

A Study of Overhead Water Tanks Subjected to Dynamic Loads

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Abstract — The present study focuses on the response of the elevated circular type water tanks to dynamic forces. Overhead water tanks consist of huge water mass at the top of a slender staging which are most critical consideration for the failure of the tank during earthquakes. Tanks of various capacities with different staging height is modelled using ANSYS software. The analysis is carried out for two cases namely, tank full and half level condition considering the sloshing effect along with hydrostatic effect. The time history analysis of the water tank is carried out by using earthquake acceleration records of El Centro. The tanks withstood the acceleration with the displacements within the permissible limits. The peak displacements and base shear obtained from the analysis were also compared.

Keywords — Elevated water tank, Sloshing, Hydrostatic Load, Convective Mass, Impulsive Mass, ANSYS Modelling, Time history analysis, Base shear.

I. INTRODUCTION

An elevated water tank is a large water storage container constructed for the purpose of holding water supply at certain height to provide sufficient pressure in the water distribution system. Liquid storage tanks are used extensively by municipalities and industries for storing water, inflammable liquids and other chemicals. Industrial liquid tanks may contain highly toxic and inflammable liquids and these tanks should not lose their contents during the earthquake. These tanks have various types of support structures like RC braced frame, steel frame, RC shaft, and even masonry pedestal. The frame type is the most commonly used staging in practice. The main components of the frame type of staging are columns and braces. The staging acts like a bridge between container and foundation for the transfer of loads acting on the tank. Thus Water tanks are very important for public utility and for industrial structure.

Elevated water tanks consist of huge water mass at the top of a slender staging which are most critical consideration for the failure of the tank during earthquakes. Elevated water tanks are critical and strategic structures and the damage of these structures during earthquakes may endanger drinking water supply, cause to fail in preventing large fires and substantial economical loss. Since, the elevated tanks are

frequently used in seismic active regions hence; seismic behaviour of them has to be investigated in detail. Due to the lack of knowledge of supporting system some of the water tanks were collapsed or heavily damaged. So there is need to focus on seismic safety of lifeline structure with respect to alternate supporting system which are safe during earthquake and also to withstand more design forces.

The frame support of elevated water tank should have adequate strength to resist axial loads, moment and shear force due to lateral loads. These forces depend upon total weight of the structure, which varies with the amount of water present in the tank container. An analysis of the dynamic behaviour of such tanks must take into account the motion of the water relative to the tank as well as the motion of the tank relative to the ground. The aim of the present work is to compare the seismic performance of elevated water tank considering variations in staging height for different capacities.

A. Sloshing Effect of Tanks

Sloshing is defined as the periodic motion of the free liquid surface in a partially filled container. It is caused by any disturbance to partially filled liquid containers.

If the liquid is allowed to slosh freely, it can produce forces that cause additional hydrodynamic pressure in case of storage tanks and additional vehicle accelerations in case of moving tanker and space vehicles. The basic problem of liquid sloshing involves the estimation of hydrodynamic pressure distribution, forces, moments and natural frequencies of the free-liquid surface. These parameters have a direct effect on the dynamic stability and performance of storage structures.

II. RELATED RESEARCH

Several researches have been done on different aspects of seismic behaviour and design of elevated water tanks. A comprehensive study in this area also primarily suggested improved recommendation for seismic design of water tanks. A report of the literature reviewed to study the dynamic behaviour of elevated water tank, liquid structure interaction is briefly discussed here.

Chirag N. Patel (2012) presented a literature review on behavior and suitability of supporting system of reinforced concrete elevated/overhead tanks during vulnerable force events like earthquake with some unusual alteration. The

literature explains the considerable change in seismic behavior of elevated tanks with consideration of responses like displacement, base shear, base moment, sloshing, torsional vulnerability etc. when supporting system is used with appropriate modifications. The importance of suitable supporting configuration to withstand against heavy damage/failure of elevated water tanks during seismic events is also highlighted. K.R Bindhu, A. Sujatha and Sreekumar .M (2012) in their work checks the adequacy of water tank for seismic excitation. Time history analysis was carried out to study the behaviour of water tank. The peak displacements and base shear were compared with the IS code provision. The peak displacements and base shear values from time history analysis were higher than that obtained from IS 1893:1984 for different water levels. The single DOF model as suggested in the code underestimates the responses of the tank under earthquake loads. Gaikwad Madhurar V (2013) aim is to compare the Static and Dynamic analysis of elevated water tank, to study the dynamic response of elevated water tank by both the methods, to study the hydrodynamic effect on elevated water tank, to compare the effects of Impulsive and Convective pressure results. For same capacity, same geometry, same height, with same staging system, with same Importance factor & response reduction factor, in the same zone; response by equivalent static method to dynamic method differ considerably. Also, as the capacity increases, difference between the response increases. Increase in the capacity shows that difference between static and dynamic response is in increasing order. For small capacity of tank the impulsive pressure is always greater than the convective pressure, but it is vice-versa for tanks with large capacity. Keyur Y. Prajapati (2014) takes an effort to identify the seismic behavior of elevated water tank under Response Spectrum Method with consideration and modeling of impulsive and convective water masses inside the container for different height wise, zone, soil type and types of staging using structural software SAP2000. The study was carried out on an Intze shape water container of reinforced cement concrete. The storage capacity of water tank is 250 m³. The staging heights considered for study are 12m, 16 m, 20 m. Results for base shear, overturning moment and top displacement by changing various parameters has been evaluated and compared for 90 water tanks. P. Muthu Vijay (2014) concentrated mainly on Sloshing Effect that is happening in the water tank during Earthquake, and how to overcome it. If the liquid is allowed to slosh freely, it can produce forces that cause additional hydrodynamic pressure in case of storage tanks and additional vehicle accelerations in case of moving tanker and space vehicles. sloshing of water considerably differs the parametric values used in design and economy of construction. So in the seismic analysis of tanks more importance should be given to Sloshing, rather than considering it as a parameter to fix the free float of the tank. Ankita R Patil (2014) studied the seismic performance of water tank for various seismic zones with variation in staging height and 3 different types of staging configuration.

Performance of radial configuration is better than normal and cross configuration.

III. SCOPE OF THE PROJECT

In the present study finite element modelling of tank was carried out using software package ANSYS 15. An attempt was made to study the effect of staging height in tanks having three different capacities. For this, seismic analysis was done using ANSYS for full water level and half water level conditions. The analytical investigation of the seismic response of elevated water tank by time history analysis considering the convective mode for an earthquake data is also included in the present study. The peak displacements and base shear obtained from the analysis were also compared.

IV. OBJECTIVES

- To conduct a study about the Static and Dynamic analysis of elevated water tanks.
- To study about the behavior of staging system under earthquake load.
- To carry out the time history analysis of the water tank for half tank level and full water level conditions by using El Centro earthquake time acceleration records and compare the response histories such as displacement and base shear.

V. METHODOLOGY

The methodology includes fixing the dimensions of components for the selected water tank and performing nonlinear dynamic analysis (Time History Analysis) by: 1893-2002 (Part 2) draft code. This work proposes to study Circular tanks of different capacity and staging height and column configuration. The analysis is carried out for tank with full capacity and half capacity and considering the sloshing effect along with hydrostatic effects. Finite Element Model (FEM) is used to model the elevated water tank using ANSYS software.

VI. MATHEMATICAL MODELLING OF WATER TANK

An elevated Water tank can be idealized as single lumped mass model, two mass model, spring mass model etc. In order to consider the effect of convective mode, the tank should be modelled as two mass model.

A. Two Mass Model

If the effect of convective mode of vibration is included, the elevated tank can be modelled as 2 DOF system, comprising of convective mass and impulsive mass. The impulsive mass includes mass of impulsive liquid, mass of container and one third mass of staging. Mass and stiffness corresponding to convective portion can be obtained using approach suggested by Housner.

The most commonly applied idealization for estimating liquid response in seismically excited rigid, rectangular and cylindrical tanks is to divide hydrodynamic pressures of contained liquid into two components: the impulsive pressure caused by the portion of the liquid accelerating with the tank and the convective pressure caused by the portion of the liquid

sloshing in the tank. The convective component was modelled as a single degree of freedom oscillator.

VII. TANK DATA AND MODELLING

In the present study, three elevated water tanks with 800m³, 1000m³ and 1200 m³ capacities are considered. Tank diameters are 17.31m, 19.36m and 21.2m respectively. In full tank condition, the water level is 3.41m and free board is taken as 0.59. The tank container is of circular type. Young’s modulus and the weight of concrete per unit volume are taken as 27386MPa and 25kN/m³. The container is filled with water of density 1000 kg/m³.

**VIII. TABLE I
DIMENSIONS OF TANK**

Capacity	800 m ³	1000 m ³	1200 m ³
Diameter	17.31m	19.36m	21.2m
Column dimension	0.4m x 0.4m		
Tank height	4.4m		
Wall thickness of tank	0.2m		
Floor beam	0.2m x 0.4m		
Ring beam	0.4mx0.7m		
Brace beam	0.25m x 0.5m		
Floor slab thickness	0.3m		
Staging height considered	12m, 15m, 18m		
Boundary condition at the base	Fixed		

In FEM, modelling of the problem is one of the aspects that govern the accuracy of the solution and efficiency of computational time. The columns and beams were modelled using beam elements. The tank wall was considered as shell element. The tank was modelled with SHELL181, the columns and beams with BEAM 188 and the water inside the tank with FLUID30 elements. Material property was assumed to be homogeneous within the material.

**IX. TABLE III
MATERIAL PROPERTIES (ANSYS INPUT)**

ANSYS15 Element	Structural Element	Material Properties	
SHELL181	Tank wall, Roof slab, Floor slab and Gallery	Young’s modulus	0.27386E+11 N/m ²
		Density	2548.42Kg/m ³
BEAM188	Beams and Columns	DAMP	0.05
		Poisson’s Ratio	0.2

FLUID30	Water	Density	1000Kg/m ³
		SonicVelocity	1440 m/s

The tank is an elevated one with moment resisting frame as supports, circular, thin walled liquid container. The liquid height is defined by h. For the present study, water tank was modelled for full tank and half tank condition. Three staging conditions were provided for each capacity of tank. The global Cartesian system was defined such as the free surface of the fluid to be at z=0, i.e., all the nodes without positive Z coordinates.

While generating a model, the usual practice is to define the relationship among different degrees of freedom by using elements to connect the nodes. In this case special association among nodal degrees of freedom can be established using coupling. In the case of using two different elements that are bounded together at a node coupling of the nodes is required. This coupling causes the nodal results to be transferred from one element to the other, so that equilibrium of nodal values will be attained. Coincident nodes in a model can be coupled by generating one coupled set for each specified DOF label at every pair of coincident nodes. If all DOFs are to be coupled for coincident nodes, it will be more efficient to simply merge those nodes together.

The interaction of the fluid and the structure at a mesh interface causes the acoustic pressure to exert a force applied to the structure and the structural motions produce an effective "fluid load. Both the structural and fluid load quantities that are produced at the fluid-structure interface are functions of unknown nodal degrees of freedom. The nodes on a fluid-structure interface have both displacement and pressure degrees of freedom.

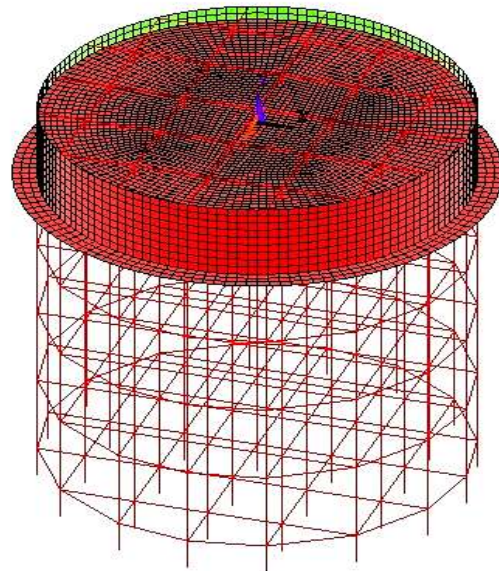


Fig. 1 ANSYS model of elevated water tank in full water level condition (1200m³- 18m staging height)

A. Time History Analysis

Time history analysis was carried out to study the behaviour of the water tank under El Centro, earthquakes acceleration- time records. Time history analysis was carried out in ANSYS using the transient dynamic analysis. The ANSYS program uses the Newmark’s time integration method to solve the dynamic equations. The time increment between successive time points is called the integration time step. Three methods to do a transient dynamic analysis are full method, mode superposition method and reduced method. In the present work transient analysis was carried out using the full method. The full method uses the full system matrices to calculate the transient response. It is the most general of the three methods because it allows all types of nonlinearities to be included (plasticity, large deflection, large strain etc.). Analysis was done from the acceleration records of Imperial Valley earthquake at El-centro array on 18.05.1940 of magnitude 7.1, and duration 31.18s.

X. RESULTS AND DISCUSSION

Time history analysis was carried out for the tank with full and half tank conditions. The maximum displacement response at the top of the tank and maximum base shear under El centro earthquake were obtained from time history analysis.

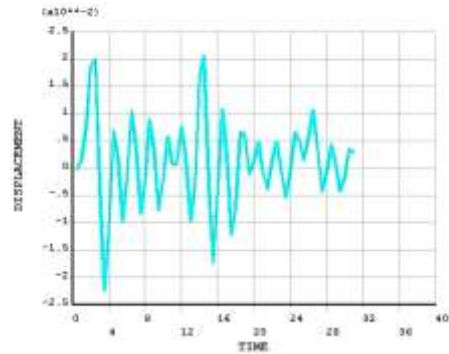


Fig. 4 Displacement response at top of tank for half tank condition

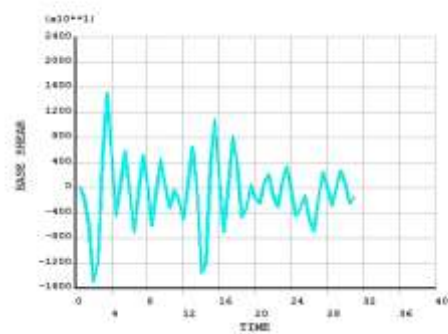


Fig. 4 Base shear response at top of tank for half tank condition

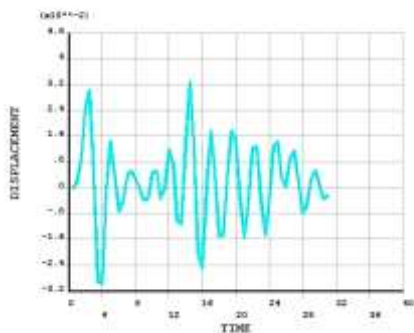


Fig. 1 Displacement response at top of tank for full tank condition

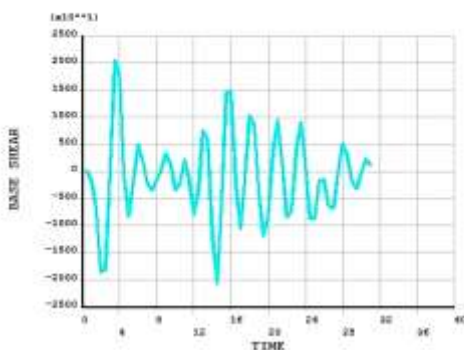


Fig.2 Base shear response at top of tank for full tank condition

A. Comparison of Displacement at the Top of the Tank

Maximum displacement values from the time history analysis for El-centro earthquake are shown in table III.

**XI. TABLE III
PEAK DISPLACEMENT IN METERS**

Capacity	Staging height		
	12 m	15m	18m
800m ³ (full)	0.0184	0.0237	0.0372
1000m ³ (full)	0.00804	0.0165	0.0213
1200m ³ (full)	0.0109	0.019	0.0331
800m ³ (half)	0.01	0.0189	0.0307
1000m ³ (half)	0.00586	0.00969	0.0204
1200m ³ (half)	0.00801	0.0175	0.0226
Permissible Displacement(H/250)	0.0656	0.0776	0.0896

The peak displacements were compared with the permissible displacement as per IS 1893 : 2002. As per this the permissible displacement 0.004 times the storey height.

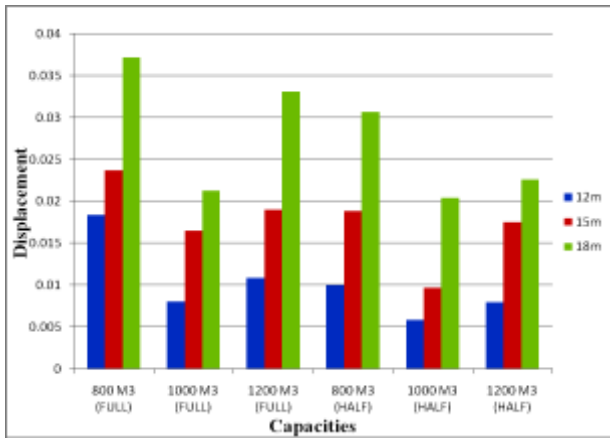


Fig.4 Comparison of peak displacement

B. Comparison of Base Shear

Maximum base shear values from the time history analysis for El-centro earthquake are shown in table IV.

**XII. TABLE IV
BASE SHEAR (N)**

Capacity	Staging height		
	12 m	15m	18m
800m ³ (full)	17751.9	27173.4	28726.76
1000m ³ (full)	10845	13703.8	17950
1200m ³ (full)	14171	19006.9	20434.8
800m ³ (half)	12120.6	15318.4	17690.7
1000m ³ (half)	7174.9	9467.28	11532.37
1200m ³ (half)	9168.1	11223.4	15169.95

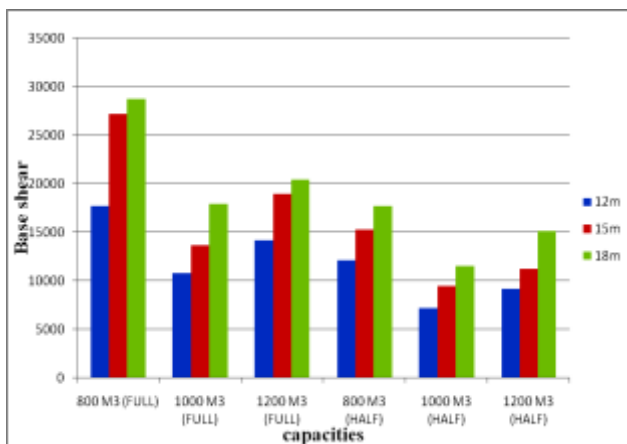


Fig.5 Comparison of base shear

XIII. CONCLUSIONS

The conclusions drawn based on the studies are given below.

- The peak displacements from the time history analysis under El Centro earthquake records are

below the maximum permissible displacement for different water levels.

- The peak displacement from the time history analysis increases with staging heights.
- But the displacement first decreases and then increases with capacities.
- The displacement for half filled tanks is lesser than the displacement for tanks with full capacity.
- The base shear values from time history analysis were increases as staging height increases. Also, the base shears decreases and then increases with capacity.
- Base shear for half capacity tanks are lesser than that for full capacity tanks under same staging condition.

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REFERENCES

- [1] S.K.Jain, and O.R.Jaiswal, 2005, "Modified proposed provision for a seismic design of liquid storage tanks: Part I – codal provisions. *Journal of structural engineering*, September, vol.32, No.3, pp 195-206.
- [2] Dutta, S.C., Jain, S.K. and Murty, C.V.R., "Assessing the seismic torsional vulnerability of elevated tanks with RC frame-type staging", *Soil Dynamics and Earthquake Engineering*, vol.19, P.P. 183-197,2000.
- [3] K.R Bindhu, A. Sujatha and Sreekumar .M, "seismic response of elevated water tank". *The IUP journal of structural engineering*, vol V, No.1, 2012.
- [4] *IITK-GSDMA Guidelines for Seismic Design of Liquid Storage Tanks 2007*.
- [5] Chirag N. Patel & H. S. Patel, Supporting systems for reinforced concrete elevated water tanks: a state-of-the-art literature review, *International Journal of Advanced Engineering Research and Studies*, Vol. II, Issue I, Oct-Dec, 2012, 68-71, E-ISSN 2249-8974.
- [6] P. Muthu Vijay & Amar Prakash, "Analysis of sloshing impact on overhead liquid storage structures", *International journal of research in Engineering & technology*, ISSN(E): 2321-8843; ISSN(P): 2347-4599 Vol. 2, Issue 8, Aug 2014, 127-142.
- [7] Jain, S.K. and Sajjid Sameer.U, 1994, "A review of requirements in Indian codes for Aseismic design of elevated water tanks" *Journal of Structural Engineering*, Vol 20, Pp 119-128.
- [8] Keyur Y. Prajapati , Analysis of hybrid staging systems for elevated Storage reservoir, *Indian journal of research* ,ISSN - 2250-1991 Volume : 3 Issue : 6 June 2014.
- [9] Gaikwad madhurar V & prof. Mangulkar madhuri N, Comparison between static and dynamic analysis of elevated water tank ,*International Journal of Scientific & Engineering Research*, Volume 4, Issue 6, June-2013, ISSN 2229-5518.
- [10] *IS: 11682-1985 "Criteria for design of RCC staging for over head water tanks"*, Bureau of Indian Standards, New Delhi.
- [11] *Criteria for Earthquake Resistant Design of structures, IS Code 1893:1984*, Bureau of Indian Standards, New Delhi
- [12] *Criteria for Earthquake Resistant Design of structures, IS Code 1893:2002(Part II)*, Bureau of Indian Standards, New Delhi.