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STRUCTURAL ANALYSIS OF THE SINGLE AND GROUP FUEL TANKS UNDER THE INFLUENCE OF SEISMIC LOADS IN BASRA GOVERNORATE

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ABSTRACT

In this paper, the finite element ANSYS software was used to study the seismic behavior of cylindrical fuel storage tanks in west of Basra governorate. Single and group tanks are analyzed under free vibration (empty and full tanks) and under the El-Centro earthquake component for an impulsive case and full tank with fuel. The interaction between tanks wall and internal fuel was considered. The study includes Hoop forces, bending moment, shear force, horizontal displacement and hydrodynamic pressure. Also, the reflection point for bending moment and shear force for tank wall is estimated.

This study shows that the response of a single tank is larger than group tanks, and the hoop force decreases about (10-17) %, while the pressure and displacement decrease about (5-10) %, and the shear force and bending moment are decreased about (37-42) %. The increase in tank diameter leads to increase the response of tank. The Time has come to the understanding that the fixed support of tank is more stable than hinge support.

KEYWORDS: Seismic Load, Dynamic analysis, Cylindrical Fuel Tank, ANSYS

1. INTRODUCTION

Storage tanks are widely used in petroleum, chemical, and other industries. Most of them are flammable, explosive, and toxic substances. They are essential facilities in industrial production. Therefore, once a tank is destroyed during an earthquake, it will not only cause direct economic losses, but it may also lead to leakage of stored materials and serious secondary earthquake disasters . Such as earthquake fires, explosions, and environmental pollution. The consequences are very serious (Lin and Shen, 2006). In the 1964 Alaska earthquake, three tanks fired on three tanks, and some tanks exploded, the fire continued for three days. It can be seen that the destruction of the tank can cause huge losses. The anti-seismic problem of storage tanks has long been valued and studied (Zhan and Chen, 1986). In 1957, Housner proposed to simplify the liquid in the storage tank as a mass-spring model. The model is to divide the dynamic liquid effect in a tank into pulsation components: that is, the liquid effect that synchronously moves with the tank wall (Ruan, 2003). In 1969 Edwards used the finite element method to simulate the seismic response of a coupled fluid-storage structure. The study used the Sander shell theory to assume that the fluid is inviscid, non-rotary, and incompressible, and the shell is discretized into rings using symmetry. Mainly: The dynamic hoop response of the tank is multi-wave shell vibration rather than beam vibration; the elastic deformation of the tank increases the hydrodynamic pressure, and the impact of the liquid surface is important for the response of the tank body (Peng, 2000).

In this paper, the finite element ANSYS software was used to simulate the seismic response of the vertical cylindrical fuel storage tank. Single and group cylindrical tanks are analyzed under free and forced vibration; also the interaction between tank wall, fuel, soil, and footing was considered.

2. FINITE ELEMENT MODEL

Numerical analysis has been developed using finite element software, ANSYS version 17.2. The software has powerful capabilities to simultaneously analyze advanced multiphysics couplings of structure, heat, fluid, magnetism, and acoustics. ANSYS software was the first design analysis software that passed through the ISO9001 quality certification, (the American Society of Mechanical Engineers) (SAS, 2017).

2.1. Geometry

The problem is representing a cylindrical tank used to save the fuel in Basra- Iraq oil field. The cylindrical tank with an inner diameter 76 m, height 12 m, and different thickness for base and wall as shown in table 1, the fuel level (F.L) in tanks about 10.5 m. Concrete ring foundation with (3 * 1.5) m under the tank wall and subbase soil under the tank, Fig. 1. (F1 and F2 is the same dimension).

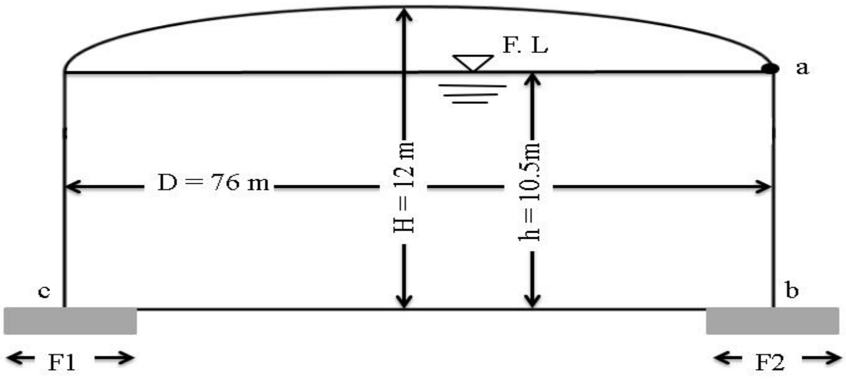


Fig. 1. The storage tank used in the study.

Table 1. Thickness of tank.

Item		Thickness, mm
	Base	8
Wall	Height from 0 to 2 m	19
	Height from 2 to 4 m	16
	Height from 4 to 8 m	15
	Height from 8 to 12 m	10
	Roof with truss	10

2.2. Model

Taking into account the characteristics of the liquid storage tank structure during the finite element modeling, SHELL 181 was used to build the tank wall model. The element has four nodes; each node has six degrees of freedom, respectively, along with the node X, Y, Z. The expression of an element defines the thickness by sections. The fluid in the tank was modeled using the FLUID 80, a modified 8-node solid element (SOLID 45) of a three-dimensional structural element that simulates a fluid without a net flow rate in the vessel, which is well suited for calculation fluid-solid interface under hydrostatic pressure. The FLUID80 has 8 nodes per cell, and each node has 3 degrees of freedom: Translation in X, Y, Z directions. Both foundation and soil are modeled using SOLID45 (8-node solid element); also CONTACT173 contact element and TARGET170 target element (4-node interface elements) are used for modeling the interface between soil, tank, and foundation. The Vertical tank is modeling by used ANSYS software as shown in Fig. 2 (ANSYS. V. 17.2., 2017).

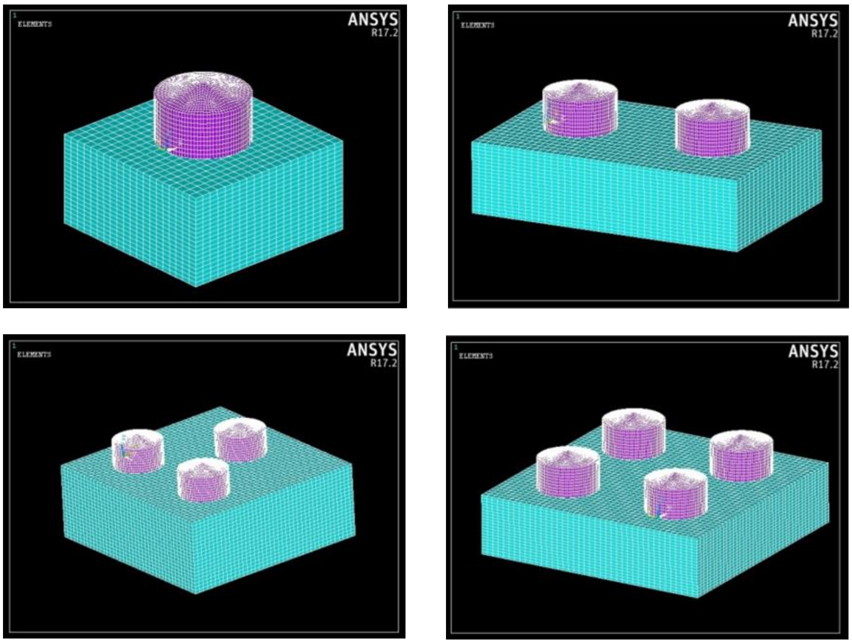


Fig. 2. Modeling of the storage tank by used ANSYS program.

2.3. Boundary condition

The boundary condition used for soil edge is about 10 footing width for all directions, soil thickness is 30 m under foundation, and fixed end support used for all the boundary conditions. Also, the clear distance between tanks is 80 m (Anil, 1980).

2.4. Material

Steel tank, concrete footing, soil, and fuel material properties are given in Table 2. The interface coefficient of friction was assumed about 0.7 (Zhai and Fan, 2014).

Table 2. Material properties.

Item	Unit	Steel tank	Concrete Footing	Soil	Fuel
Density	KN/m^3	78.5	24	17.5	7.02
Young's modulus	N/mm^2	2E9	23000	44	0.2E9
Poisson's Ratio		0.2	0.3	0.35	0.49
Uniaxial compressive stress	N/mm^2	-----	21	-----	-----

2.5. Loading

In this paper, Elcentro earthquake is applied on the soil. This type of earthquake consists of several sub-events, and the magnitude of these events was unusually strong in aftershocks, AbdulMutalib, (AbdulMutalib, 2010) concluded that Elcentro wave usually occurred in Iraq.

Also, the study is assumed modification factor to represent the horizontal time history employed in the ground as shown in Fig. 3. The modification factor used to reach the acceleration to the ground acceleration. The peak acceleration of Elcentro earthquake is 0.319g. The damping ratio is assumed 5% for whole study (Jayalekshmi, 2014).

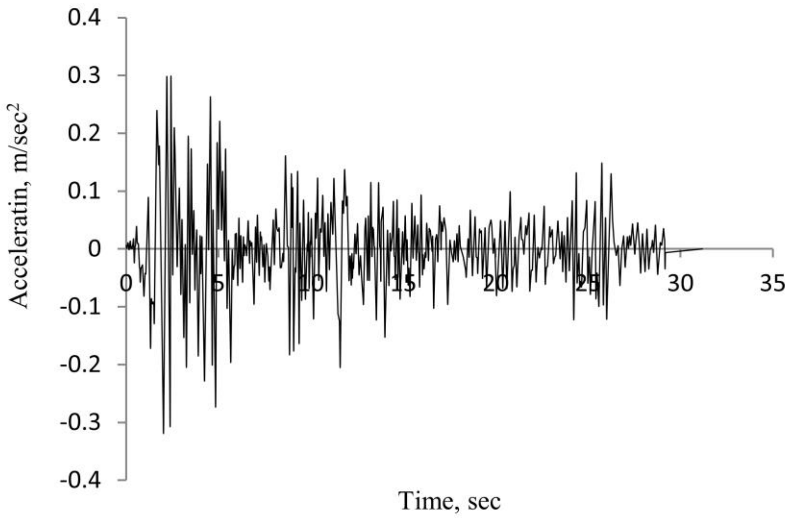


Fig.3. Acceleration time history "Elcentro earthquake"

2.6. Dynamic analysis

For simulation exact seismic condition, acceleration time history of seismic is applied on down boundary of soil model. The transient dynamic analysis is used to analyze the seismic response of a single tank and group tanks supported on soil. ANSYS software uses three transient method in analysis, full analysis method, reduced analysis method and superposition analysis method, where the full analysis method is used in this study, this method is directly solve and no need additional assumptions, and is suitable to nonlinear analysis (ANSYS. V. 17.2., 2017).

3. RESULTS

3.1. Free vibration analysis.

Free vibration for tanks is carried out before performed time history vibration. The natural frequencies are obtained by used finite element method for impulsive modes. Table 3 shows the natural frequencies computed by finite element method for tanks with empty or full with fuel. From Table 3 it can be observed, the decrease in natural frequency (30 - 50) % due to increasing the number of tanks in the case of tanks empty and full.

Table 3. The natural frequencies for tanks.

No.	Models	One Tank		Two Tanks		Three Tanks		Four Tanks	
		Empty	Fill	Empty	Fill	Empty	Fill	Empty	Fill
1	Sloshing	1.67	0.63	1.18	0.46	0.96	0.38	0.83	0.33
2	Circular multi-wave	2.23	0.83	1.54	0.62	1.28	0.51	1.11	0.45
3	Impulsive	2.51	0.94	1.76	0.71	1.45	0.57	1.24	0.49

3.2. Time history vibration

The response of the tanks under the El-Centro earthquake component for an impulsive case and the fuel tank is represented by the maximum hoop force, bending moment, shear force, hydrodynamic pressure and horizontal displacement on the tank wall. Figs. 4 and 5 show the maximum hoop force and bending moment, respectively. It is observed from Fig. 4 that the hoop force is happening far of the tank base and about the middle height of the wall. Fig. 6 shows the maximum shear force, the maximum bending moment and maximum shear force are happen at the wall base of a tank. Fig. 7 show the distribution of hydrodynamic pressure along tank wall and Fig. 8 shows the maximum horizontal displacement at top tanks. Figs. 4–8 show the increase in tanks number decreases the force about (10-17) % and decrease the pressure and displacement about (5-10)%, while the shear force and bending moment is more effective by the number of tanks and reduce from (37-42)% because increase in mass leads to increase the stiffness of system.

3.3. Soil behavior

3.3.1. Settlement under tank base

Fig. 9 shows the magnitude of settlement under tanks base. For group tanks, the tank which has maximum value of settlement under the El-Centro earthquake component for an impulsive case is used. The maximum settlement was occurred under tank wall because the vertical force is concentrated in this point. The unsymmetrical in Fig. 9 is due to the sub-events in earthquake wave. Also, the increase in the number of tank leads to increase the group stiffness and decreased in settlement.

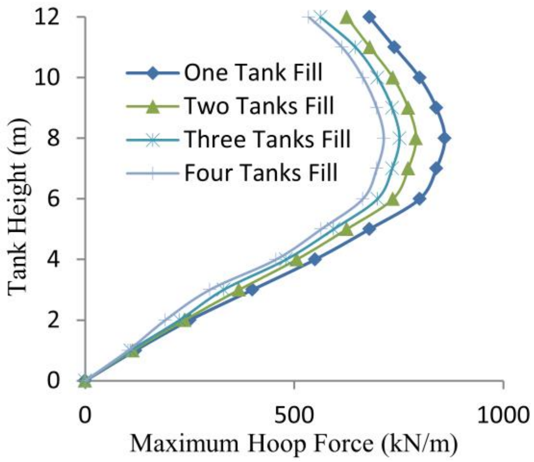


Fig. 4. Shows the Maximum Hoop Force under Seismic Wave

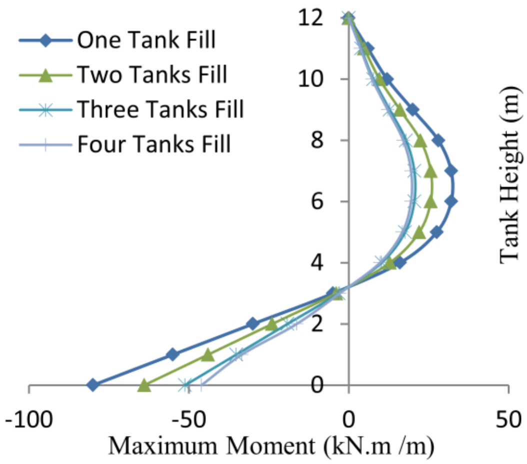


Fig. 5. Shows the Maximum Bending Moment under Seismic Wave

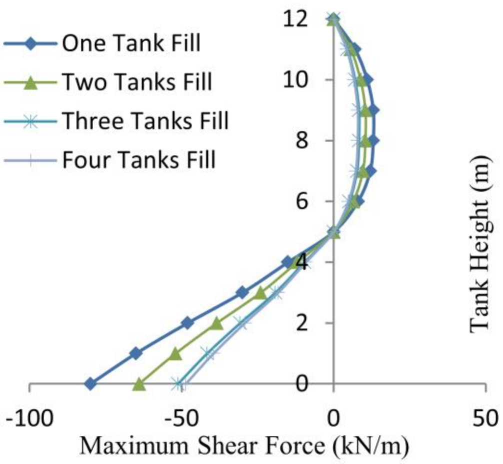


Fig. 6. Shows the Maximum Shear Force under Seismic Wave

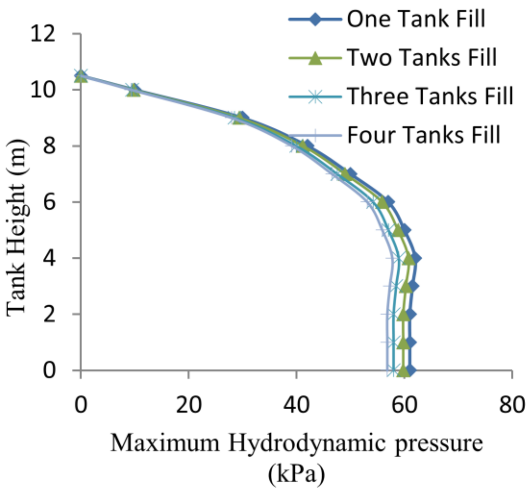


Fig. 7. Shows the Maximum Hydrodynamic pressure under Seismic

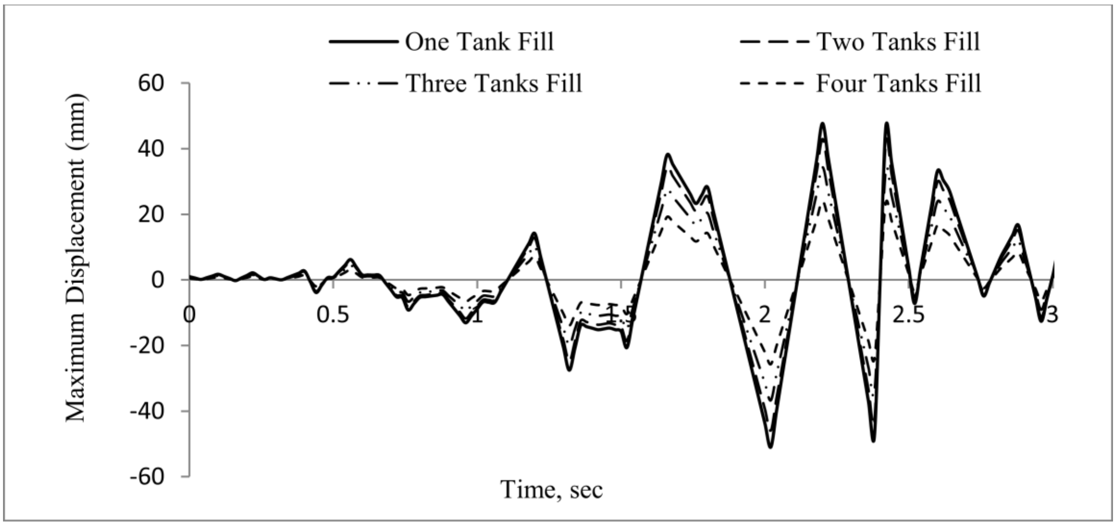


Fig. 8. The Maximum Displacement at point (a) tank under Seismic Wave

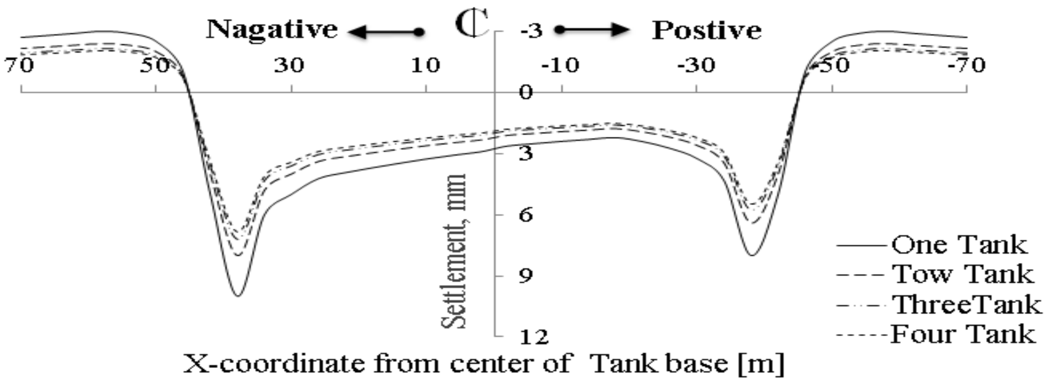


Fig. 9. Shows the Maximum Settlement under tank base

3.3.2. Contact pressure below the foundation

When the load is constant and symmetric, the contact pressure under the foundation is equal in all direction before soil failure occurs. Fig. 10 shows the magnitude of contact pressure below tank foundation F1 and F2 under the impact of the earthquake. It is observed that the contact pressure at the interior edges is higher than that one on the base. It is also noticed that the amount of contact pressure in the group tank is less than that in the single tank for the reason indicated in the above paragraph.

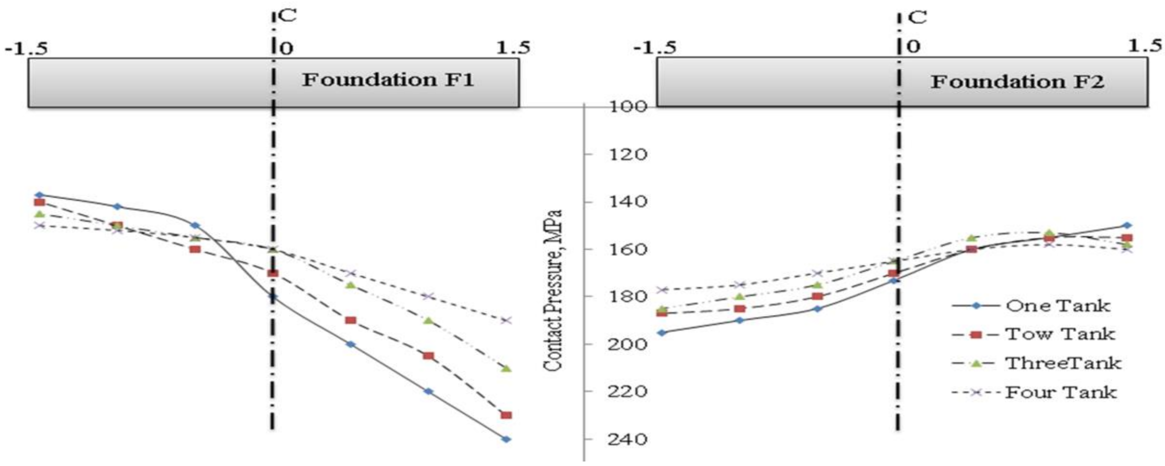


Fig. 10.Contact Pressure under Foundation

3.3.3. Effect of tank diameter

The diameter of the tank has a significant and clear effect on the hoop force, bending moment and shear force with constant tank height and fixity. Fig. 11 shows the effect of increasing the diameter of the tank on hoop force, where the increase is linearity. Figs. 12 and 13 show the effect of the diameter on bending moment and shear force respectively, the nonlinear relation between them and diameter.

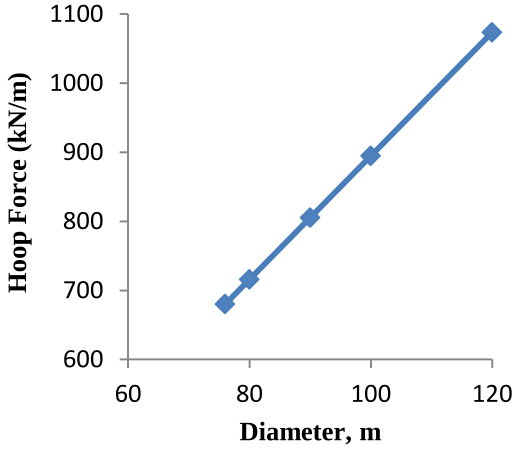


Fig. 11. The effect of increasing the diameter of the tank on hoop force

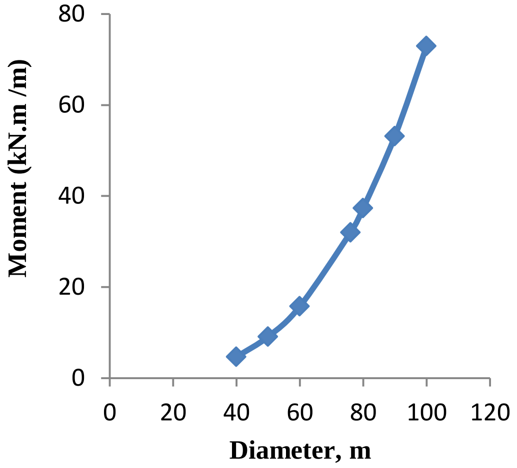


Fig. 12. The effect of the diameter on bending moment

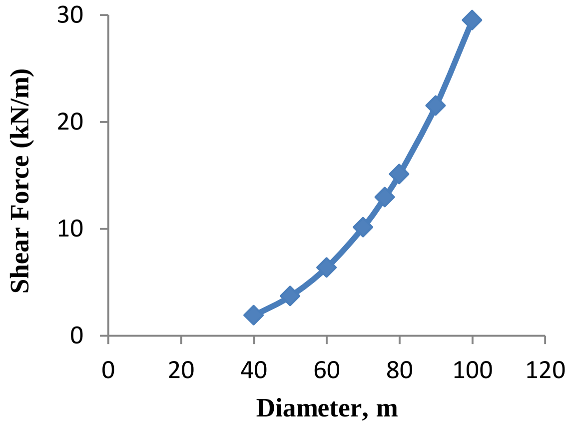
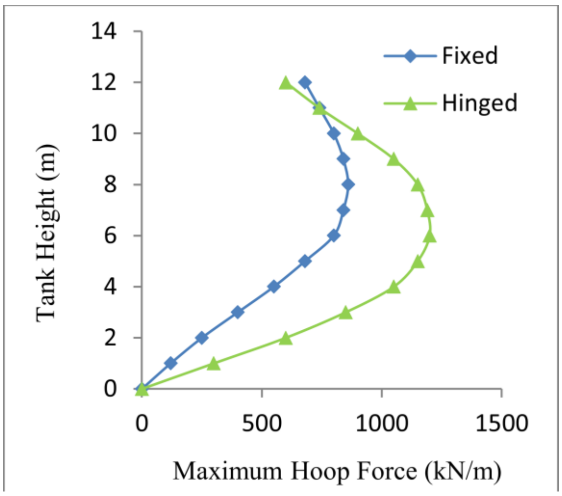


Fig. 13. The effect of the diameter on shear force

3.3.4. Effect of base fixity

The fixed support is more stable than the hinged support and this can be observed in Figs. 14–17. These figures show the effect of the fixity on the maximum value of the hoop force, bending moment, shear force and hydrodynamic pressure.



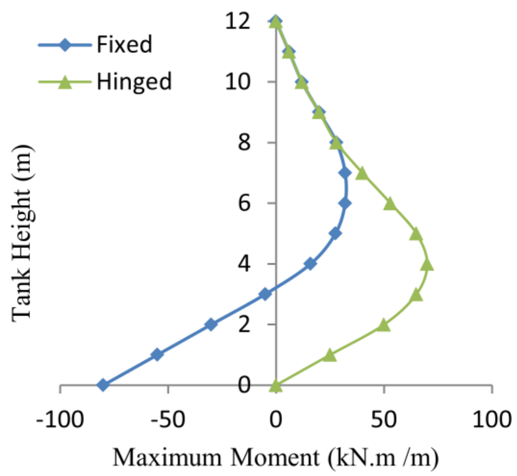


Fig. 14. The effect of the fixity on the hoop force

Fig. 15 .The effect of the fixity on the Bending moment

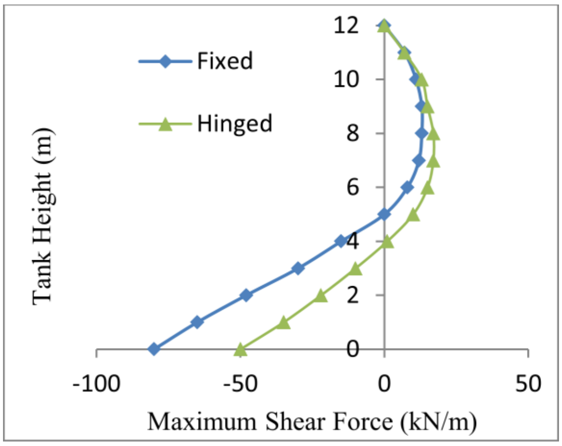


Fig. 16. The effect of the fixity on shear force

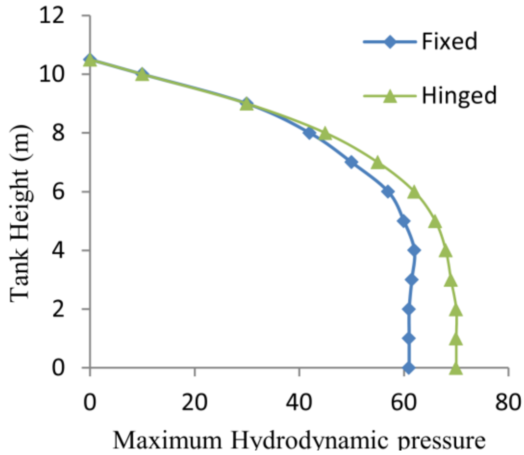


Fig. 17. The effect of the fixity on the hydrodynamic pressure

4. CONCLUSION

It can be concluded as stated in the above search on the following.

1. The finite element method takes agreement investigation for study in the dynamic response of three dimensions cylindrical fuel tank supported on the earth by concrete footing.
2. From free vibration of a tank, it can be observed the amount of fuel in the tank has increased the stability and the increase in the number of tanks is increases the total mass and therefore decreases the natural frequency about (30 - 50) % in the case of empty and full tanks.
3. The dynamic analysis of tank under seismic load shows the location of maximum hoop force over the middle height of the tank, while the location of shear force, bending moment, and hydrodynamic pressure near the base.
4. The reflection point about 0.33 of the tank height in the case of bending moment while it is about 0.42 of the tank height in the case of shear force.
5. Tank displacement is decreased about (5-10) % by increasing the number of tanks.
6. It is preferable to install a group of a full tank instead of the single tank because of their low response to the seismic loads.

7. Increasing the tank diameter increases the dynamic response, and this increase is linear for hoop stress and nonlinear for bending moment and shear force.

8. Bending moment and shear force is more sensitive than hoop force and hydrodynamic pressure for tank fixity. For hoop force in hinge, support is located under the middle of the tank while the location over the middle in fixed support. But the location of maximum shear force and bending moment is the same for both types of fixity.

9. The contact pressure at the interior edges is higher than that one on the center of foundation. Also, the displacement is maximum under the tank wall.

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