Effect of Roof on Seismic Behavior of Elevated Tanks Considering Fluid–Structure Interaction

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Abstract – *Elevated tanks are considered very sensitive to seismic excitations. That is why several researchers have studied the performance of these structures under seismic loading. The elevated tanks design are the most responsible reason of the damages and failures of this kind of structure. In this work we study the effect of roof on the dynamic behavior of the elevated tank-liquid system through a modal and time history analysis using a detailed FE technique in a three-dimensional space taking into account the interaction between fluid and structure in the presence of sloshing. The general purpose FE analysis software ANSYS is used for dynamic analysis of elevated liquid tank models. The results found show that the elevated tank model having no roof are virtually identical with those of the roofed elevated tank.*

Key Words: Elevated tank, Fluid structure interaction, Finite elements, Earthquake, Roof.

1. INTRODUCTION

Storage tanks are strategic structures. They are generally used as water storage in our daily lives and as a hydrocarbon storage in the industry. They can take different shapes (Rectangular, cylindrical ....). However, cylindrical tanks are the most used because of their simplicity in the designing and the construction, as well as their good resistance to hydrostatic and hydrodynamic loads.

To ensure the desired pressure, water tanks are generally installed on tower supports (steel or reinforced concrete) to avoid pumping installations. The necessary pressure is then ensured by gravity. Tanks in the seismic area should be functional after earthquakes.

This is due to the need of water during earthquakes. However, the tanks of the nuclear power plant and oil could cause the irreparable environmental pollution. Many tanks have been severely damaged and some have collapsed with disastrous results.

For example, the severe damage sustained during the earthquake, Alaska 1964, Niigata 1964, Parkfield 1966, San Fernando 1971, Miyagi prefecture 1978, Imperial County 1979, Coalinga 1983, Northridge 1994, Asnam 1980 and Koaceli 1999.

Many researchers have studied the dynamic behavior of these tanks using two-mass method. (1963) Housner [1] has allowed practicing engineers to perform the analysis of the seismic responses of the elevated rigid tanks by using the two-mass method.

In this paper the fluid domain was modeled by three dimensional elements which permits a more suitable consideration of fluid-structure interaction and hence, enhanced the information about the effect of the roof of the behavior of elevated tanks under earthquake.

2. Theoretical simplified model

The method of Housner used in many applications divide the fluid into two parts, the first called impulsive is rigidly attached to the structure and the second is called convective are vibrates freely to the structure. Masses and rigidities of these components are done respectively by [4] [5] [6] :

$$k_c = m_c \frac{g}{R} 1.84 \tanh\left(\frac{1.84\ h}{R}\right) \tag{1}$$

$$m_c = m_e \frac{R}{h} 0.318 \tanh\left(\frac{1.84\ h}{R}\right) \tag{2}$$

$$h_c = \left[1 - \frac{\cosh(1.84\ h/R) - 1}{1.84\ h/R\ \sinh(1.84\ h/R)}\right] h \tag{3}$$

$$m_i = m_e \frac{\tanh\left(1.74\ {}^{R}/_{h}\right)}{\left(1.74\ {}^{R}/_{h}\right)} \tag{4}$$

$$h_i = \frac{3}{8} h \tag{5}$$

The rigidity of support can be calculated by using the finite element method or according to [7] [8] [9] :

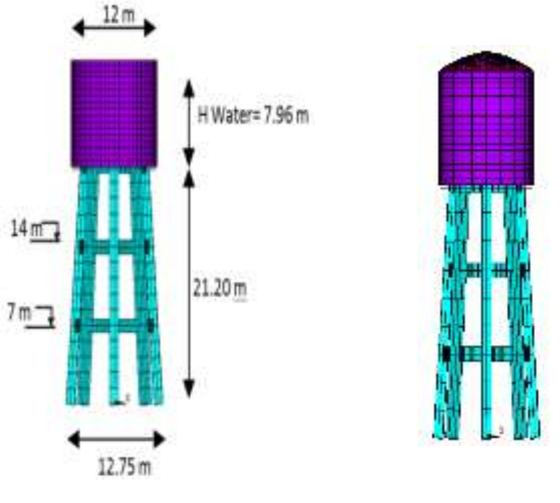
$$k_i = \frac{12\, E_{c1}\, I_{c1}\, N_{c1}}{h_{c1}^3}\left[\frac{1}{\frac{2\, I_{c1}\, N_p\, (4\, N_p^2 - 1)}{A_c\, R_s^2} + N_p + 2(N_p - 1)\frac{\frac{E_{c1} I_{c1}}{h_{c1}}}{\frac{E_b I_b}{L}}}\right] \qquad (6)$$

3. Numerical model

To illustrate the effect of roof of dynamic behavior of the elevated tanks, we use two elevated tanks (with roof and without roof) . The two elevated water tanks consisted of eight column 1.2x1.2 m and three beams 1.2x0.60m Fig.1[10] . The two used elevated tanks are assumed to be fixed at their bases .Elevated tank materiel properties are indicated in the Table 1.

Table-1: Material characteristics

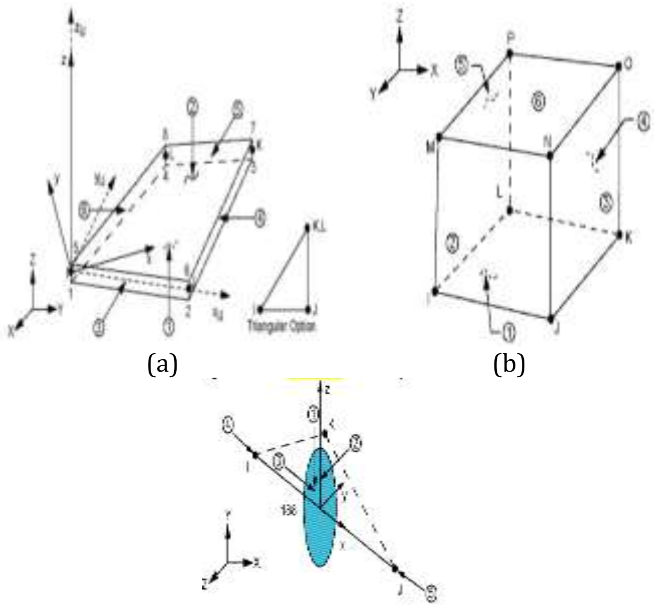
Water	
Density	1000 kg/m^3
Bulk modulus	2.0684 109 Pa
Viscosity	1.13 10-3 N.S/m^2
Concrete	
Density	2500 kg/m^3
Young's modulus	350 10^8 Pa
Poisson's ratio	0.2



Type 1 (a) Type 2 (b)

Figure-1: Elevated tank geometries

The model of the structure as well as the fluid was done using ANSYS software [11]. The used elements are : The tank wall and the roof are modeled with SHELL63, this element has six degrees of the freedom at each node .The frame support is modeled with beam188 that has six or seven degrees of the freedom at each node. The fluid domain is modeled with the fluid element (FLUID80) with three degrees of the freedom at each node.



(a) (b)

(c)

Figure-2: (a) shell 63 , (b) fluid 80 , (c) Beam 188

3.1 Fluid structure Interaction

The effect of the fluid-structure interaction is taken into account by properly coupling the nodes that lies in the common faces of these two domains[12][11] .

4. Results and discussion

4.1. Modal analysis of Elevated tank without roof

The period and the mass participation factors are obtained by using the finite element and the analytical methods (EC8) for impulsive and convective modes , the results are presented in Table 2 and Figure 3 .

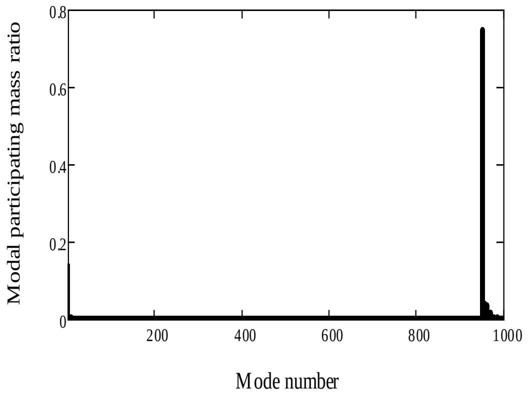
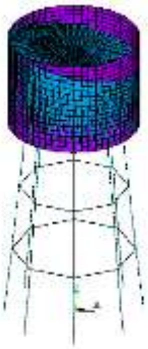


Figure- 3: Mode participation mass ratio

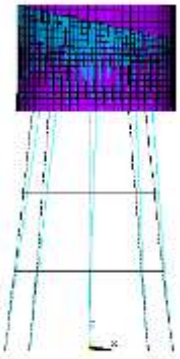
Table- 2: Period and effective mass fraction

	Finite elements		Eurocode 8	
Type	Order	Period (s)	Effective mass fraction	Period (s)
Convective	1*	3.71	0.1419	3.70
	2	2.27	0.0042	/
	3	1.88	0.0010	/
Impulsive	1*	0.49	0.7470	0.47
	2	0.13	0.0391	/
	3	0.042	0.0348	/

* Fundamental mode



Fundamental convective mode



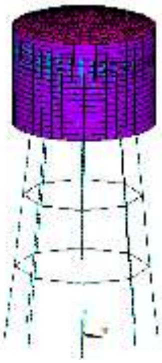
Fundamental impulsive mode

Figure- 4: Modal shape (without roof)

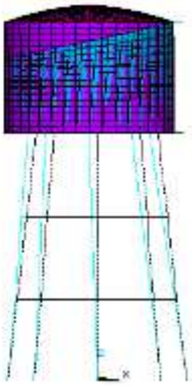
Comparing the results obtained from finite element analysis and analytical model (Table 2) , it can be concluded that: the analytical results agree very well with the numerical ones.

4.1.2 Modal analysis of Elevated tank with roof

The obtained results show that the convective period of the fundamental mode remains unchanged due to inclusion of the roof. However, the natural period of the fundamental impulsive mode is negligibly decreased from 0.49 s (without roof) to 0.51 s (with roof) .



Fundamental convective mode



Fundamental impulsive mode

Figure- 5 : Modal shape (with roof)

4.2 Transient analysis

In order to analyze the effect of the earthquake on the dynamic behavior of elevated tank's, The two elevated tanks are subjected to the horizontal excitation of San Fernando 1971 earthquake.

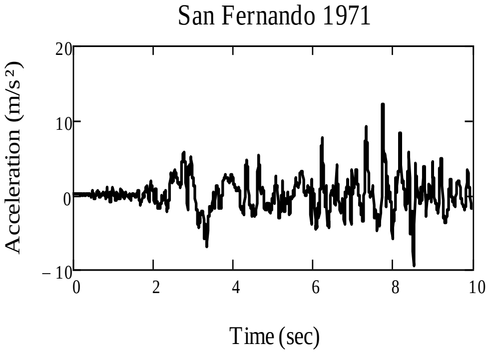


Figure- 6: Accelerograms: San Fernando , (c) PGA =12.02 m/ s^2,

4.2.1 Sloshing displacements

From the figure 7 and the Table 3; we can observe that the obtained results are the same which means that the roof does not have a great influence on the sloshing.

Table -3: Maximum value of sloshing displacements

	Sloshing
Without roof	1.04 m
With roof	1.05 m
Difference	0.95 %

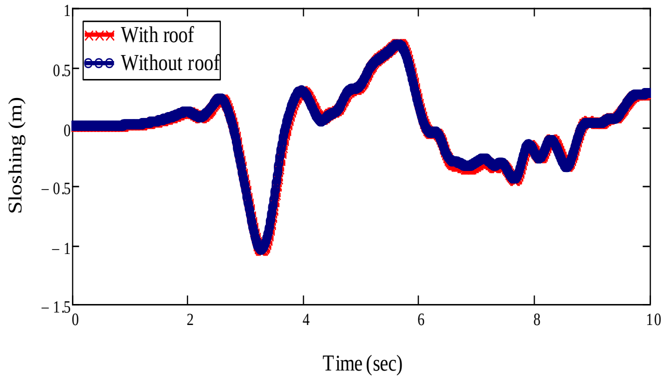


Figure 7 - : Deviations of the sloshing displacements

4.3 The displacement at the top of the tank

As obvious from the figure 8 and the Table 4, the effect of inclusion of the roof on displacement is quite negligible.

Table-4: Maximum value of displacement at the top of the tank

	Displacement
Without roof	0.041 m
With roof	0.045m
Difference	8.88 %

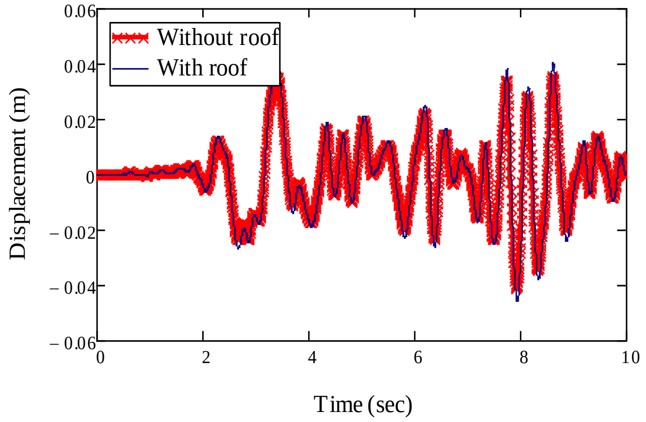


Figure- 8 : Time-history of the top displacement

5. CONCLUSIONS

Based on the obtained results from this study was carried out on elevated tanks through a modal and time history analysis using a detailed FE technique in a three-dimensional space taking into account the interaction between fluid and structure in the presence of sloshing. : we can conclude that:

- The convective period of the fundamental mode and the sloshing displacement remains unchanged due to inclusion of the roof.
- Inclusion of the roof has almost negligible effect on the impulsive period of the fundamental mode and displacement at the top. The roof mass can be included in the impulsive component of the analytical models which is known in the current practice.

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