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Research Paper

The effect of frame bracing and filling percent on the natural frequency of an elevated concrete tank

Mawahib A. Gate'a(1) Noor Ali Abdulridha(2)
College of engineering , University of Thi-Qar , Iraq(1+2)

ABSTRACT
Liquid storage tanks are structures of high importance which are considered as main lifeline elements in modern life. In this work an empty elevated tank made from concrete supported on concrete frame consisting of four stories had been studied for free vibration analysis. Cross bracing is added to the supporting frame on it's four sides in order to study it's effect on the values of natural frequencies. The results were different between increment and decrement in the values of natural frequencies according to the location of the bracing and the number of mode, also, filling percent had been studied to know it's effect on natural frequency
Keywords: *elevated tank, bracing location, filling percent, mode shape.*

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I. INTRODUCTION

Water tanks are critical elements in local water supply which used for firefighting systems and in many industrial facilities for storage of water [1]. The failure of this type of structures may cause some hazards for the health of city due to the shortage of water or being difficult to put out fire during critical conditions [2].

Housner 1963 noticed that the maximum force to which the half-full tank is subjected may be less than half the force to which the full tank is subjected. The actual forces may be as little as 1/3 of the forces anticipated on the basic of a completely full tank.

Ekbote et. al. 2013[4] used different types of staging patterns to understand the effect of supporting system on the responses of the elevated storage tank system. They concluded that performance of Hexagonal and Radical type bracing was the best among the different types that they used.

Gandhi and Rajan 2014[1] studied the necessity of analyze classic staging system of elevated water tank with different type bracing in staging system for elevated water tank. As a result, only frame type staging with one row of columns along the periphery of a circle are not adequate to support container of the tank.

Ahmad and Singh 2019 [5] analyzed three types of bracing ; horizontal, radial and x- bracing for an elevated water tank with 800 m^3 using software [Sap and Etabs], they found that x- bracing system is better arrangement for water tank under seismic forces and total base shear and base moment in empty condition.

Nidhi and Bajpai 2020 [6] analyzed and compared a sample of RC elevated water tank [Intze] under tank empty condition and tank full condition for different bracing patterns in different seismic zones.

Kumar et. al. 2021[7] discussed the use of steel vertical bracing at each staging level , they used double channel section back to back for vertical bracing and compared to conventional design of elevated water tank without vertical bracing for each seismic zones in India.

Singh and Tiwary 2024 [8] found that the composite columns in the stage of overhead water tanks improve the performance under earthquakes and help to control the roof displacement due to more stiffness given by composite columns.

II. Characteristics and modeling of the Tank

2.1 Description of container

A reinforced concrete elevated tank with a container of 50 m^3 is considered in the analysis as shown (Fig.1). The vessel is cylindrical with base and cover rigidly connected with the tanks' walls. The radius of container is 4.65m and a 3.3m height. Roof thickness of container is 120 mm, walls and floor plate have the same thickness of 200 mm. The ring beam under the tank is of rectangular cross section with (250*600) mm^2 cross sectional dimensions.

2.2 Description of supporting frame

The elevated tank is supported by a frame structure consisting of four columns have circular cross section with 450 mm diameter, beams that connect among columns are rectangular shape having cross section of (300*450) mm^2 , the stories of the frame are 3, 6, 9 and 12m above ground.

2.3 Finite element modelling

The system is modelled by(**ANSYS11)**, finite element software, while the supporting frame is modeled with an elastic beam (**BEAM4**) element with six degrees-of-freedom per node and the container walls, roof, floor and the ring are modeled with quadrilateral shell **(SHELL63)** element with four nodes and six degrees-of-freedom for each node. The finite element model is shown in Figure (1, B).

III. Governing Equation of motion

For a system subjected to an earthquake, the equation of motion can be written as:

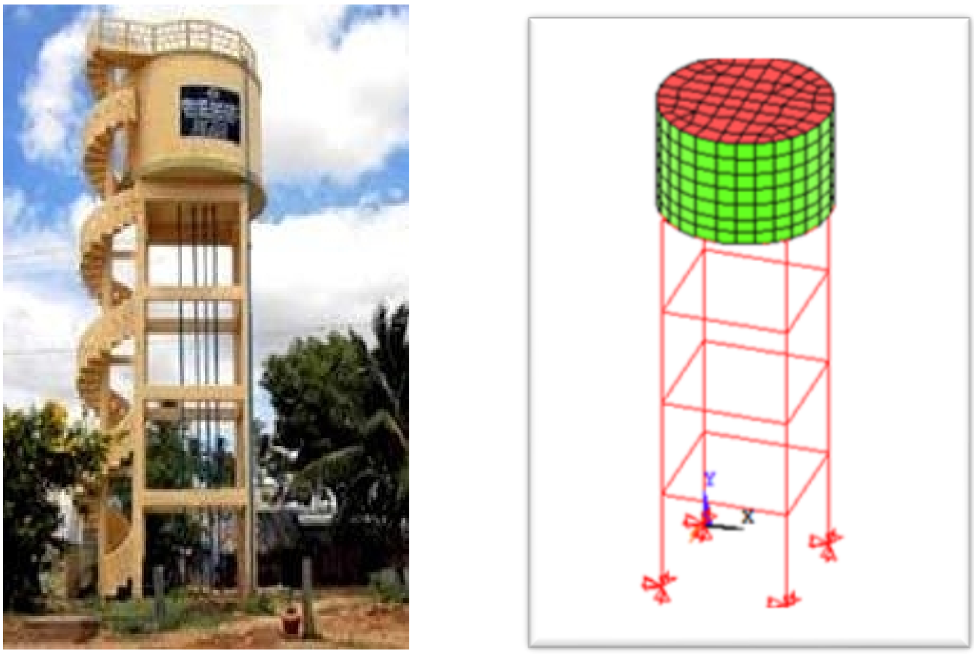
$$M\ddot{U} + C\dot{U} + kU = -M\ddot{U}_g$$

where M is the mass matrix, C the damping matrix, K the stiffness matrix,$\ddot{U}_g$ the ground acceleration, U the relative displacement and the over dots denote the derivatives of U with respect to time.

The method used to handle the fluid–structure interaction is the added mass approach, the fluid mass in this approach is added to the mass of the structure at the fluid–structure interface. When the added mass approach is used, the previous equation will be as the following :

$$M^*\ddot{U} + C\dot{U} + kU = -M^*\ddot{U}_g$$

Where M* is the total mass matrix which include structural mass matrix (M) and added mass matrix (Ma). This approach assumes that the added mass (Ma) which will be added to nodes on the wall, are determined from the mass of the impulsive liquid.



(A) (B)

Figure (1) elevated tank considered in this study. A) Real model, B) finite element

IV. Results and discussion

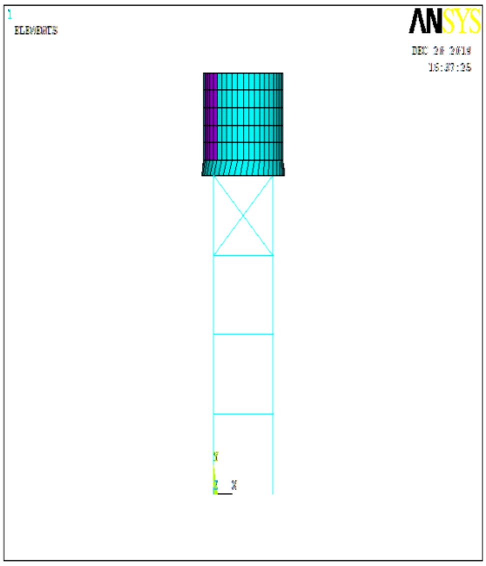
4.1 Free vibration analysis

Natural frequencies and the corresponding mode shapes were obtained for the general case of the empty tank. The results obtained are shown in Table (1).

4.2 Bracing Location Effect

Cross bracing is added to the supporting frame on it's four sides in order to study it's effect on the values of natural frequencies. Three cases of bracing arrangements are examined: the first is when it is put in the top story directly under the container as shown in figure (2), another location is in the third story from the top; the bracing location is shown in figure (3). Third case is when the cross bracing is located in both stories as shown in figure (4).

Every case has been studied separately, and both locations are studied together. Table (2) and figure (5) are explaining the results for various cases of bracing.



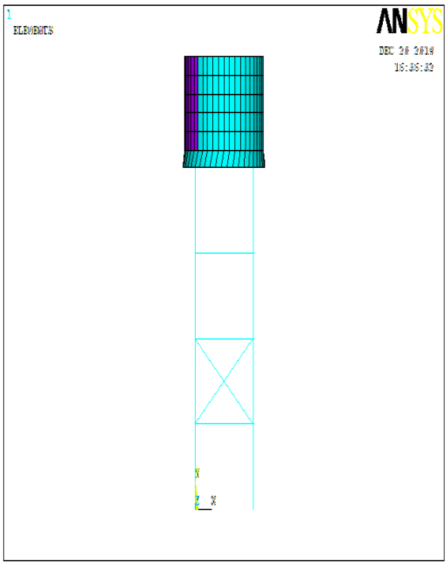


Figure (2) Top level bracing

Figure (3) Third level bracing

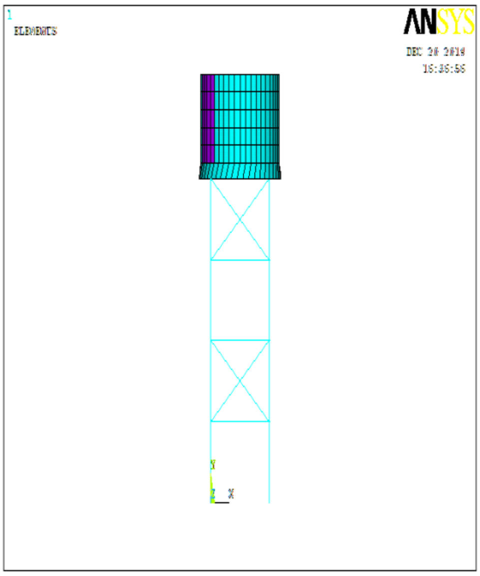


Figure (4) Two levels bracing

Table (1) free vibration analysis for the first five modes

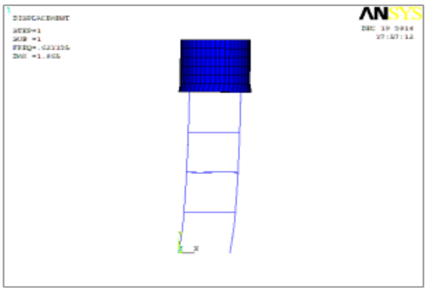
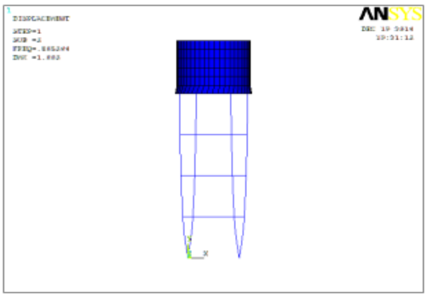
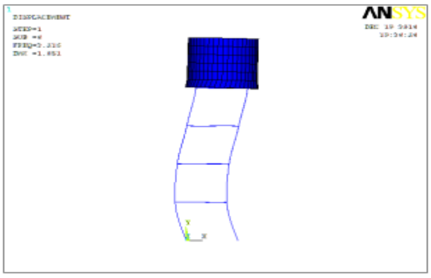
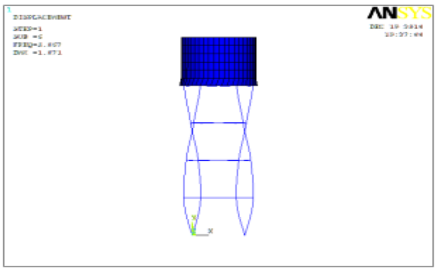
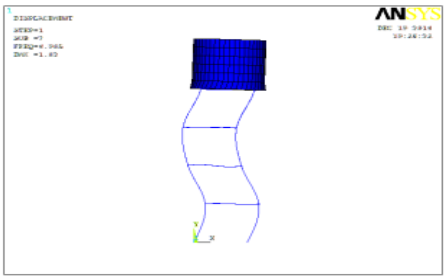
Mode No.	Mode shape	Mode description	Natural frequency (Hz)
1		Beam mode (cantilever 1)	0.631
2		Twisting mode (rotation 1)	0.805
3		beam mode (cantilever2)	2.316
4		Twisting mode (rotation 2)	3.067
5		beam mode (cantilever 3)	4.905

Table (2) results for different bracing conditions

Mode No.	Natural frequency (Hz)		
	Bracing in the 1st story	Bracing in the 3rd story	Bracing in two stories
1	0.584	0.797	0.715
2	0.744	0.949	0.867
3	2.831	2.189	2.533
4	3.617	3.008	3.549
5	4.685	6.501	8.096

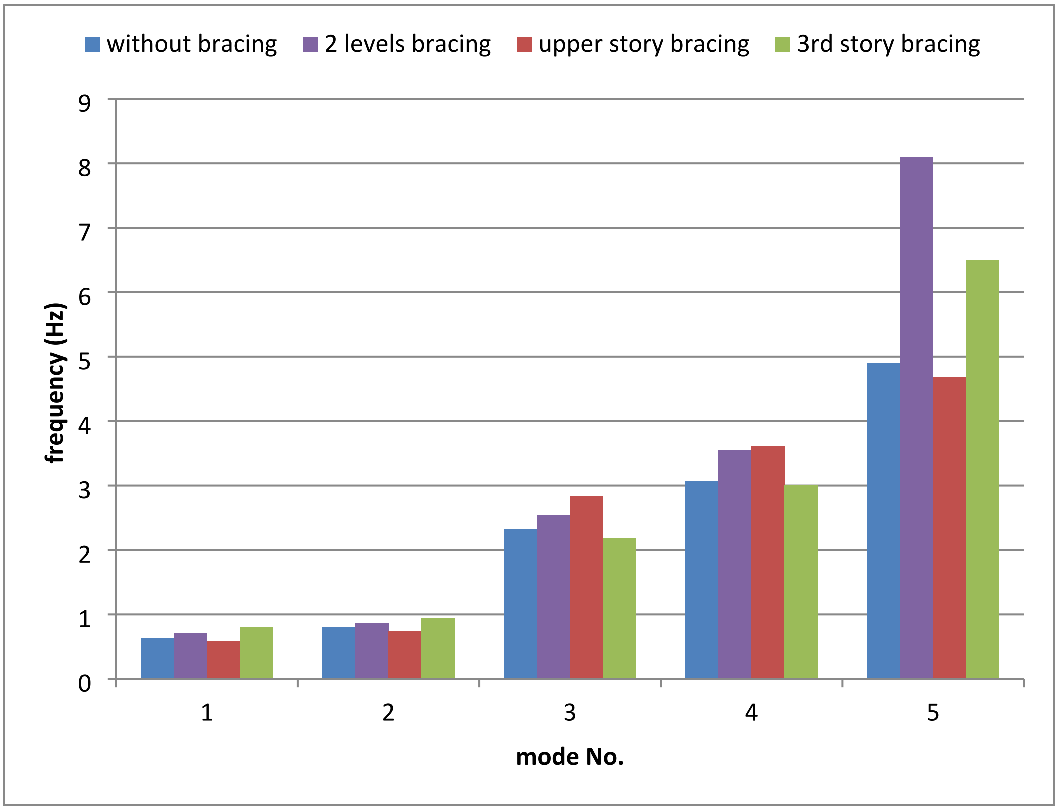


Figure (5) effect of different bracing conditions on natural frequency

The cross bracing in the upper level (near top), as noticed in figure (4.11) by the red column is more effective through first and second modes in lessening frequency because this restriction is far from center of rotation (base of frame) whereas frequency get larger near point of restriction. When the vibration wave go away from center point up to the structure (third and fourth mode) it become near upper bracing, this result in frequency increment. In fifth mode, center of wave become far from bracing area, frequency, therefore, decrease again. In case of third story bracing, which presented in green column, where the angle of deflection and rotation respectively is low, the restriction near base (point of fixing) increase so, the frequency increase trough first two modes, and for next two modes frequency decrease due to the long distance between bracing and center of their wave. In last mode when curvature of waves doubled first wave comes near lower restriction so frequency increase. It is very clear that the behavior of the two levels bracing which presented by purple bar and it's effect on results is average between the two cases. This explains the reason for putting cross bracing in all levels of the supporting structures of elevated tanks in order to give suitable restriction prevent the movement of structure laterally and torsional movement which may cause damage, and increase the natural frequency of the structure to resist high frequencies which may occur during strong earthquakes.

4.3 effect of water filling ratio

The mass of liquid contained inside the container is divided into two parts: impulsive mass which is connected rigidly to the walls of the tank and convective mass which connected to the walls of the container with a mass spring.

In this study, all water behave as impulsive mass, full and half full in addition to empty container have been discovered.
The mass of water is modeled using the added mass method. In this method the mass of water is divided at each level to a number of divisions equal to the number of nodes at this level. The mass of each division is replaced by mass element MASS21 and attached to the nearest node at the wall.
It is noticed that, with increasing the height of water the natural frequency of the system decrease because of the mass added to the tank's mass by the water, the decrement is too low due to the little increase in the whole structure's mass, e.i the concrete structure has a big mass does not affected mainly by the little mass of water, this is shown in figure 7

Table (3) results of three filling percentages

Mode No.	Natural frequency (Hz)		
	Empty	Half full	Full
1	0.631	0.603	0.583
2	0.805	0.769	0.744
3	2.316	2.228	2.165
4	3.067	2.932	2.846
5	4.905	4.806	4.733

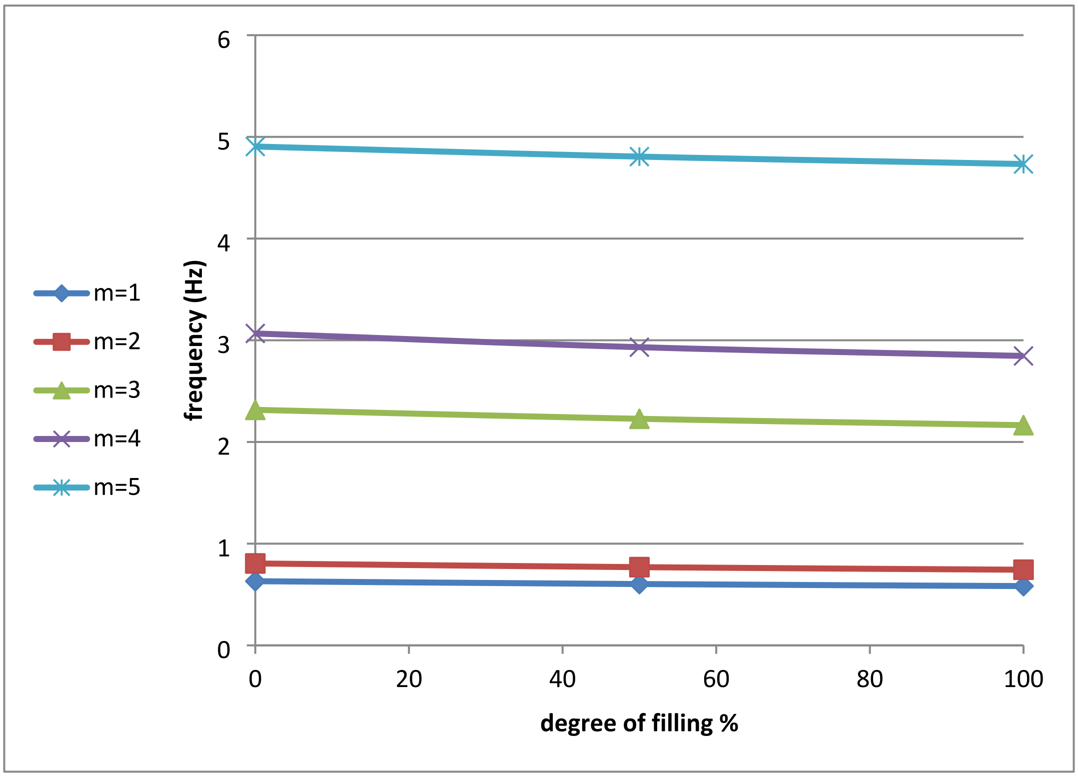


Figure (6) effect of filling percentage on the natural frequency for different modes

V. Conclusions

The main conclusions that can be obtained are:
1. The effects of bracing on the stiffness and hence, the natural frequency of the system depends on its location in the frame stages and the number of mode.
2. The natural frequency of the tank containing water is less than that of empty tank.

References

[1]. Ghandhi M.N. & Rajan A. "Necessity of Dynamic Analysis of Elevated Water Storage Structure Using Different Bracing in Staging", international Journal of research in advent Technology, Vol.2, No.2, February, 2014.
[2]. Omidinasab F. & Shakib H. "Seismic vulnerability of elevated water tanks using performance based- design", the 14th world conference on earthquake engineering, October, 12-17, 2008, Beijing, China.
[3]. Housner, George W. 1963 " The dynamic behavior of water tanks ", Bulletin of the seismological society of America, Vol.53, No. 2, 381_387.

[4]. Ekbote S. and Kori G. "Seismic behavior of RC elevated water tank under different types of staging pattern", Journal of engineering, computers and applied sciences (JEC &AS), vol.2, PP. 23-29, August, 2013.
[5]. Ahmad M. & Singh V. K. " Seismic performance of elevated water tank with different bracing pattern considering fluid structure interaction" , Journal of emerging Technologies and innovative research (JETIR), Vol.6 , Issue 5, May 2019.
[6]. Nidhi & Bajpai A. " Study of Intze tank with different horizontal bracing patterns", International journal of new innovations in engineering and technology, vol. 14, Issue 1, June 2020.
[7]. Kumar, Sakalle & Choubey "Influence of vertical steel bracing at staging of R.C.C elevated water tank" International research journal of engineering and technology , vol.8 Issue: 01\ Jan 2021.
[8]. Singh H. & Tiwary A. K. " Dynamic analysis of RCC elevated water tank considering effect of conventional and composite staging" , ICONN_2023.