

A Study on Design of Water Tanks using SAP

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Abstract: Elevated water tanks are integral part of lifeline facilities in any town/city. They are used to store water for various purposes like drinking etc and are vulnerable in resisting earthquake forces due to presence of large mass on a slender staging. This study is mainly focused in understanding the seismic behaviour and vulnerability of elevated reinforced concrete water tanks and supporting structures for various seismic intensities, soil conditions, staging heights etc. with respect to the provisions of IS1893 Part2 and guidelines proposed by IITK-GSDMA. Finite element modelling and dynamic analysis of elevated water tanks has been performed using SAP2000. Further, Nonlinear static analysis has been performed to assess the ductility characteristics of the water tank for varying staging heights, for a given capacity of water tank (Empty and Full water level conditions). In this study Circular water tank has been chosen as a case study and analysed for staging heights 5, 8,11,14,17,20,23 & 26, for an interval of 3 meters.

Keywords: IITK-GSDMA, Dynamic Analysis, SAP2000.

I. INTRODUCTION

An elevated RC intze tank is a large water storage container constructed for the purpose of holding water supply at certain height to pressurize the water distribution system. Many new ideas and innovation has been made for the storage of water and other liquid materials in different forms and fashions. Liquid storage tanks are used extensively by municipalities and industries for storing water, inflammable liquids and other chemicals. Thus Water tanks are very important for public utility and for industrial structure. Elevated water tanks having Large diameter with a conical dome at its bottom are known as intze tanks consists of huge water mass at the top of a slender staging which are most critical consideration for the failure of the tank during earthquakes. A large number of elevated water tanks damaged during past earthquake were found to be supported on shaft staging. It is observed from the past earthquake; most of the elevated water tanks undergo damage to their staging. The seismic analysis of these tanks has been carried out by different methods firstly based on Indian standard code 1893,(part 1) i.e. adopting lumped mass modal method and second is based on IS 1893(part 2) draft code and IITK-GSDMA guidelines considering two mass modal (convective and impulsive mode) method. It can be observed that reinforced concrete elevated water tanks with frame staging, has shown better seismic resistance than reinforced concrete elevated water tanks with shaft staging. These can be attributed to the seismic energy absorption capacity of the staging patterns. Hence this study is primarily focussed on understanding the seismic behaviour and performance characteristics of elevated RC intze tank with different

staging patterns in Warangal city. In the present study, Dynamic analysis of RC intze tank and evaluation of ductility characteristics of different staging namely, frame staging and shaft staging is also carried out. Software package SAP2000 has been used for modelling and analyzing the elevated water tank supported on frame and shaft staging.

II. LITERATURE REVIEW

Malhotra PK [1] Used Finite element method to model the elevated tank, Columns and beams in the support system are modelled as frame elements. For different water conditions like empty, full and half-full case was studied and the time period, modal participation mass ratio were calculated. Base shear, overturning moment, roof displacement, sloshing displacement were studied. Conclusions arrived are, Maximum displacement of the elevated tank occurs in the joint between the support system and the container. Maximum displacement of the elevated tank does not occur in roof of the elevated water tank. Because of the difference in impulsive and convective mass time periods and the difference in the frequency contents and properties of the earthquake records used, the occurrence time of maximum roof and sloshing displacements are different. Responses such as base shear force, overturning moment and impulsive displacement (roof and floor displacement) depend more on the tank impulsive mode, while sloshing displacement depends more on the tank convective mode.

MANISH N. GANDHI [2] Explained about frame staging type Elevated water tanks, which 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. Many of the water tanks which failed due to earthquake forces are shaft supported water tanks, which are needed to be avoided in seismic zones. It was also identified that, for higher seismic zones general frame staging is not sufficient special staging with bracings are required. The conclusions arrived from these paper was that the slender staging that results from the low design forces is a very unfavourable feature for seismic areas for elevated water tanks. The current designs of RC shaft type circular staging for elevated water tanks are extremely vulnerable to lateral loads caused by earthquakes. It is evident from the damages sustained to staging as far as 125km away from the epicentre of the Bhuj earthquake. Supporting structures of elevated water tanks are extremely vulnerable under lateral forces due to an earthquake.

Housner [3] proposed two mass model for elevated tank which is more appropriate and is being commonly used in most of the international codes including Draft code for IS 1893 (Part-II). The pressure generated within the fluid due to the dynamic motion of the tank can be separated into impulsive and convective parts. When a tank containing liquid with a free surface is subjected to horizontal earthquake ground motion, tank wall and liquid are subjected to horizontal acceleration. The liquid in the lower region of tank behaves like a mass that is rigidly connected to tank wall. This mass is termed as impulsive liquid mass which accelerates along with the wall and induces impulsive hydrodynamic pressure on tank wall and similarly on base. Liquid mass in the upper region of tank undergoes sloshing motion. This mass is termed as convective liquid mass and it exerts convective hydrodynamic pressure on tank wall and base. For representing these two masses and in order to include the effect of their hydrodynamic pressure in analysis, spring mass model is adopted for two-mass model for elevated water tanks.

Dutta[4] Studied torsional response of RC elevated water tanks supported on axisymmetric frame-type staging. He studied that Elevated water tanks have failed during past earthquakes owing to large torsional response. Considerable torsional response may occur due to accidental eccentricity if the uncoupled torsional and lateral natural periods of the tanks are closely spaced.

Research Significance: Study of seismic resistant design of elevated water tanks as per IS 1893(part1) and IITK-GSDMA guidelines. Finite element modelling and dynamic analysis of elevated RC intze water tank with different staging patterns with lumped mass modal as per IS: 1893 (part1) and two mass modal method as per IS1893 (part2) and IITK-GSDMA guidelines respectively. Since earthquake data for Warangal city is not available, response spectrum analysis has been carried out for elevated RC intze water tank supported with different staging patterns using SAP2000 software. Analyse the influence of staging patterns on the base shear and ductility characteristics of elevated intze water

tank by performing nonlinear static analysis using the software SAP2000.

III. SEISMIC ANALYSIS OF ELEVATED RC INTZE TANK WITH DIFFERENT STAGING PATTERNS

Analytical studies dealt with the hydrodynamics of liquids in rigid tanks resting on rigid foundations. It was shown that a part of the liquid moves in long-period sloshing motion, while the rest moves rigidly with the tank wall. The latter part of the liquid also known as the impulsive liquid experiences the same acceleration as the ground and contributes predominantly to the base shear and overturning moment. The sloshing liquid determines the height of the free-surface waves, and hence the freeboard requirement. The flexibility of the tank wall may cause the impulsive liquid to experience accelerations that are several times greater than the peak ground acceleration. Tanks supported on flexible foundations, through rigid base mats, experience base translation and rocking, resulting in longer impulsive periods and generally greater effective damping. These changes may affect the impulsive response significantly. The convective (or sloshing) response is practically insensitive to both the tank wall and the foundation flexibility due to its long period of oscillation. For the purpose of this analysis elevated tanks is considered as a single degree of freedom with their mass concentrated at their centre of gravity.

IV. LUMPED MASS MODAL METHOD

A. Horizontal pressure

For the purpose of this analysis, elevated tanks shall be regarded as systems with a single degree of freedom with their mass concentrated at their centre of gravity. The damping in the system may be assumed as 5 percent of the critical for concrete.

B. Two Mass Modal Method

Most elevated tanks are never completely filled with liquid. Hence a two-mass Idealization of the tank is more appropriate as compared to a one mass idealization. Failure of tanks during Chilean earthquake of 1960 and Alaska earthquake of 1964 led to beginning of many investigations on seismic analysis of liquid storage tanks and this aspect came to forefront that consideration should be given to sloshing (convective) effect of liquid and flexibility of container wall while evaluating the seismic force of tank.

C. Seismic Analysis Of Intze Tank With Frame Staging

Capacity of tank = 1000 kilolitre and Supported on R.C. frame staging of 12 columns with horizontal bracing
Details of sizes of various components and geometry are shown in Table 1.
Weight calculation of various components are shown in Table2

D. Seismic Analysis of Intze Tank with Shaft Staging

Capacity of tank = 1000 kilolitre and Supported on R.C. Shaft staging

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Details of sizes of various components and geometry are shown below in Table 3.

Weight calculation of various components in Table 4.

V. NONLINEAR STATIC ANALYSIS

A. Modelling of Elevated Water Tank in SAP2000

Steps followed for modelling the staging and tank container using SAP2000: Define element type: Here frame/cable type element is used for ring beam, bracing, column and area element (shell) is used for top dome, bottom dome, cylindrical wall and shaft type staging. Define Material properties: Here we provide the properties of the beam and shell such as elastic modulus, shear modulus, Poisson's ratio, weight density, etc. Define sections: Frame sections define the width and depth for line element and area sections define thickness for shell element. Modelling geometry: Here water tank geometry is model by using grid system. Apply loads and boundary condition: Define menu provides option for specifying the boundary conditions and loads. Deflection results: The solution is obtained using the display option in main menu.

B. Evaluation of Ductility

Nonlinear static analysis capabilities are provided in the nonlinear version of SAP2000. For a beam default hinges that yield based upon flexure (M3) is assigned. For the column default hinges that yield based upon the interaction of the axial force and bending moment (P-M2-M3) is assigned. For a bracing default hinges that yield based upon flexure (M3) is assigned. Currently, hinges can be introduced into frame objects only. After assigning hinge properties to the structure analysis is carried out to get the pushover curve.

VI. RESULT DISCUSSIONS

The present study looks into two alternative configurations of staging of elevated water storage tank: intze tank supported on frame staging and shaft staging. The seismic analysis of these tanks has been done by two different methods, first lumped mass modal and second is two mass modal methods. Ductility of frame and shaft staging has also been evaluated. The outcome of this study can be briefly summarized as follows, Comparison of different seismic analysis parameters of intze tank supported on frame staging and shaft staging is shown in table 5 and 6. In this table all parameter for single mass modal as well two mass modal for frame staging and shaft staging are summarized. Time period of water tank supported on frame staging is higher as compare to tank supported on shaft staging because lateral stiffness of shaft staging is much higher than the frame staging. The hydrodynamic pressure also is higher in shaft staging when compared to framed staging. Graphical representations of hydrodynamic pressure on cylindrical wall as well as bottom of the tank for lumped mass modal and two mass modal are shown in figure 2 to 5.

VII. CONCLUSIONS

Seismic analysis and performance of elevated RC intze water tanks have been presented in this study for different staging patterns. Modelling, dynamic analysis and nonlinear static analysis is performed using SAP2000 software.

Further, the behaviour of elevated water tanks with various staging patterns are analysed using single mass modal and two mass modal methods. It can be observed from the analyses that elevated water tank with frame type of staging perform better than shaft type of staging due to the following characteristics.

- Time period of elevated water tank supported on frame staging is higher than the tank supported on shaft staging. Since the lateral stiffness of shaft staging is much higher than the frame staging.
- Due to higher lateral stiffness of shaft staging, lateral forces are also high as compare to frame staging. The study shows that the base shear in tanks supported by shaft staging is higher than the tank supported on frame staging.
- Impulsive hydrodynamic pressure in shaft staging is higher than the frame staging, while the convective hydrodynamic pressure is same in both type of staging.
- After non-linear static analysis of frame staging and shaft staging, it is known that the ductility of shaft staging is lower than the frame staging. It can be observed in this study that ductility of RC intze tank with frame staging is 6.65 and that of shaft staging is 3.12.

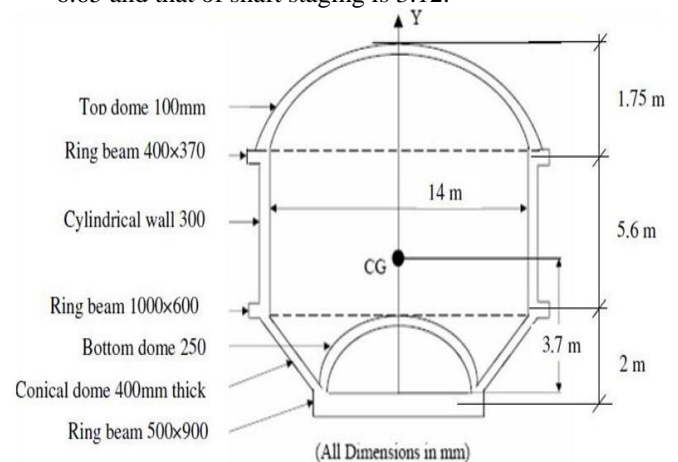


Figure1. Container parameters in frame staging tank.

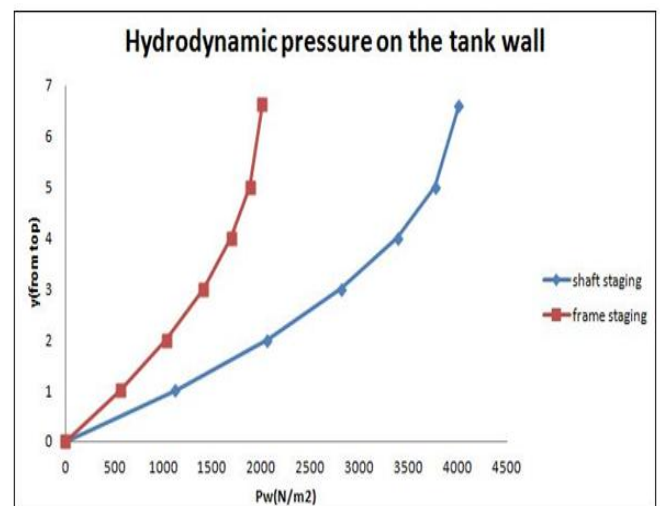


Figure2. Hydrodynamic pressures on the tank wall (Lumped Mass Modal).

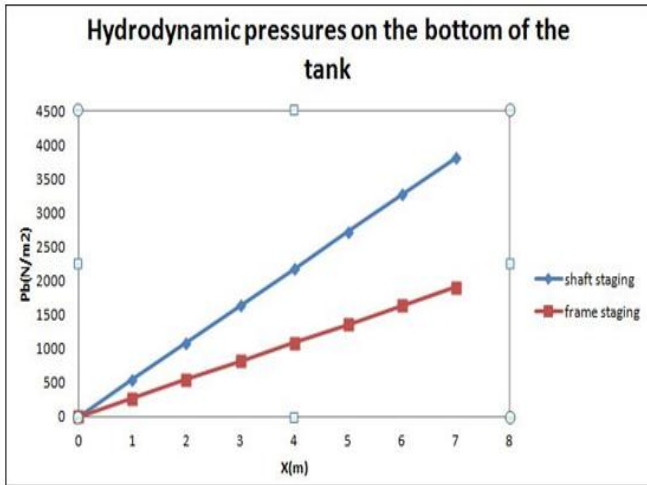


Figure 3. Hydrodynamic pressures on the bottom of tank (Lumped Mass Modal).

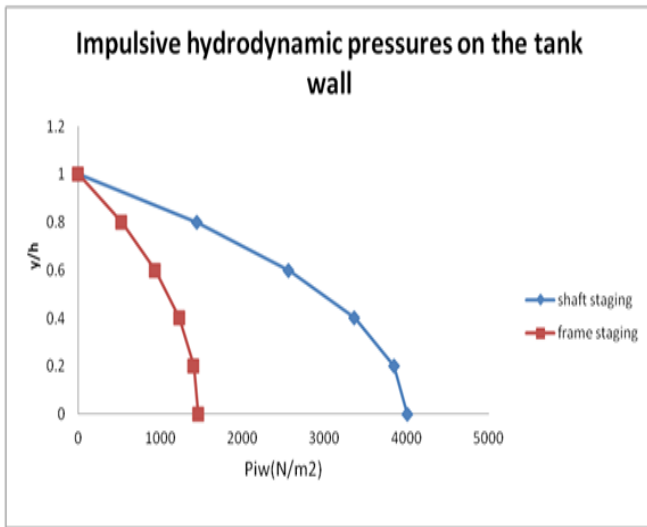


Figure 4. Impulsive Hydrodynamic pressures on the tank wall (Two Mass Modal).

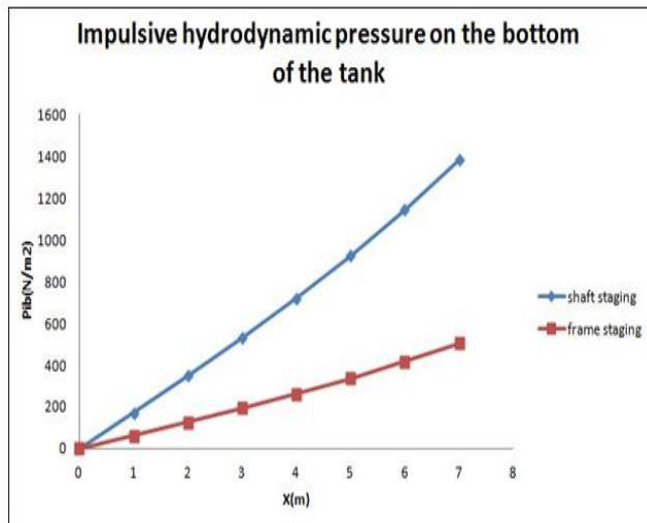


Figure 5. Impulsive Hydrodynamic pressures on the bottom of tank (Two Mass Modal).

Table 1. Preliminary Data

Component	Size (mm)
Top Dome	- 100 thick
Top Ring Beam B1	- 370×400
Cylindrical Wall	- 300 thick
Bottom Ring Beam B3	- 1000×600
Conical dome	- 400 thick
Bottom dome	- 250 thick
Circular Ring Beam B2	- 500×900
Column	- 800mm dia
Bracing	- 300×600

Table 2. Weight calculation frame staging tank

Component	Calculation	Weight kN
Top Dome	$2\pi R_1 \times h_1 \times t \times 25$ $2\pi \times 14.875 \times 1.75 \times 0.1 \times 25$	408.690625
Top Ring Beam B1	$\pi \times (14+0.4) \times 0.4 \times 0.37 \times 25$	167.2992
Cylindrical Wall	$\pi \times 14.3 \times 0.3 \times 5.6 \times 25$	1885.884
Bottom Ring Beam B3	$\pi \times (14+1) \times 1 \times 0.6 \times 25$	706.5
Conical dome	$\pi \times [(14+10)/2] \times 2.8 \times 0.4 \times 25$	1055.04
Bottom Dome	$2 \times \pi \times 8.02 \times 1.75 \times 0.25 \times 25$	550.8737
Circular Ring Beam B2	$\pi \times 10 \times 0.9 \times 0.5 \times 25$	353.25
Column	$\pi/4 \times (0.8)^2 \times 16 \times 12 \times 25$	2411.52
Bracing	$0.3 \times 0.6 \times 2.588 \times 12 \times 4 \times 25$	559.000

Table 3. Preliminary Data

Component	Size (mm)
Top Dome	- 100 thick
Top Ring Beam B1	- 370×400
Cylindrical Wall	- 300 thick
Bottom Ring Beam B3	- 1000×600
Conical dome	- 400 thick
Bottom dome	- 250 thick
Circular Ring Beam B2	- 400×600
Shaft Staging	- 220 thick.

Table 4. Weight calculation shaft staging tank

Component	Calculation	Weight KN
Top Dome	$2\pi R_1 \times h_1 \times t \times 25$ $2\pi \times 14.875 \times 1.75 \times 0.1 \times 25$	408.690
Top Ring Beam B1	$\pi \times (14+0.4) \times 0.4 \times 0.37 \times 25$	167.2992
Cylindrical Wall	$\pi \times 14.3 \times 0.3 \times 5.6 \times 25$	1885.884
Bottom Ring Beam B3	$\pi \times (14+1) \times 1 \times 0.6 \times 25$	706.50
Conical dome	$\pi \times [(14+10)/2] \times 2.8 \times 0.4 \times 25$	1055.04
Bottom Dome	$2 \times \pi \times 8.02 \times 1.75 \times 0.25 \times 25$	550.8737
Circular Ring Beam B2	$\pi \times 10 \times 0.6 \times 0.4 \times 25$	188.4
Shaft Staging	$\pi \times 10 \times 0.22 \times 16 \times 25$	2763.2

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Table 5. Comparison of Seismic Analysis Parameter of Intze Tank Supported On Frame Staging and Shaft Staging

staging. Soil Dynamics and Earthquake Engineering. 2000 Apr 30;19(3):183-97.

S.No	Component	Frame staging	Shaft staging
A	Lateral Stiffness (K_s)	50787.202 kN/m	1.41×10^6 kN/m
B	lumped mass modal		
1	Time period (a) tank is empty (b) tank is full	0.695 sec 1.129 sec	0.129 sec 0.212 sec.
2	Base shear (a) tank is empty (b) tank is full	321.17 kN 604.01 kN	441.28 kN 1190.47 kN
3	Hydrodynamics pressure on the wall	2003.5 N/m ²	4007.78 N/m ²
4	Hydrodynamics pressure on the base	1905.19 N/m ²	3810.38 N/m ²

Table 6 Comparison of Seismic Analysis Parameter of Intze Tank Supported On Frame Staging and Shaft Staging in Two mass modal.

S.No	Two mass modal		
1	Time period (a) impulsive mode (b) convective mode	1.095 sec 4.0 sec.	0.208 sec 4.0 sec
2	Base shear (a) impulsive mode (b) convective mode (c) total base shear	415.3 kN 59.11 kN 419.48 kN	1580.17 kN 82.10 kN 1582.30 kN
3	Overtuning moment (a) impulsive mode (b) convective mode	8631.17 kN-m 1288.21 kN-m	32840.72 kN-m 1789.18 kN-m
4	Hydrodynamics pressure on the wall (a) impulsive mode (b) convective mode	0 (Top) 1462.31 N/m ² (Bottom) 666.26 N/m ² (Top) 227.57 N/m ² (Bottom)	0 (Top) 4006.06 N/m ² (Bottom) 666.26 N/m ² (Top) 227.57 N/m ² (Bottom)
5	Hydrodynamics pressure on the base (a) impulsive mode (b) convective mode	0 (at centre) 504.36 N/m ² (at wall) 0 (at centre) 226.56 N/m ² (at wall)	0 (at centre) 1381.73 (at wall) 0 (at centre) 226.56 N/m ² (at wall)
6	Pressure due to wall Inertia	205.32 N/m ²	562.5 N/m ²
7	Pressure due to vertical excitation	0 (Top) 3246.22 N/m ² (Bottom)	0 (Top) 3246.22 N/m ² (Bottom)

Table 7 Ductility of frame staging and shaft staging

S.No	Staging type	Ductility
1	Frame	6.65
2	Shaft	3.12

VIII. REFERENCES

- [1] Malhotra PK, Wenk T, Wieland M. Simple procedure for seismic analysis of liquid-storage tanks. Structural Engineering International. 2000 Aug 1;10(3):197-201.
- [2] Manish N. Gandhi, Prof.A.Rajan, Necessity of Dynamic Analysis of Elevated Water Storage Structure Using Different Bracing in Staging. International Journal of Research in Advent Technology, February 2014, Vol.2, No.2.
- [3] Hounser. Dynamic behaviour of liquid water emerging from a GDL pore into a PEMFC gas flow channel. Journal of Power Sources. 2007 Oct 11;172(1):287-95.
- [4] Dutta SC, Jain SK, Murty CV. Assessing the seismic torsional vulnerability of elevated tanks with RC frame-type