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Dynamic Behavior of Elevated Water Tanks under Seismic Excitation

Nasser Dine Hadj-Djelloul, Mohammed Djermane, Noor Sharari, Soufiane Merabti

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 support's design are the most responsible reason of the damages and failures of this kind of structure . In this present paper, we are used the finite element technique to study the seismic response of them with taking into account the interaction between fluid and structure in the presence of sloshing. Modal and transient analysis are carried out on two types of the elevated tanks support, while keeping the same quantity of concrete and the same fluid volume. The displacements at the top of the tank and The fundamental period of the impulsive mode of the elevated water tank with shaft support decreased compared to the elevated water tank with frame support .The obtained results confirm the supporting system effect on dynamic behavior of elevated water tanks .

Keywords* : *Elevated tank . Fluid structure interaction . Finite elements . Earthquake. Supporting system .

I. 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.

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* Correspondence Author

Nasser Dine Hadj-Djelloul*, [1]Department of Civil and Hydraulic Engineering , Faculty of technology, Tahri Mohammed University – Bechar. BP 417-(08000),Algeria FIMAS laboratory . Email: hadjdjelloul_nasserddine@yahoo.com

Mohammed Djermane ,[2]Department of Civil and Hydraulic Engineering , Faculty of technology, Tahri Mohammed University – Bechar. BP 417-(08000),Algeria FIMAS laboratory . Email: djermcub@yahoo.fr

Noor Sharari , [3]Department of Civil Engineering,University of Technology Sydney, Sydney, NSW, Australia, .Email: Noor.sharari@student.uts.edu.

Soufiane Merabti Department of Mechanical Engineering, University of Tahri Mohamed, Béchar, BP 417-(08000),Algeria ENERGARID laboratory Email: merabti.soufiane1@gmail.com

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 [5] .The Damages caused by the past earthquakes showed the importance of the supporting system for the elevated tanks. Many researchers have studied the effect of the supporting system on 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. 2014 Prajapati et al [2] used spectrum method to analyzed different supporting staging on the base shear, displacement and moment with different soil types . 2016 Shrigondekar and Padhye [3] used linear dynamic method to studied displacement of tank , moment and base shear at the base with different type of bracing arrangements of supporting systems. This study prevails the response, frequency and time history analyses of an elevated tank for studying the behaviour of the structure with different types of support.

(a) (b) (c) (d)

Fig. 1.(a) Horizontal and diagonal circumferential cracks ,(b) vertical cracks ,(c) Flexural-shear failure is the repeated damage pattern of beams, (d) collapse elevated tank 1980 El- Asnam earthquake , Algérie

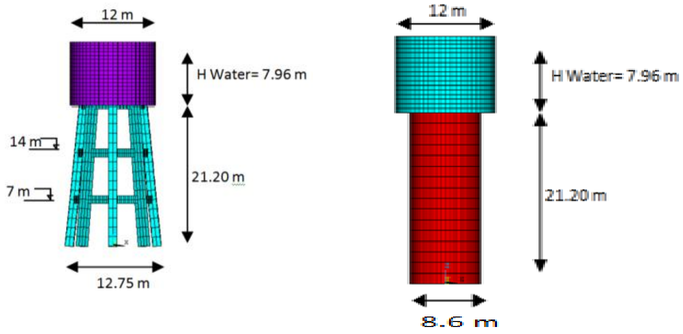
II. TYPE OF SUPPORTING SYSTEMS

In order to compare the two most used types of the supporting systems, we analyzed in this work the two elevated tanks with the same quantity of the concrete for supporting systems and the same fluid volume (900 m3) for tank,

the first one is consisted of eight column 1.2x1.2 m and three beams 1.2x0.60m Fig.2.a and the second model is a cylinder of 0.55 m thickness Fig.2.b The two used elevated tanks are assumed to be fixed at their bases .
Elevated tank materiel properties are indicated in the Table 1

Table I: Material characteristics

Water	
Density	1000 kg/m3
Bulk modulus	2.0684 10^9 Pa
Viscosity	1.13 10^{-3} N.S/m2
Concrete	
Density	2500 kg/m3
Young's modulus	350 10^8 Pa
Poisson's ratio	0.2



Type 1 (a) Type 2 (b)

Fig. 2.Elevated tank geometries

III. 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] [6]:

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

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

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

$$m_i = m_e \frac{\tanh\left(1.74\, R/h\right)}{\left(1.74\, R/h\right)} \quad (4)$$

$$h_i = \frac{3}{8} h \quad (5)$$

The rigidity of support can be calculated by using the finite element method or according to:

A. Case 1: frame Type

The rigidity of a support of column is given by [7] :

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

B. Case 2: shaft Type

By the method of Rayleigh , the rigidity of a tower with a constant section is given by [8]:

$$k_i = \frac{P}{P'} \frac{3\, E\, I}{l^3} \quad (7)$$

$$I = \pi\, R^3\, e \quad (8)$$

$$P' = P + \frac{33}{140}\, p\, l \quad (9)$$

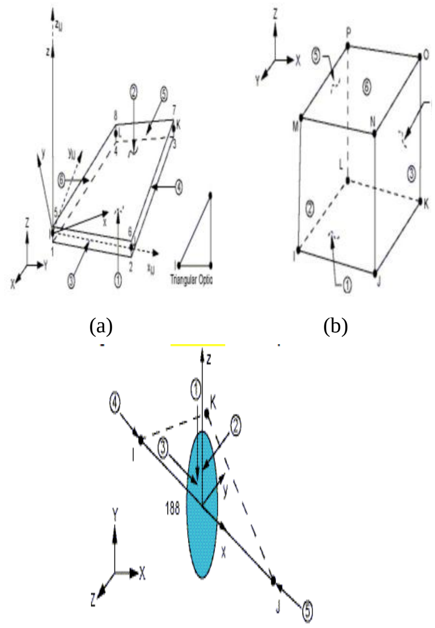
IV. NUMERICAL ANALYSIS

A. Modelisation

The model of the structure and cylinder as well as the fluid was done using ANSYS software.

The used elements are [09] [10]:

The tank wall and the tower shaft 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)

Fig. 3.(a) shell 63 , (b) fluid 80 , (c) Beam 188

B. 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 [10].

V. RESULTS AND DISCUSSION

A. Modal analysis

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 Tables 3, 4 and Fig. 4,5

- **Type 1**

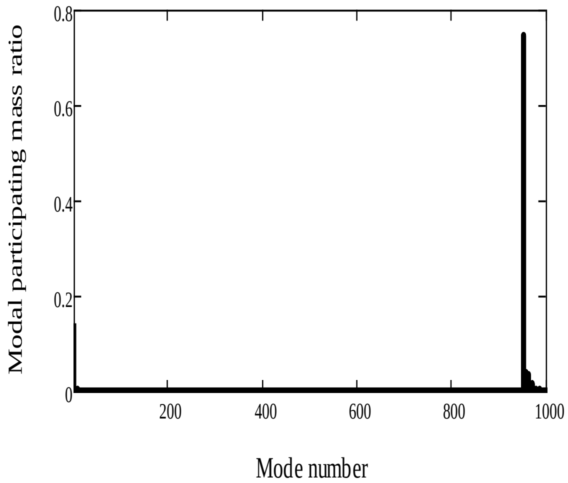


Fig. 4.Mode participation mass ratio (Type 1)

Table II : Period and effective mass fraction (Type 1)

	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

- **Type 2**

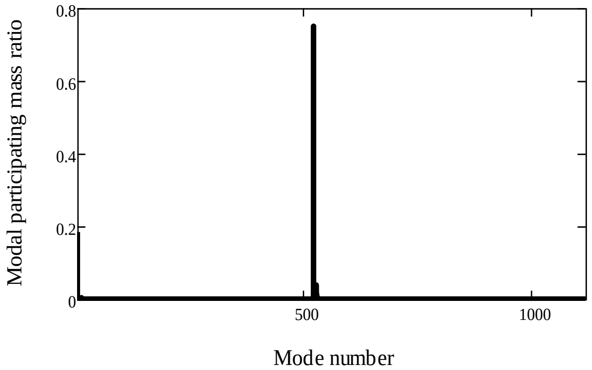
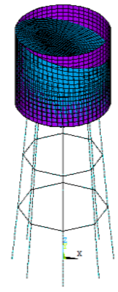


Fig. 5.Mode participation mass ratio (Type 2)

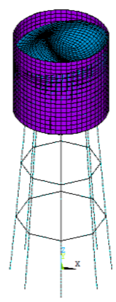
Table III : Period and effective mass fraction (Type 2)

	Finite elements			Eurocode 8
Type	Order	Period (s)	Effective mass fraction	Period (s)
Convective	1*	3.73	0.1831	3.70
	2	2.26	0.0045	/
	3	1.88	0.0010	/
Impulsive	1*	0.27	0.7509	0.24
	2	0.083	0.0373	/
	3	0.067	0.0200	/

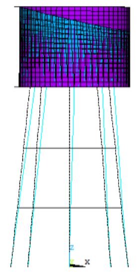
* Fundamental mode



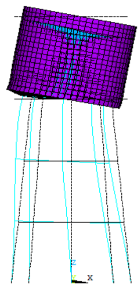
Fundamental convective mode



Second convective mode

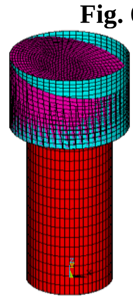


Fundamental impulsive mode

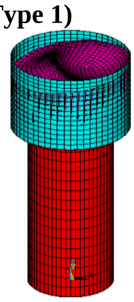


Second impulsive mode

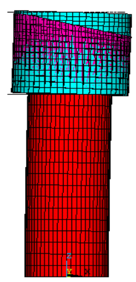
Fig. 6. Modal shape (Type 1)



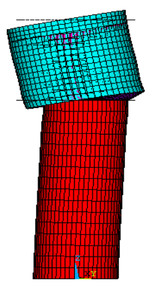
Fundamental convective mode



Second convective mode



Fundamental impulsive mode



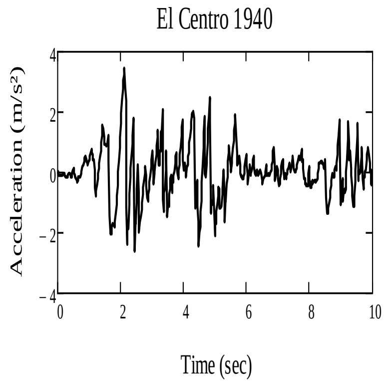
Second impulsive mode

Fig. 7.Modal shape (Type2)

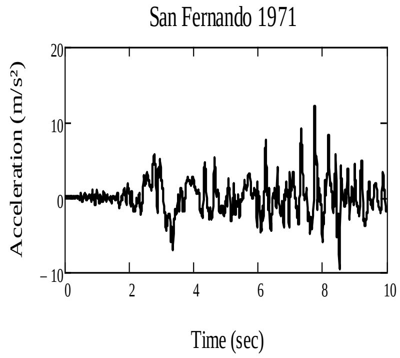
We can also realize that the convective period is remained the same for the two types of the supporting systems. On the contrary, a significant difference is observed between the impulsive periods of the two types. The analytical results agree very well with the numerical ones.

B. Transient analysis

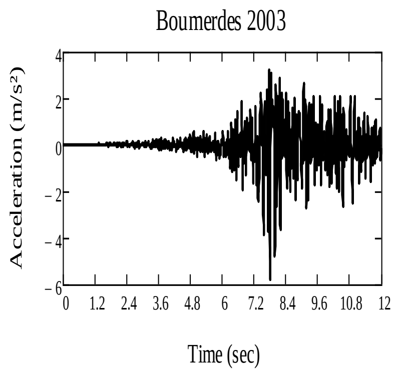
In order to analyze the effect of the earthquake on the elevated tank's dynamic behavior, The two types of support are subjected to the horizontal excitations of the El Centro 1940, San Fernando 1971 and Boumerdes 2003 earthquakes.



(a)



(b)



(c)

Fig. 8.Accelerograms : (a) El centro PGA =3.41 m/ s² , (b) San Fernando , (c) PGA =12.02 m/ s², Boumerdes PGA =5.77 m/ s²

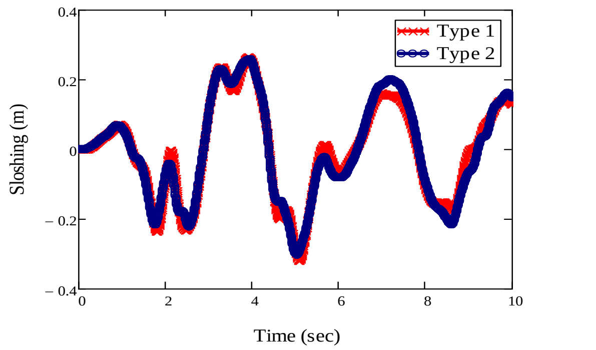
1.1.1. Sloshing displacements

From the Fig.9 and the Table 5; we can observe that the obtained results are the same for each type of the support under the three seismic excitations which means that the rigidity of the support does not have a great influence on the sloshing

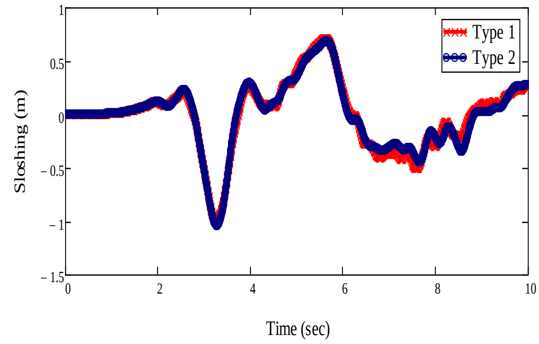
Table IV: Maximum value of sloshing displacements

	El Centro	San Fernando	Boumerdes
Type 1	0.319 m	1.04 m	0.115 m
Type 2	0.302 m	0.987 m	0.115 m

Difference	5.32 %	5.09 %	0.00 %



(a)



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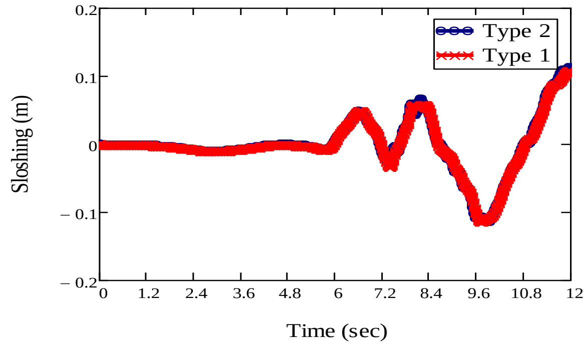

(c)

Fig. 9.Deviations of the sloshing displacements (a) El centro , (b) San Fernando , (c) Boumerdes

1.1.2. The displacement at the top of the tank

The comparison between the response value of the top displacement for the shaft and the frame support models shows clearly differences between the two models, the values of this displacement are significantly different due to the rigidity of the support

Table V : Maximum value of displacement at the top of the tank

	El Centro	San Fernando	Boumerdes
Type 1	0.028 m	0.041 m	0.0064 m
Type 2	0.0094 m	0.026 m	0.0060 m
Difference	66.42 %	36.58 %	6.25 %

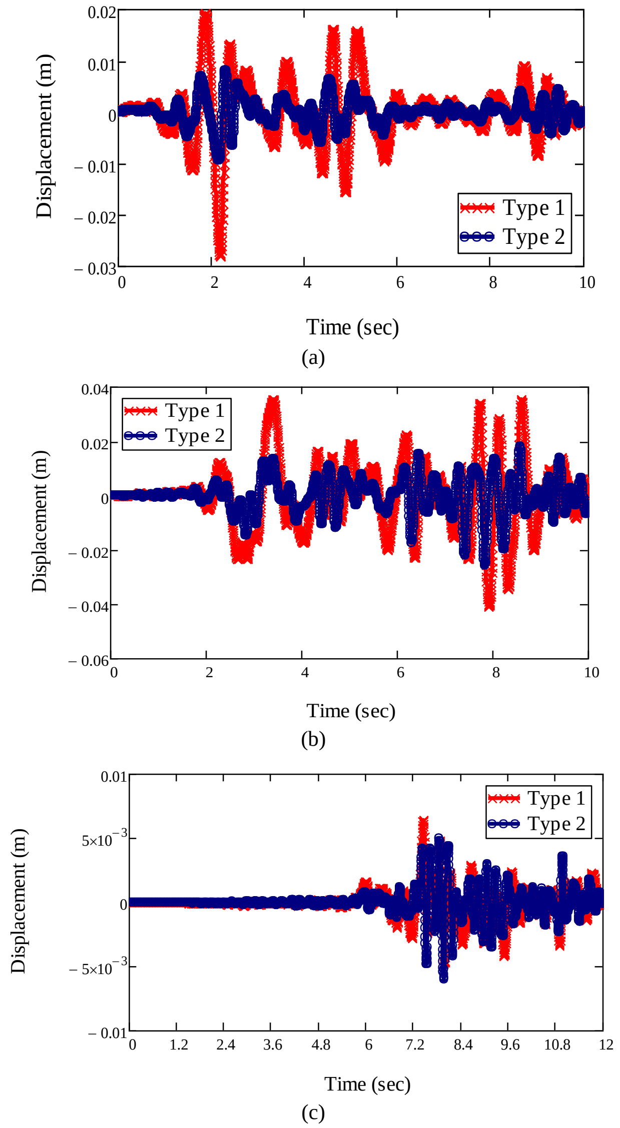

Fig. 10. Time-history of the top displacement (a) El Centro , (b) San Fernando , (c) Boumerdes

VI. CONCLUSIONS

In the present work, an efficient 3D finite element method analysis was analyzed using ANSYS software to know the dynamic behaviour of elevated tank, considering the following factors: the walls flexibility,the fluid-structure interactions and the sloshing effect .

The results show that the :

- The period of the convective mode and the sloshing displacements are the same for the shaft and frame supports which mean that the convective component is independent of the supporting system.
- The period of impulsive mode and the displacement at the top of the tank are changed according to the rigidity of the structure and it can also be seen that the second type (shat support) is more rigid than the first one (frame support).

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