ISSN XXXX XXXX © 2017 IJESC

Research Article Volume 7 Issue No.7

Analysis and Design of Water Tank with Interaction between Fluid and Structure When Subjected to Earthquake Forces

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Abstract:
This research paper briefly describes the dynamic analysis of water tanks with interaction between fluid and structures and how Liquid storage tanks are essential structures in water, oil and gas industrials and the behavior of them during earthquake is more important than the economic value of the tanks and their contents.

Keywords: Dynamic, Earthquake, Gas, Industrials, Liquid, Numerical, Mass, etc.

1. INTRODUCTION

Liquid storage tanks are essential structures in water, oil and gas industrials and the behavior of them during earthquake is more important than the economic value of the tanks and their contents. It is important that utility facilities remain operational following an earthquake to meet the emergency requirements such as firefighting water or meet the public demands as a source of water supply. For these reasons, serviceability becomes the prime design consideration in most of these structures. A good understanding of the seismic behavior of these structures is necessary in order to meet safety objectives while containing construction and maintenance costs. One of the problems that are important in analysis and designing of these structures is the interaction between fluid and structure. Prediction of analytical response of coupled field systems is very complex and approximately no available. So most of investigations are concerned about numerical methods such as finite element method[2].

The Numerical analysis of elevated concrete water tanks with central shaft is performed by using of finite element software which fluid- structure interaction is considered[4].

2. DISCUSSION

Methods of considering interaction between fluid and structure are variety. These methods are basically divided to three groups, such as:

a)Added mass method, b) The Eulerian-Lagrangian method, c) The Lagrange-Lagrangian method. In the first method, some of the fluid mass is added to structure at interface of them and structure is subjected to dynamic analysis[1, 3]. In this method the structure is considered flexible and the compressibility and stiffness of fluid are neglected in most cases. This method is relatively simple and used for 2-D and 3-D structures but results will be often with considerable errors.

In the second method the main purpose is the solution of governing equation for fluid and structure domain. The governing equation of fluid domain for an ideal, homogenous, inviscid, compressible and irrotational flow in term of velocity potential variable, φ, is:

$$\nabla^2 \emptyset \ = \frac{1}{C^2}\frac{\partial^2 \emptyset}{\partial t^2} \ldots(1)$$

Where C is the velocity of acoustic waves.
By this assumption that fluid is incompressible, the Eqn.1 is conformed to Laplace Eqn.2.

$$\nabla^2\varphi = 0\ldots(2)$$

With solving Eqn.1 or Eqn.2 for fluid domain in terms of variables P or φ, that p is pressure variable, behavior of fluid is modeled in term of time for nodes with constant coordinates. Because the requisite variable for structure domain is nodal displacement, equations for couple field system of fluid and structure will be unsymmetrical and their solution is complicated. In the third method a particle has been considered in term of time and variable for fluid and structure domain is nodal displacement in finite element method. The most important advantage of this method is the use of same equation for fluid and structure domain and by solving just this motion equation, displacement, pressure and stress for fluid and structure domain have been determined.

The Langrage-Lagrange method is used to modeling interaction between fluid and structure. Elements that are used for Fluid and structure in ANSYS software are Fluid80 and Shell63 where Fluid80 element has eight nodes with three degrees of freedoms in each node and Shell63 element has four nodes with six degrees of freedom in each node.

The following assumption is considered in this research:

1-The foundation of structure is assumed to be rigid, 2-The tank and the water are assumed to have a linear and elastic behavior. Material properties of concrete and water are listed in Table.1 and the finite element characteristics of reservoir geometry as shown in figure.1 are listed in Table.2. In this Table the number of fluid and structure elements is obtained by using of sensitivity analysis of displacement for static and dynamic analysis.

Table.1. Material properties

water			Concrete		
Kinematics viscosity (m^2/s)	Specific mass (kg/m^3)	Bulk modulus (N/m^2)	Poison ratio	Specific mass (kg/m^3)	Modulus of Elasticity (N/m^2)
0.005	1000	2.2e9	0.27	2400	2e10

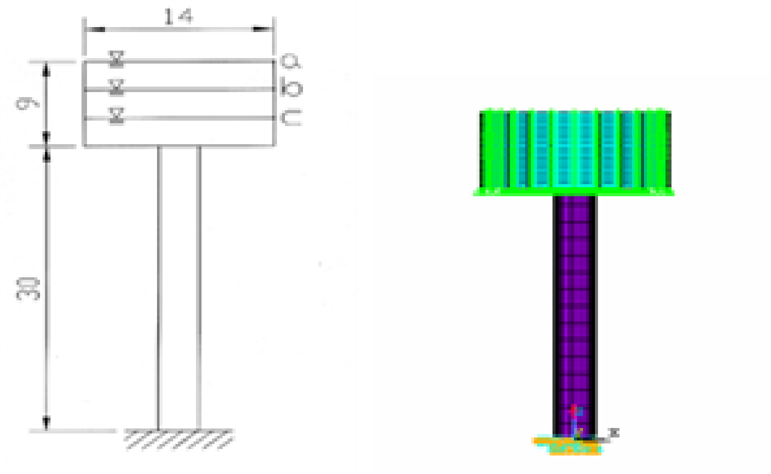

Figure 1Finite element model of elevated water tanks.

Table .2. Geometric characteristic of tank

Reservoir of tank			shaft			Number of elements		Numbers of nodes	
Thickness Of wall (m)	diameter of wall (m)	Height of wall	Thickness Of wall (m)	diameter of wall (m)	Height of wall	Fluid	tank	Fluid	tank
0.3	14	9	0.5	3	30	3135	929	25080	3716

3. STATIC ANALYSIS RESULT AND DISCUSSION

In order to study of modeling proportion, displacement and hydrostatic pressure are compared by using of theoretical and finite element methods. Eqn.3 and Eqn.4 are used to calculate the result of fluid weight as shown in Figure 2 To compare of this result with finite element one, the wall of tank are assumed to be rigid. The results are shown in Figures 2 and 3, which show a relatively compatibility between numerical and theoretical methods.

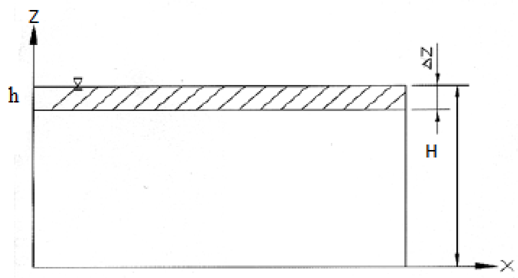

Figure 2 Tank with water

$$U_z = \frac{1}{k}\int_H^h \gamma z dz = \frac{\gamma}{k}\left[\frac{Z^2}{2}\right]_H^h = \frac{-\rho g}{2k}\left[H^2 - h^2\right] \ldots (3)$$

where K is the bulk modulus,γρ ,are specific weight and specific mass, P is the hydrostatic pressure in depth of hfrom free surface, z,uis the displacement in Z-direction and g is the gravity acceleration.

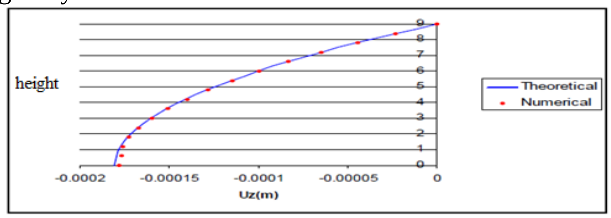

Figure .3. Displacement variation along the height of water for theoretical and numerical method

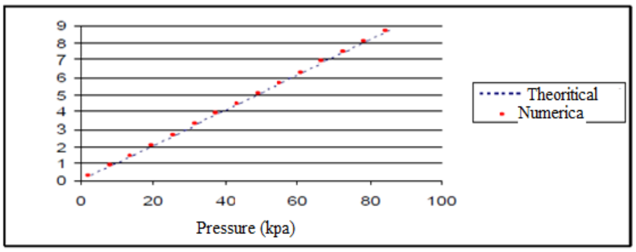

Figure. 4. Hydrostatic pressure variation along the height of water from theoretical and numerical methods

4. PERIOD AND DAMPING COEFFICIENTS IN SOFTWARE

By solving Eigen-value for tank with different elevation of water (Empty.1/3 full, 2/3 full), the natural period of system are obtained. A summary of the calculation results is listed in table.

Table.3. periods of system with different elevation of water

Mode number	Period (sec)			
	Empty	$\frac{1}{3}$ Full	$\frac{2}{3}$ Full	Full
1	1.608	2.42	2.95	3.175
2	1.608	2.42	2.95	3.175
3	0.626	0.669	0.67	0.466
4	0.626	0.669	0.67	0.2
5	0.491	0.491	0.49	0.2
6	0.336	0.36	0.48	0.05

$[K][M] = [M][\emptyset][\cap^2]$
…(4)

where, [K], [M] ,are stiffness and Global mass matrices. And Φ is the eigen-vector.

Figure5 Mode shapes (left to right)

$[C] = \propto [M] + \beta[K]$

$$\beta = \frac{2(\rho_i \omega_i - \rho_j \omega_j)}{(\omega_i^2 - \omega_j^2)}$$

$\alpha + \beta\omega_i^2 = 2\omega_i\rho_i$

Where,αand β are the coefficients related to mass and stiffness matrices ω_i , ω_j are periodsof i and j modesρ_i, ρ_j, damping ratio of I and j nodes.

Table 4 data for α and β with ($\rho = 0.05$)

water elevation	Empty	$\frac{1}{3}$ Full	$\frac{2}{3}$ Full	Full
α	0.281	0.203	0.177	0.152
β	0.0072	0.0086	0.009	0.0093

5. RESULT OF HARMONIC ANALYSIS

To study the behavior of structure subjected to seismic loads, these forces must be known in first step. Because the acceleration of ground motion is arbitrary and containing of different frequencies, cannot observe the behavior of structure subjected to seismic excitations in terms of specific parameters such as period, vibration amplitude and etc. but these acceleration are capable to be converted harmonic functions by using of Fourier Integration. With this method we can study behavior of structure subjected to harmonic excitation and effect of different parameters instead of earthquake excitation. In this investigation the harmonic analysis are done for tank with different elevation of water and result are represented for an elevation for example 1/3 full.

6. RESULT OF DYNAMIC, PSEUDO STATIC AND PSEUDO

DYNAMIC ANALYSIS

In this investigation by using of seismic characteristic of available accelerogram, velocity of shear wave in soil condition of accelerogram site and compatibility between it and soil condition of structure, distance of accelerogram with fault and also accelerogram frequency content, is used from three couple accelerogram concerned about Tabas, Manjil and Northridge earthquakes. These accelerogram are scaled to 0.26g and suggested so that peak ground acceleration (PGA) in these accelerogram becomes 0.26g.

Results of Dynamic Analysis

By using of scaled accelerogram, Dynamic analysis are performed on a storage tank for longitudinal component of earthquake one time and for both components of earthquake in the form of 100 percent of longitudinal component and 30 percent of lateral component. A summary of these results is listed. In some cases, effects of vertical component are also considered. Results show that this component is not effective on the response accurate, so it is negligible.

Table .5. Base shear force of storage tank for Tabas, Manjil and Northridge earthquakes

Tank	Longitudinal Component			%100 Longitudinal+%30 Lateral Component		
	Northridge	Manjil	Tabas	Northridge	Manjil	Tabas
Empty	449	1508	1519	479	1528	1550
$\frac{1}{3}$ Full	403	1351	1394	427	1376	1495
$\frac{2}{3}$ Full	412	876	1475	422	1306	1500
Full	389	1120	1639	489	1247	1690

From obtained result for each accelerogram.It is observed that lateral component of earthquake have not important effect on structure response. This problem are resulted primary from this fact that lateral peak ground acceleration is 30 percent of longitudinal peak ground acceleration and secondary storage tank is symmetric in tow normal direction. Also the comparing of obtained results from different accelerogram demonstrated that effect of frequency content on structure response is important. In order to comparing the effect of frequency content on structure response, base shear force time history and maximum displacement of structure for these three earthquakes are obtained for different elevation of water and for example result of elevation 1/3 Full with period, T=2.42sec, are demonstrated in Figure.4.8 and 4.9This difference is described by frequency content of Tabas, Manjil and Northridge earthquake accelerogram.

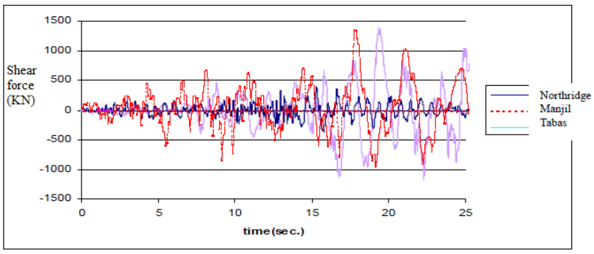

Figure 6Base shear force time history for Tabas, Manjil and Northridge earthquakes for elevation 1/3 Full

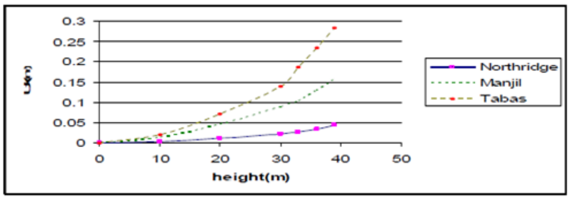

Figure.7. Maximum horizontal displacement of tank along height for elevation 1/3 full

Result of pseudo static analysis

In this section base shear force is calculated by using of pseudo static analysis. And the summary of the calculation results are listed in table.

$$C = \frac{ABI}{S} \ldots (6)$$

$$V = C \times W \qquad \ldots (7)$$

Where W, V,C are Structure Weight, base shear force and earthquake coefficient respectively. Parameters concerned about C, I is this Importance coefficient of structure and for water storage tank is equivalent 1.4, R is response modification factor of tank .A is the base design acceleration and by this assumption that soil type is III, is considered 0.3.B is the structure reflection coefficient that is obtained by using of soil condition and design spectrum. By comparing the results from Tables 6 and 7, it is observed that results of pseudo static analysis for base shear is much higher than those of dynamic analysis in all cases.

Table.7. Result of pseudo static analysis

Tank	Period (T) (sec)	B	I	R	C	W (kN)	V (kN)
Empty	1.25	1.868	1.4	3	0.261	7211	1882
$\frac{1}{3}$ Full	1.75	1.493	1.4	3	0.209	11742	2454
$\frac{2}{3}$ Full	2.138	1.306	1.4	3	0.183	16272	2977
Full	2.466	1.188	1.4	3	0.166	20803	3453

Result of Pseudo Dynamic Analysis of Water Storage Tank

Pseudo dynamic analysis of structure can be used for structure analysis. A summary of results is listed in Table.8 based on pseudo dynamic analysis for period higher than 0.4secFrom this table, it is observed that results in pseudo dynamic analysis are much higher than those in pseudo static and dynamic analysis.

Table. 8. Result of pseudo dynamic analysis

Tank	Shear Force (kN)					
	Mode 1	Mode 2	Mode 3	Mode 4	Mode 5	CQC
Empty	1140	1140	956	956	8.7	2107
$\frac{1}{3}$ Full	1600	1600	2680	2680	399	4412
$\frac{2}{3}$ Full	2050	2050	2750	2750	4030	7100
Full	2620	2620	118	-	-	3714

7. CONCLUSION

From analytical results of cylindrical elevated water storage tank with central shaft and considering linear behavior of material subjected to different harmonic and earthquake excitation, it is concluded that:

1. The base shear force resulted of structure in pseudo static analysis for Empty tank is four times and for tank with water is seven times as much as those from linear dynamic analysis that these difference are resulted from response modification factor, R.
2. Vibration periods are less than those from dynamic analysis with finite element method that these differences in this investigation reach to 27 percent for empty tank, 22 percent for tank with 1/3 water, 22 percent for tank with 2/3 water and 27 percent for full tank.
3. Base shear force in pseudo dynamic analysis is much higher than that in static analysis. So that it is more than the result of dynamic analysis surely.
4. The effect of vertical component of three accelerograms for base shear force and maximum displacement of storage tank is not significant and we can neglect it in calculation.

8. REFERENCES

[1]. Housner, G.W. (1963).The Dynamic Behavior of Water Tanks. Bulletin of Seismological Society of America53, 381-387. Hamdi, M.E. (1978). A Displacements for the analysis of vibrations of coupled fluid- structures systems. Int. J. Num. Meth.,13,139-150.

[2]. Wilson, E.L. and Khalvati.M. (1983). Finite Elements for Dynamic Analysis of fluid- structure systems. Int. J. Num. Meth. E 19, 1657-1668.

[3]. Sharan, S.K., Gladwell, G.M. (1985). A general method for the dynamic response analysis of fluid-structures systems. Comput. and structures,21:5, 937-943.

[4]. Olson, L.G., Bathe, K.J. (1985). Analysis of fluid-structure interaction. A direct symmetric coupled formulation based on the flow velocitypoten