [K] are the damping matrix coefficients α and β are the damping coefficients proportional to the mass and stiffness. Equation 3 is used to calculate the attenuation coefficients assuming constant damping ratio between both frequencies of

$$\begin{Bmatrix}\alpha\\ \beta\end{Bmatrix} = \frac{2\xi}{\omega_1+\omega_2}\begin{bmatrix}\omega_1\omega_2\\ 1\end{bmatrix} (3)$$

Several models with different dimensions were created and analyzed to determine the soil mass dimensions until reaching the size of dimensions to the size does not increase the accuracy of the results. Thus, the soil boundary in a form a cube with dimensions 150 × 150 × 40 m is considered. Moreover, the viscous damper is used in order to prevent the return of waves hitting the soil boundary at the edges.Constant coefficients of the damperunit perpendicular to tangent to the area were obtained by the following relationships:

$$\mathbf{C_n = \rho V_p} \qquad (4)$$

Where ρ is soil density, andV_p wave velocity (P shear wave). $C_n$is surface unit constant in the direction perpendicular to the surface boundaries. Also, to calculate V_p the following equation was presented used by Laysmr [6] to calculate the V_p:

$$\mathbf{V_p = \frac{3.4V_s}{\pi(1-\nu)}} (5)$$

Tanks Modeling

To evaluate the seismic performance of steel storage tanks two wide and high-profile tanks according to Table 2 were studied.To model the tank shell four-nodes double curved membrane elements with reduced integration were used. Steel tank shell and floor is made of steel with material with elastic modulus 210G Pa, Poisson ratio of 0.3, 240 M Pa yield stress and ultimate stress is 360 MPa.

Table 2 Tanks Dimensions

h/D Ratio	D(m)	h(m)	h_w(m)
0.343(Wide)	35	12	10
1.53(Tall)	15	23	20

In the above table *D* is tank diameter, *h* heightof tank shell and h_w height of the fluid in the tank.Finally wide and tall tanks were modeled according to Fig. 2 and 3.

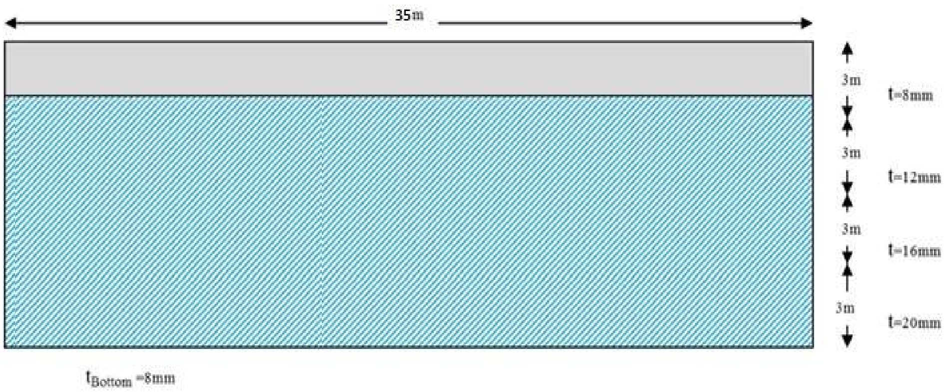


Figure 2 Wide tank

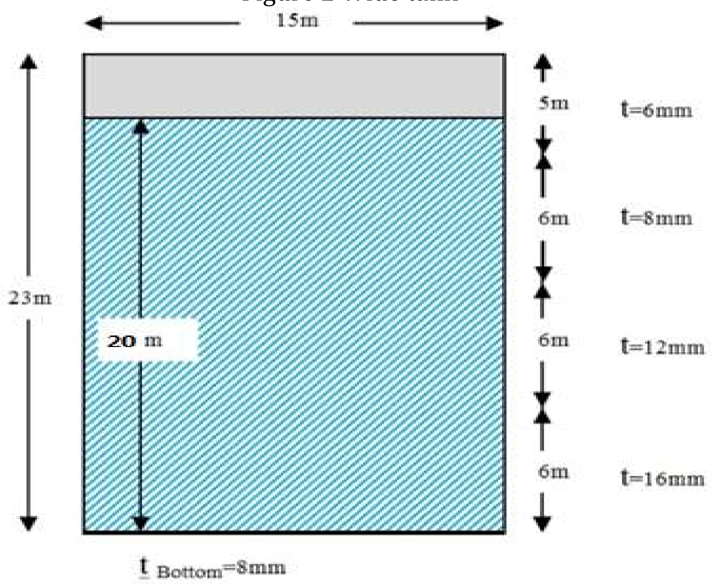


Figure 2 Tall tank

Fluid Modeling

The fluid in this research is water. There are two distinct effective components on fluid hydrodynamics problems namely the fluid transfer component and sloshing component.Sothe phenomenon of surface waves must be considered for correct modeling of the fluid. For this purpose, a special material called (EOS) was used in the finite element program ABAQUS for modeling the surface wave's phenomenon. We need the speed of sound in the fluid volume for modeling fluid with this type of material. We know that the speed of sound in water equals to 1450.6 meters per second.

Foundation Modeling

The 8-node elements with reduced integration are used in foundation modeling. Behavioral model intended for the foundation materials is the elastic model. Three different models are intended for foundation, the soil foundation (flexible), widespread concrete foundation and concrete annular. We use the following equation to calculate the elastic modulus of concrete:

$$\mathbf{E_c = 0.043\rho^{1.5}\sqrt{f'_c}} \qquad (6)$$

In the above equation, ρ is concrete density in kilograms per square meter and f'_c its compressive strength on MPa. Accordingly, concrete elastic modulus is calculated in MPa. Thus, considering the fact that $\rho = 2400\frac{kg}{m^3}$ and $f'_c = 35MPa$, concrete elastic modulus is obtained as the following:

$$E_c = 0.043\rho^{1.5}\sqrt{}$$

The behavioral characteristics of foundation materials considered in this study have been determined in accordance with Table 3.

Table 3: The behavioral characteristics of foundation materials

Foundation Stiffness	Material			
Flexible	Soil	2000	0.29	0.8256
Solid	Concrete	2400	0.2	29.9

Regulations API650 on widespread concrete foundation design was used todesign dimensions and depth of the foundation, this regulations has been delegated this type of foundation to ACI318. The foundation was established on the recommendations of the regulations by dimensions as shown in Table 4.

Table 4: Tanks foundation view appearance

h/D Ratio	R(m)	d(m)
0.343(Wide)	18.5	1
1.53(Tall)	8.7	1.2

In the above table *R* and *d* are respectively the radius and depth of the foundation. Also, a concrete strip with a width of 2 meters and height of widespread foundation is considered in order to model annular foundation Figures 4 and 5 show wide tank models as an example.

Figure 4: Mesh model of wide tank

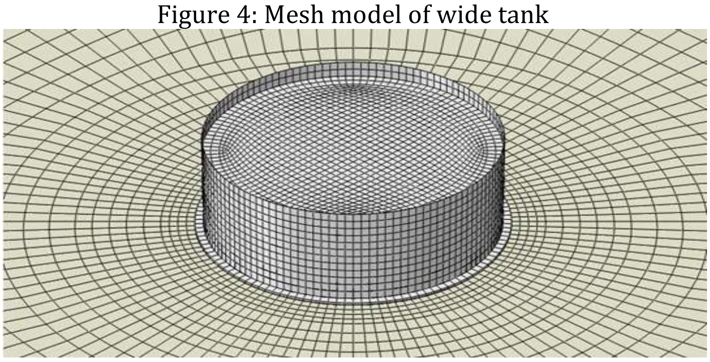
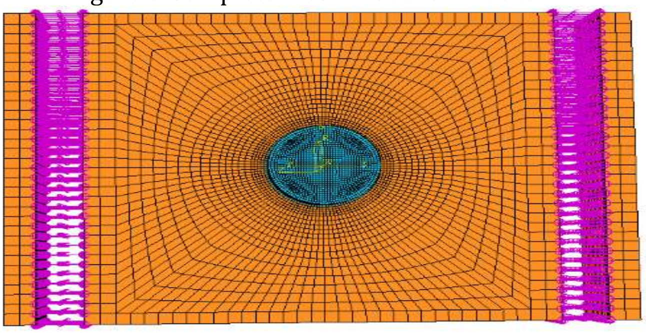


Figure 5 Complete mesh model of wide tank



3- The earthquake records

Records required were selected using by the guidelines of 2800 earthquake Code of Regulations in Iran as : well as 038 Regulation of petrochemical industries according to the following criteria

A) Accelerogram belongs to the earthquakes that satisfy the design earthquake conditions in which the
. effects of the magnitude distance to the fault and seismic source mechanisms are considered
. B) Accelerogram site is similar as possible in terms of geological, tectonic and seismic geology features
. C) The duration of strong ground motion in accelerogramsshould be at least equal to 10 seconds
. Records were selected according to Table 5 and 2800 code method was used in equalizing them

Table 5: Selected records

Records	Name	Station	Magnitude	Site Conditions	PGA(g)
1	Kobe (270)1995/01/16	KJMA	6.9	Geomatrix or CWB(B) USGS (B)	0.599
2	Loma Prieta (270)1989/10/18	57007 Correlates	6.9	Geomatrix or CWB(B) USGS (B)	0.644
3	Northridge (270)1994/01/17	24278 Castaic - Old Ridge Route	6.7	Geomatrix or CWB(B) USGS (B)	0.568

RESULTS

Tables of results

Dynamic explicit analysis was used to analyze the model. First, the total weight of the system in a second applied linearly and then to remove excess vibration no force applied for a second and each unidirectional accelerograms applied in the x-direction after 10 seconds of strong motion. The analysis results are shown in Tables 6 to 9.

Table (6) the effect of foundation type on the maximum annular stress in the uninhibited tank (S11 - max)

	Kobe		Loma		North	
	wide	Tall	wide	tall	wide	tall
Widespread concrete foundation	316	245	268	275	315	269
Soil foundation	349	247	289	278	378	273
Annular concrete foundation	305	233	260	274	295	281

Table (7) the effect of foundation type on the minimum annular stress in the uninhibited tank (S11 - min)

	Kobe		Loma		North	
	wide	tall	wide	tall	wide	Tall
Widespread concrete foundation	317-	64-	191-	154-	312-	115-
Soil foundation	323-	78-	267-	146-	361-	118-
Annular concrete foundation	313-	318-	244-	225-	254-	262-

Table (8) the effect of foundation type on the minimum annular stress in the inhibited tank (S11 - max)

	Kobe		Loma		North	
	wide	tall	wide	tall	wide	tall
Widespread concrete foundation	284	248	256	263	325	531
Soil foundation	293	285	310	441	408	557
Annular concrete foundation	269	239	264	244	318	316

Table (9) the effect of foundation type on the minimum annular stress in the inhibited tank (S11 - min)

	Kobe		Loma		North	
	wide	tall	wide	tall	wide	tall
Widespread concrete foundation	284-	196-	268-	159-	338-	517-

Soil foundation	284-	460-	258-	431-	395-	558-
Annular concrete foundation	244-	272-	178-	230-	291-	248-

Example of the results
Figure 6 is a diagram of the maxima and minima of the annular stress presented as an example. The shape of the results:

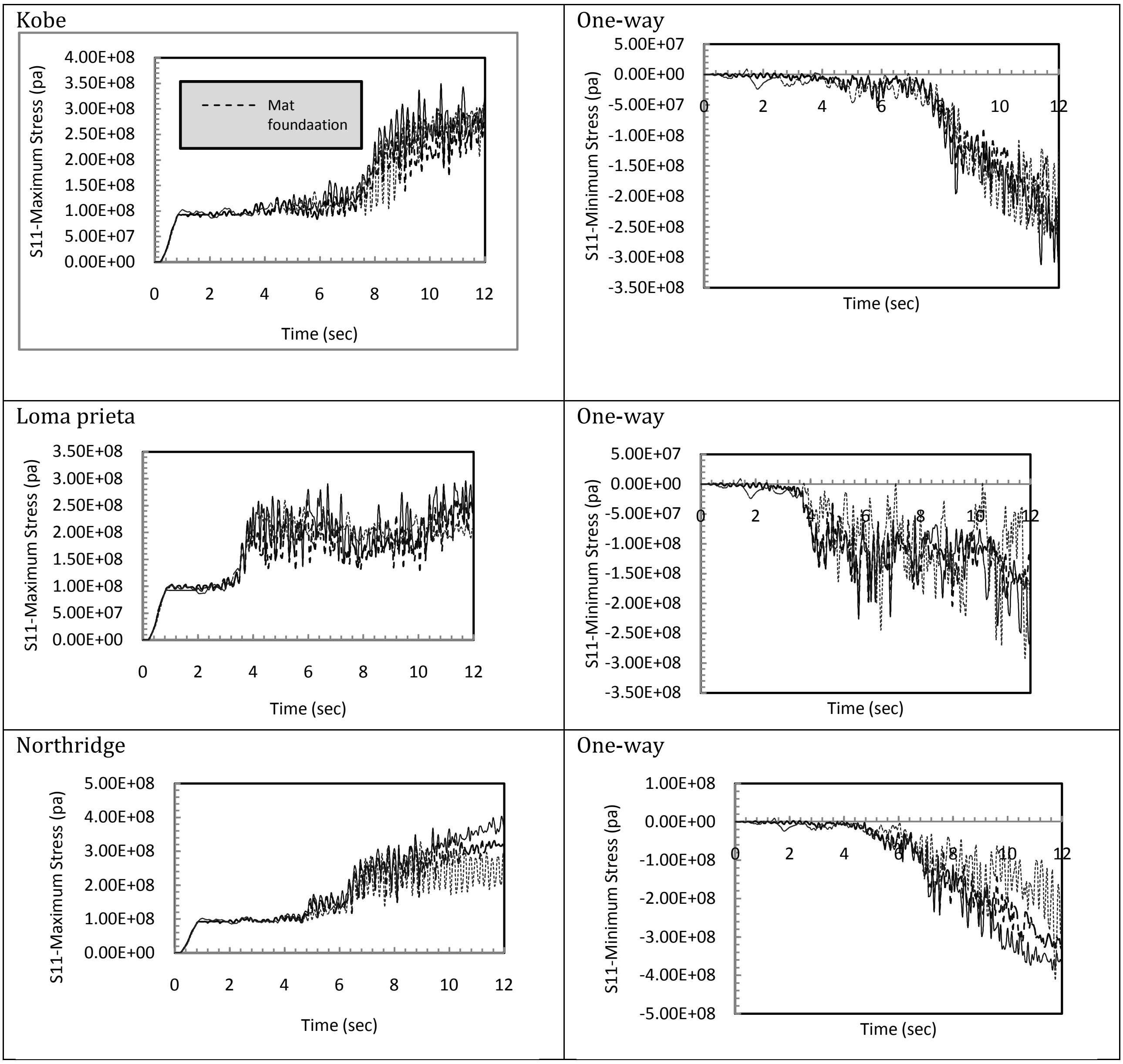


Figure (6)) the effect of foundation type on the maximum and minimum annular stress in wide uninhibited tank wall by unidirectional stimulation

The results obtained showed that the annular stresses on the uninhibited wide tank wall on soil foundation show the higher value than that of widespread foundation. But there is no difference among three types of foundations on annular stress minimum.

CONCLUSION
The main results obtained are as follows:

1- Wide uninhabited tank wall annular stress on soil foundation shows higher values than that of widespread foundation, but in the tall uninhibited tanks there are no significant differences in the results in soil foundation and widespread foundation.

2- In the case of uninhibited tanks located on the annular foundation the maximum stress results almost coincide on widespread concrete foundation, this indicates that the use of all concrete foundation is of little advantage.

3- Thebehavior pattern is different in wide and tall uninhibited tank in terms of minimum stress, while there are no differences in wide tank annular stress in three types of foundations. In tall tanks, the minimum annular stress is strongly negative in ring foundations goes toward compression and is more than two other stress modes in numerical value.

4- In both wide and tall inhibited tanks, annular stress on tank wall on soil foundation is higher than that of widespread foundation. The difference is significantly high in the tall tank.

5- Wide inhibited tanks on ring concrete show higher tank wall stress among all other types of foundations and largely close to the results of the tank on widespread concrete foundation.

6- There are differences in seismic behaviors of wide and tall tanks in terms of annular stress.

ACKNOWLEDGMENTS

I sincerely acknowledge and appreciate Dr. Javad Salajegheh with hope for more success for him.

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