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AN ANALYTICAL STUDY OF THE DYNAMIC RESPONSES OF RC ELEVATED WATER TANKS IN SYRIA UNDER THE EFFECT OF THE FEBRUARY 2023 EARTHQUAKE

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ABSTRACT

The hydrodynamic behavior of RC elevated water tanks is quite complex, and understanding the hydrodynamic behavior effect of the soil structure interaction is necessary for predicting the dynamic response of the elevated tank.

In Syria, all RC elevated water tanks were designed to withstand seismic loads that arehigher than the 6th of February earthquake, in which many elevated water tanks had collapsed. In the current study, the reasons behind these collapses will be investigated, and solutions will be proposed.

The present work will discuss a case study, which is the most common RC elevated water tank model used in Syria, with the most number of collapses through the last earthquake. This case study represents a cylindrical tank with 200 m3 capacity, elevated on six columns with a length of 15 [m], and a cross section of 50x80 [cm^2], this model was design 50 years ago using the classical method where the hydrodynamic effect of the water was not taken into account. In the present study, a numerical simulation will be obtained for this tank, while the hydrodynamic effect of the water will be taken into account using the equations of American standards ACI 350.3-6, while the time history method, where the Turkey-Syria seismic record was adopted.

Two strengthening methods ware suggested, the first one using bonding slabs, and the other one using bonding beams.The shear force, overturning moment and the maximum displacement were obtained and compared with those calculated from the strengthened models. It was noticed that strengthening methods decreased the shear force, overturning moment, and the maximum displacement.

***KEYWORDS*: RC elevated water tanks, hydrostatic stress, FEM, Dynamic analysis.

1-INTRODUCTION

Fulfilling the safety standards of RC elevated water tanks constructed in earthquake-prone areas is one of the important issues to ensure that they remain in service after the earthquake. The dynamic response of elevated-water tanks wasn't taken into account when they were designed 50 years ago, as many elevated-water tanks had failed during the last earthquake, the hydrodynamic behavior of this model will be investigated and verified.

Dynamic response of elevated concrete water tank can be handled through many techniques, and it can be investigated using different methods like Lagrangian [Wilson, E.L., Khalvati 1983],added mass [Westergaard 1931],Eulerian [Zienkiewicz, O.C., Bettes 1987], and Lagrangian Eulerian approach [Donea et al. 1982], which can be achieved via FEM, or can be handled analytically.

A hydrodynamic study was conducted using the Etabs program, where the seismic response of the RC elevated water tank was investigated under the Syria-Turkey seismic records using the time history method. This depends primarily on the structural system that supports the tank and the ability to withstand the forces resulting from earthquakes, taking into account the effect of mutual action (liquid - Structure - soil).Therefore, a model of anRC elevated watertank commonly used in the Syrian northwas simulated and evaluated under the seismic response, where some parameters, like

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the maximum displacement of the top of the tank, the base shear force, and the overturning moment for two cases, (emptyand full) were verified. A strengthening method was proposed, by adding 15 cm connecting slabs between the columns and the central core on two levels. After this,hydrodynamic analysis was performed on the new model and compared with the response values of the reference model.

Many researchers have investigated the seismic response of RC elevated-water tanks. Researchon RC elevated-water tanks with various load-bearing systems was done by [Pavan et al. 2013]. It was discovered that the bonding beams enhance the model's seismic sensitivity. Bozorgmehrnia et al.'s study about the dynamic response for a tank with a 900 m3 capacity [GREANE et al.'s 2013] was conducted, but this study omitted the impact of the interaction between the soil and the structure on the dynamic response..[Tehrani et al.'s 2013] studied a 150 m^3 RC elevatedwater tank using a model forverifying the impact of soil structure interaction SSI on the tank's dynamic response.By considering the dynamic loads of the water, [GAREANE et al. 2013] also investigated the dynamic response of RC elevated water tanks, While another dynamic characteristics and responses like natural frequency of reinforced concrete elevated water tank were discovered using computer vision-based approach [sangirardi et al.'s 2023],and the study's findings were in line with earlier research.

2. RESEARCH IMPORTANCE AND OBJECTIVES

The importance of this research dependence on the selection of the analytical study of the private structures and the explanation of their actual behavior during the seismic event and their application to a high water tank model commonly used in the north of Syria. The objective of the research is to evaluate the dynamic response of this model, which is represented by the maximum displacement of the top of the tank, the basic shear force and the overturning moment, while taking the interaction between (liquid - origin - soil) into account.

Strengthening the frames system of the common model by connecting the vertical elements with the horizontal elements on two levels and conducting the dynamic analysis of the models under the time history record of the Syria-Turkey earthquake2023.

3. RESEARCH METHODOLOGY

studying a common model for high water tanks in Syria and conducting an analytical study containing the differential equations for the dynamic analysis of high water tanks after that simulating it with a numerical model in a finite element program with the addition of strengthen connecting systems to the load-bearing structure system which are slaps and beams, with taking the interaction (liquid - structure - soil) then, observing the effect of model system on the maximum displacement at the top of the water tank and the base shear force. and overturning moments finally comparisons for the filled and empty cases for each of the models.

4. Dynamic analysis of RC elevated water tanks:

Differential equations governing the response of multi-degree-of-freedom (MDF) systems with the effect of ground acceleration$\ddot{u}_g(t)$Caused by an earthquake.

$$[m]\ddot{u} + [c]\dot{u} + [k]u = -[m]\ddot{u}_g(t)(1)$$

Wherem, c, k, are the stiffness, damping, and mass matrices for the studied structure, and$\ddot{u}, \dot{u}, u$are the acceleration, velocity, and displacement vectors. The coordinates represent the sum of the typical contributions, where:

$$U(t) = \sum_{n=1}^{N} Øn\ qn(t) \quad (2)$$

Where:Ønis the shape of the mode.

qn(t): Typical coordinates related to time. By transposing equation (2) and its first and second derivative with respect to time in equation (1)

It represents a system N, a non-correlated equation in terms of typical coordinates, in which the analysis was done by the time-record method of the Syria-Turkey earthquake, as shown in Figure (1).

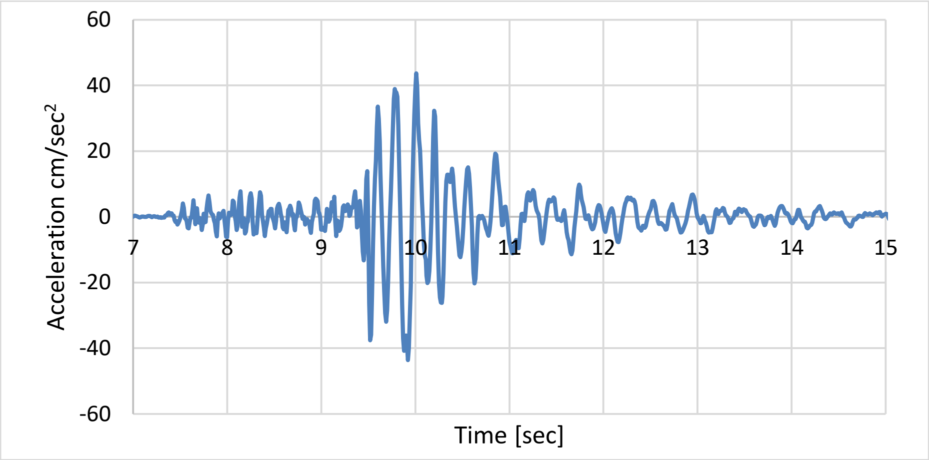

Fig. (1):- Time Record of the Syria-Turkey earthquake

5. THEINTERACTION BETWEEN STRUCTURE AND SOIL

The structure interacts with the surrounding soil, and this causes changes in the effect of seismic waves, and the parameters includethe dynamics of the site are the soil elasticity factor, the dynamic soil shear factor, the Poisson factor, and the soil damping. The Moure-Culomb relationship was presented as a simplified form of the linear relationship between the shear stress and the effecting stress at thesurface as in the following relation [2]:

$$\tau = c + \sigma n \,.\, \tan\varphi \quad (3)$$

Where is: τ: shear stress, σ_n: vertical stress, c soil cohesion, φ:internal friction angle. And based on the definition of Moore-Coulomb, when the stress on a level reaches the relationship (3), the deformations become plastic. The yield limit was calculated in Moore-Coulomb by considering all the superposition of stress that cause yield as in the previous case. In the Moure-Culomb area, the hydrostatic stress is effective in subjecting the material, in contrast to the previous relationship [2].

$$-\frac{1}{2}(\sigma1-\sigma3).\, \text{Cos}\varphi = c - \left(\frac{(\sigma1+\sigma3)}{2} - \frac{(\sigma1-\sigma3)}{2}\sin\varphi\right)\tan\varphi - (\sigma1-\sigma3) = 2c\cos\varphi - (\sigma1+\sigma3)\sin\varphi (4)$$

In the hydrostatic axis and considering the relationship $\sigma_1 = \sigma_2 = \sigma_3$, we can conclude that cohesion in granular materials

$$\sigma m = c \,.\, \cot\varphi \ (5)$$

The function is defined according to the relationship of (Moore - Coulomb) in the following relationship [2]:

$$F = \sigma m \,.\, \sin\varphi + \sqrt{J2}\left(\cos\theta - \frac{1}{\sqrt{3}}\sin\theta \,.\sin\varphi\right) - c\cos\varphi = 0 \quad (6)$$

The structure and the main sections of the soil are modeled using the finite element method. Therefore, the most important issues in modeling the interaction between the structure and the soil are the ones that use the model that simulates the nonlinear behavior of the soil. The most common method for modeling the surrounding soil is the elastic-plastic model, which takes into account the interaction between the structure and the soil and the propagation of waves in the soil,where is the angle of incidence of seismic waves.

This model includes non-linear behavior, and we can consider the yield limit of the soil based on the level of yield in the plane (stress-strain). In this article, the (DruckerPrager) model was used - which is an approximation of Coulomb's law. It was presented by the researchers (Drucker - Prager) 1952. The Drucker - Pragerfunction is defined for the limit of submission according to the formula [2]:

$$F = \alpha.J1 + \quad J2 - K = 0 \quad (7)$$

Where J1 is the first constant of the flow of hydrostatic stress, J2 is the second constant of the flow of hydrostatic stress. And k, α values, parameters of the model calculated based on the cohesion and angle of friction in the soil as shown by the following relationships [2]:

$$\alpha = \frac{2 \sin\emptyset}{\sqrt{3}.(3-\sin\emptyset)} \quad (8)$$

$$k = \frac{6C\sin\emptyset}{\sqrt{3}(3-\sin\emptyset)} \quad (9)$$

WhereØ, C are the angles of internal friction and cohesion of the soil. K is the stiffness factor.

Accordingly, one of the advantages of the (Drucker-Prager) model is to compensate for the lack of double response given in the Moore-Columb method. In the previous relations and in this research, the nonlinear behavior of the soil was modeled using the ETABS program. Taking into account the cohesion C and the angle of internal frictionØ, the contact with the soil was modeled. According to the special solicitation elements in the Etabsprogram.

There are two ways to represent the contact elements: surface-to-surface contact and node-to-surface contact, where the surface-to-surface contact method gives more accurate results than the node-to-surface contact, as it provides the possibility of relative transition. Between the soil nodes and the structure nodes with the possibility of slipping, as the forces are transmitted through friction

6. CHARACTERISTICS OF THE STUDIED MODEL

A case study foranRC elevated watertank was investigated, the case represents one of common used elevated water tanks in Syria with a storage capacity was200 m^3. Its structural system is a frame system. This type of tank is widely used in Syria. Figure (2) shows the details of the mathematical model for the studied and symmetrical RC elevated watertank, where the water within the basin was modeled according to the method of (GAREANE A. I. (2013) ALGREANE et.al.[7] The dimensions of this tank are shown in Table (1).

Table (1):-Dimensions of the studied RC elevated water tank

Tank basin characteristics		Characteristics of columns, load-bearing beams and base dimensions	
200 m^3	the volume of the potter's basin	0.5x0.8 m	the dimensions of the columns
4 m	The inner diameter of the potter's basin	15 m	The height of the columns
4.17 m	the height of the potter's basin	1.6 m	The outer diameter of the core
0.15 m	the thickness of the upper roof	0.5 m	The thickness of the base
0.25 m	the thickness of the walls of the tank	4 m	The radius of the base

Fig. (3):-The mathematical models of the studied RC elevated watertank

Table (2) presents the properties of the construction materials for the studied tank, as well as the properties of the soil. As most of tanks were built 30 to 50 years ago, so the steel used in those tanks had a yielding stress about 240 MPa, and plain bars were used.

Table (2) :-properties of the materials

concrete	Soil	Characteristics
2500	1800	Material density (kg /m^3)
21000	1000	Young factor MPa
0.2	0.3	Poisson factor

7. Research method (numerical modeling):

The dynamic load of water was calculated through the equations of American standards ACI 350.3-6, and the time history method was adopted in this study, where the Turkey-Syria seismic record was adopted.Figure 4represent The dynamic simulation of the water according to ACI 350. 3-6 while The figure (5) represent the three studied model.

$$\frac{h_i'}{h_l} = \frac{0.866\frac{D}{h_l}}{2\tanh(0.866\frac{D}{h_l})} - 0.125 \quad for\ \frac{D}{h_l} \geq 0.75$$

(10)

$$\frac{h_c}{h_l} = 1 - \frac{\cosh\left(3.68\frac{h_t}{D}\right)-1}{3.68\frac{h_t}{D}\times\sinh(3.68\frac{h_t}{D})} \qquad (11)$$

$$\frac{h_c}{h_l} = 1 - \frac{\cosh\left(3.68\frac{h_t}{D}\right)-2.01}{3.68\frac{h_t}{D}\times\sinh(3.68\frac{h_t}{D})} \qquad (12)$$

$$K_C = 3.68\frac{m_c\times g}{D}\tan\left(3.68\frac{h_l}{D}\right) \qquad (13)$$

$$\frac{m_i}{m_l} = 0.23\frac{\tan h(3.68\frac{D}{h_l}}{0.866\frac{D}{h_l}} \qquad (14)$$

$$\frac{m_c}{m_l} = 0.23\frac{\tan h(3.68\frac{h_l}{D}}{\frac{h_l}{D}} \qquad (15)$$

$$\frac{h_i}{h_l} = 0.5 - 0.09375\frac{D}{h_l}\ \text{for}\ \frac{D}{h_l} < 1.333 \qquad (16)$$

$$\frac{h_c}{h_l} = 0.375\ \text{for}\ \frac{D}{h_l} \geq 1.333 \qquad (17)$$

$$\frac{h_c}{h_l} = 0.45\ \text{for}\ \frac{D}{h_l} < 0.75 \qquad (18)$$

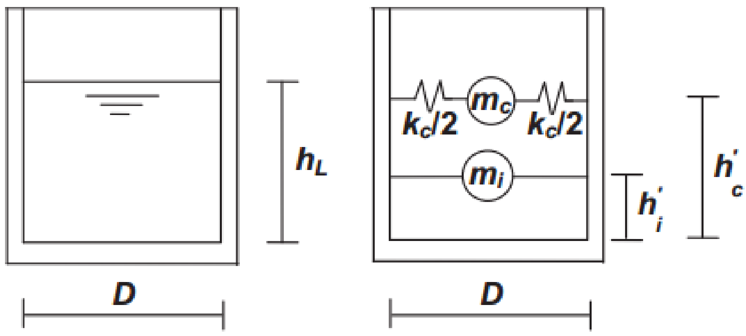

Fig. (4):-The dynamic simulation of the water according to ACI 350. 3-6

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a b c

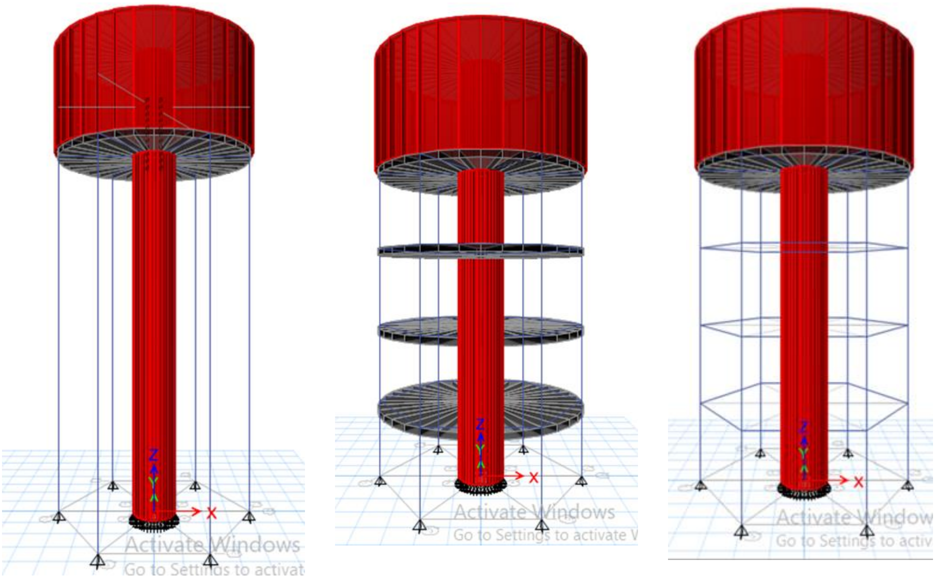

Fig. (5):-The numerical models represents the common model in the north of Syria.
a: No. (1) , b: No. (2) , c: No. (3)

8.results and discussion:

The results of the dynamic analysis for both models of the studied tank showed: Model 1 (without strengthening the load-bearing structureAnd Model 2 (with the reinforcement of the load-bearing structure). The response values represented by the top the tank displacement, the base shear, and the overturning moment, respectively, for the cases of empty, full and tanks. These values are shown in table 3.

Table (3):-The results of the dynamic analysis for the three models (empty and full cases)

	Model I		Model II		Model III	
Response type	Empty	Full	Empty	Full	Empty	Full
Maximum horizontal displacement of the tank top (cm)	2.73	3.34	2.21	2.53	2.42	2.50
Base shear force (KN)	235.9	317.3	139.6	167.6	185.4	187.5
Overturning moment (KN.m)	778.8	1102	360.5	358.1	401.5	470.6

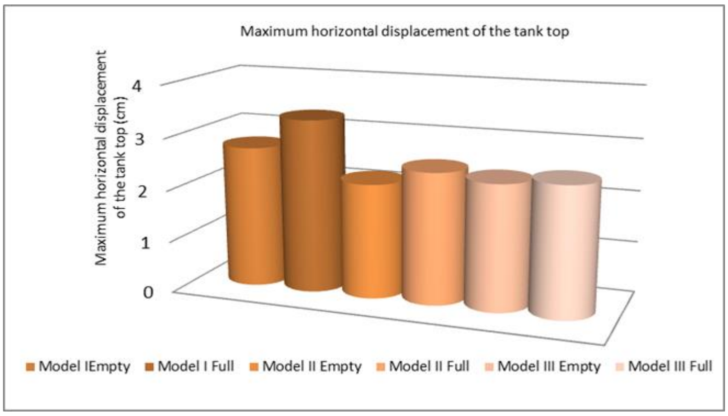

Fig. (6):- comparison betweenthe Maximum horizontal displacement of the tank top for the three models in full and empty cases

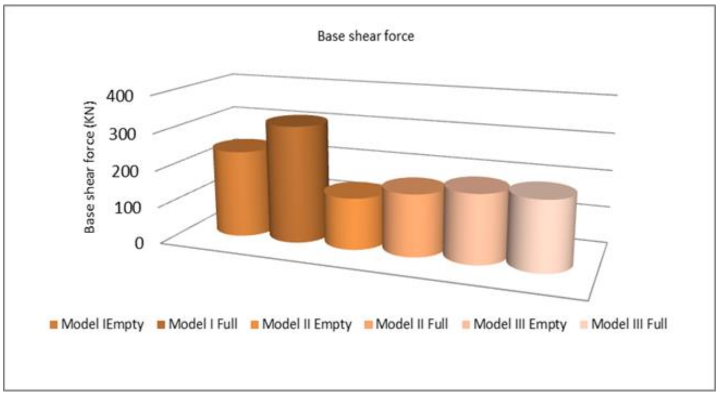

Fig. (7):-)comparison betweenthe Base shear force for the three models in full and empty cases

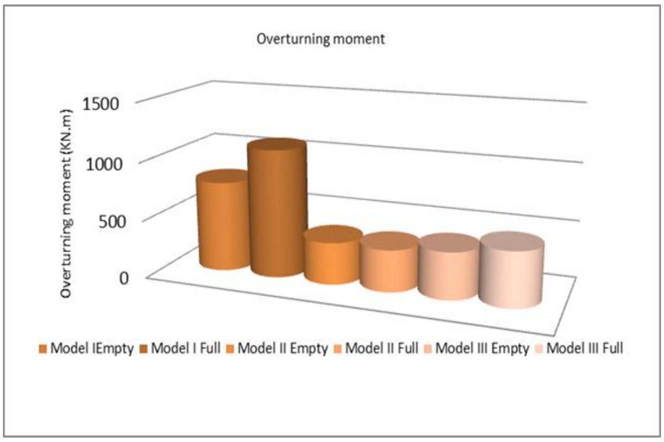

Fig. (8):- comparison betweenthe Overturning moment for the three models in full and empty cases

9. Conclusions and recommendations:

This work presents a case study for a most common elevated water tank in the north of Syria that suffered from failure during the last earthquake. This tank was simulated usinga numericalmethod taking into account thehydrodynamic behavior. Two strengthening methods were proposed, the first one usingslabs with a thickness of 15 [cm], and the second method using boning beams with dimensions of 50x50 [cm^2]. The results of the hydrodynamic analysis were obtained through Etabs program.

The hydrodynamicsimulation for ModelII, IIIhas shown better hydrodynamic responsein comparison withModelI for the cases (empty,and full) according tothe decrease in the results of the maximum displacement value of the top of the tank, shear force, and overturning moment.

The maximum displacement value of the top of the tank decreased by about (19-26%), the shear force of the base decreased by about (41-47%), and The overturning moment by (53-57 %) for the strengthening methods in empty and full cases.

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