Performance study of Different Staging Patterns on Elevated Intze Tank according to IS 1893 (Part –II) 2014

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Abstract

This research paper compares the performance of Elevated Intze water tanks with the different staging patterns in context of their 1] Base shear 2] Overturning moments 3] Stress variations 4] Area of Steel. The design basis furnished in IS 1893-1984 for elevated water tanks are based on one-mass idealization of elevated water tanks which is not appropriate for large (large width to depth ratio) and partially filled tanks. Also the design features of this standard lead to very weak and slender support system which renders the superstructure quite vulnerable in the high seismic area. Also the seismic forces so suggested by this standard are the same as that for the most ductile building framing system. The code does not take into account the convective and impulsive pressure which in turn comes in role during horizontal excitations. Therefore the objective of this study is to assess the impression of seismic forces on two type of tank systems differentiated on the basis of their supports classified as Framed Staging and Shaft Staging. The analysis of the systems is carried out using Response Spectrum Analysis and the behavior of these staging systems is analyzed as per IS 1893 (Part 2) 2014.

Introduction

Earlier the primary uses for liquid containers were restricted in the petroleum industry and in municipal water supply systems only but with the consistent scientific research into the dynamic behavior of liquid storage tanks the significance of these structures have been surged and their usage has also been extended to nuclear reactor installation thus making the study of their vibration response a matter of sheer importance. Seeking the importance of elevated water tanks as stated above it becomes imperative for these structures to remain operational during all times even in times of natural calamities. Of all the natural calamities occurring in India, Earthquake has an everlasting effect on elevated tank structures. There are three types of water reservoirs which are into service i.e. ground supported tanks, underground tanks and overhead tanks (elevated Intze tanks). The elevated tank is held up at a required height by means of support system technically called as Staging. The staging may vary in accordance to the shape and size and thus categorized into two parts known as Framed Type staging and Elevated shaft type staging. The Framed staging consist of an assembly of Beams and Columns provided in accordance to the over head load whereas the shaft supported system consist generally of a circular concrete shaft which originates from the top of footing and ends at the bottom of tank.

Literature Review

Various research works have been conducted for studying the design patterns of water storage tanks envisaging number of Indian as well as international design standards. *IS: 1893 Criteria for earthquake resistant design of structures (Part-II) - Liquid retaining structures, revised in year 2014 and ratified in 2016*, has been referred to conduct the research work.

G.W. Houser [1963] studied the behavior of the ground supported tanks and elevated tanks after the Chilean earthquake of May 1960. He recommended that the Two spring mass idealization adequately represents the dynamic behavior of the elevated tanks in case of horizontal excitation.

Jain Sudhir K [1990] conducted his study on the Indian Standards provisions for calculating the design seismic forces, which he found that were very less which in turn ascribes underestimated structures. He conducted experiments on few models and suggested that the design seismic forces depend on the flexibility of the tank and the time period of vibration.

Durgesh C Rai [2002] in his studies found that the Indian seismic code IS:1893-1984 recommends the same basic seismic force as that for the most ductile building framing system which ascribes the seismic forces the least. He also concluded that the one mass idealization is not ideal for the tank having width to depth ratio more than 2.

Pavan S Ekbote (2013) studied the response of the elevated tank and considered certain parameters and theories which were recommended by G.W Housner which are more acceptable and are being adopted in many of the international codes. His aim was to study the performance of the elevated water tanks under different kinds of staging patterns.

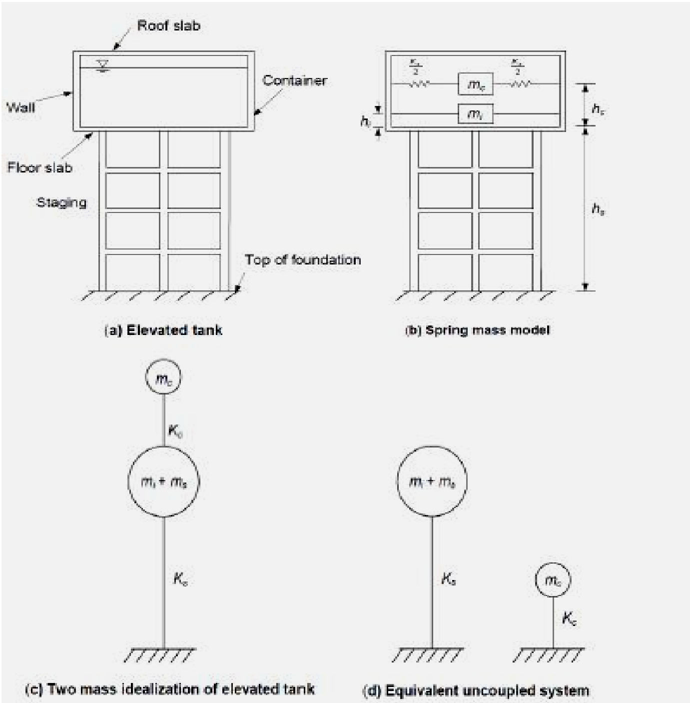
Aims and Objectives

a) To determine the hydrodynamic effects on elevated water tank, with different staging systems i.e., framed staging and concrete shaft placed in same seismic zones, using the method established in *IS: 1893-2014 Part-II*.
b) To determine maximum nodal displacement at the top.
c) Free vibration analysis for both frame type and shaft type staging in Zone IV.
d) To determine overturning moment over the height for frame type and shaft type staging.
e) To determine base shear for frame type and shaft type staging.

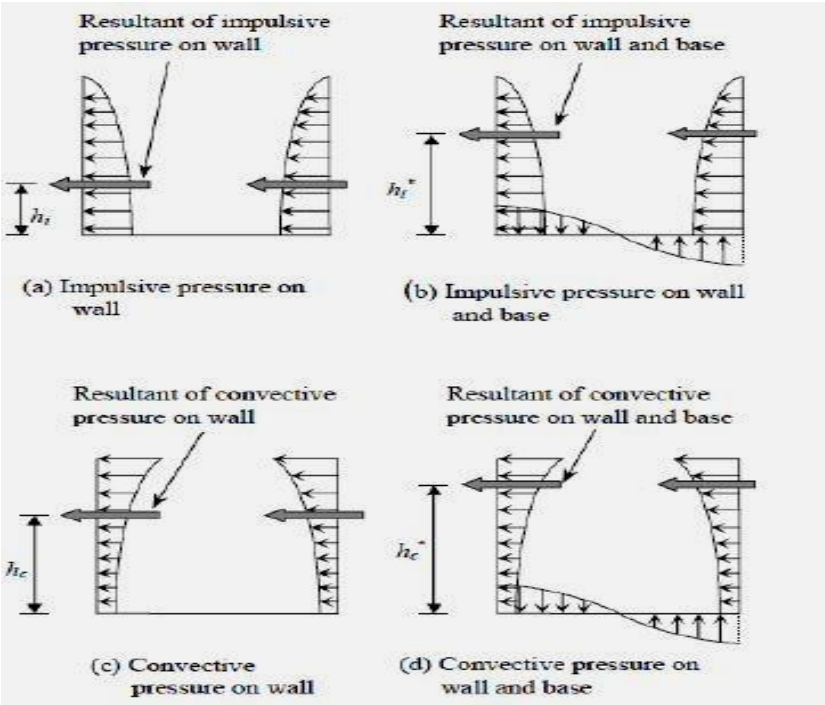
Principle of Two Mass Idealizations

Analyzing elevated water tanks as a single degree of freedom system is not satisfactory because these are never completely filled and there comes the effect of sloshing effect. The respective lateral stiffness of the different type of tanks can be calculated by any FEM based Software

(STAAD PRO-V8i used for this paper) where as the stiffness for shaft type can be calculated by applying an arbitrary force at the centre of Gravity of the elevated tank.



The total mass of water is divided into two different masses as illustrated in the above figure the mass of water which moves along with the tank wall with the horizontal excitation is known as Impulsive Mass (m_i) and on the other hand the mass of water which moves relative to the tank wall is known as Convective Mass whereas the K_s and K_c are the corresponding stiffness of the structure and the convective mass of water.



The above figure depicts the hydrodynamic pressure distribution for both the cases and their corresponding centre of pressures where as the h_i* and h_c*are the height of pressure inclusive of base pressure (Sloshing effect).

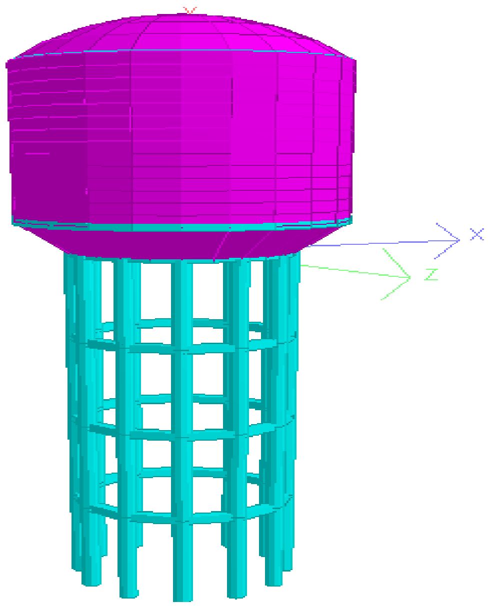
S.No.	Structural parameters	Properties
1.	Model	Circular Elevated Intze Tank
2.	Capacity	500 m^3
3.	Height of supporting tower	16 m
4.	Depth of foundation	1m
5.	No. of staging columns	8
6.	Height of structure	26.5
7.	Grade of concrete	M:30
8.	Grade of steel	Fe 500
9.	Diameter of tank	9 m
10.	Thickness of tank	250mm, i.e. constant as per IS:3370 (Par-II)
11.	Rise of Top dome	2 m
12.	Radius of dome	6.06 m
13.	Height of tank portion	7 m
14.	Live load	0.6 KN/m^2
15.	Factored load	1.5
16.	Seismic zone factor	Zone-IV, z=0.24 as per IS: 1893-2002 (Part-I)
17.	Type of soil	Hard and Rock Strata soil
18.	Damping	5%

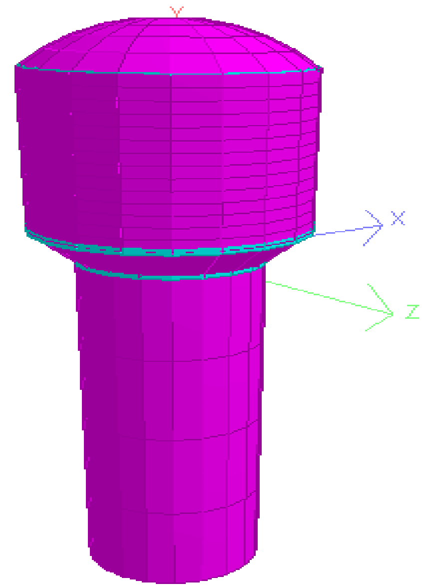
19.	Importance factor	1.5
20.	Response reduction factor	4
21.	Top dome	100mm
22.	Top ring beam	110mm ×110 mm thick
23.	Tank wall	250 mm thick
24.	Bottom dome	200 mm thick
25.	Bottom ring beam	300 mm×300mm
26.	Column staging	500 mm diameter
27.	Braces	350 mm×350 mm

Research Methodology

This paper envisages the steps and procedures followed in this project to achieve the aims furnished above. According to the objectives of the project, Five models each with a distinct loading pattern for all the three staging systems have been created over STAAD Pro – V8i (SS6) and are analyzed simultaneously. The Hydrostatic and Hydrodynamic Pressures along with their corresponding Base shear and overturning moments have also been calculated and are compared with the values so computed by the software. Since the revised code hasn't been incorporated in STAAD Pro therefore the Hydrodynamic pressure values are calculated manually and are applied in software to get the membrane stresses, Nodal Displacements and Storey Drifts.

The Frame type staging is commonly adopted supporting system for elevated tanks as compared to the shaft type staging due to the better performance of the former. The performance of frame type staging has been observed as the best in case of horizontal excitations due to the proven redundancy and the ductile behavior of the staging system. The assembly of beams and columns provide better flexibility and provide alternate load paths for the escapement of the load cycles. The geometric specifications generally depend on the type of the container and the desired capacity of the tank. The ease of construction and the solid form makes the shaft type staging the best option for constructing large capacity tanks but the recent earthquakes proved these type of staging patterns the most vulnerable due to the lack of redundancy and ductility.





For the analysis following values of loadings are used on the bottom dome as well on the wall of the tank:

Seismic loads are assigned as per IS: 1893 (Part-I) in one direction viz. +X, seismic load is applied as per zone-IV.

Water pressure in the tank is regarded as the live load, it acts a static load on the bottom dome whereas the hydrodynamic pressure depends on the volume of water in the tank . In addition to this the vertical excitation force will over load the structure which creates an extra pressure on the bottom dome of the tank. The finish load and the live load on the top dome due to repair and maintenance of the tank is taken as 0.6 KN/m^2 according to Table No. 2 of IS 875 (Part-II).

Type of Tank	A	B	C
Top dome (LL)	0.6	0.6	0.6
Bottom dome (Static)	70	70	70
Bottom dome (Impulsive)	2.578	2.578	8.46
Bottom dome (Sloshing)	0.173	0.173	0.17
Base wall (Impulsive)	1.85	1.85	6.07

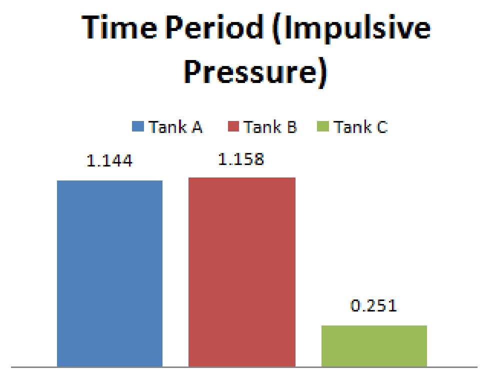
Top wall (Convective)	1.176	1.176	2.8

Results and Discussions

Here the discussion over the variation in results of the Time Period, Base shear at the bottom of staging their corresponding Over turning Moments for the three different Supporting Systems of the elevated tank in the tabular as well as in graphical form. In the final results the required quantity of steel and concrete is computed and the results will be shown in graphical form.

Maximum Time Period

Time Period (Secs) for Impulsive Hydrodynamic Pressure	
Tank A	1.144
Tank B	1.158
Tank C	0.251

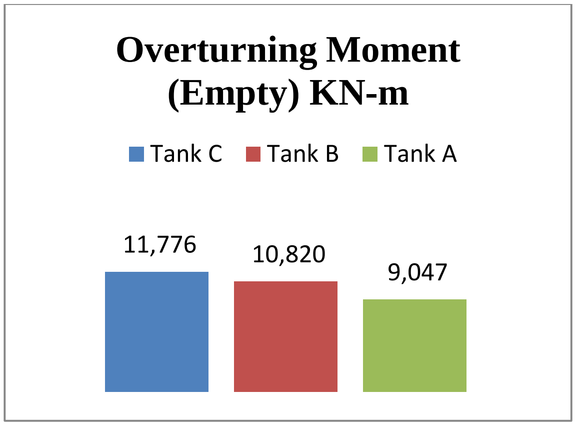


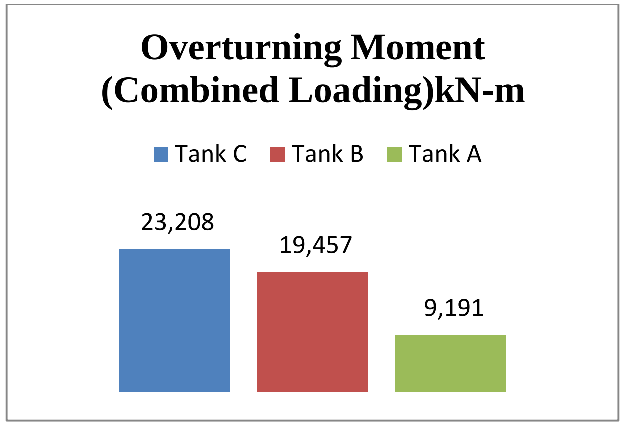
The Time period for the case of convective mode is found to be the same for all type of tanks which is 3.06 secs.

Overturning Moments

Following are the table and bar graph used to represent value of Overturning Moments induced due to the Seismic Waves and the corresponding Base Shear due to applied loads on structure. Since the empty and the combined loading conditions are illustrated as the most vulnerable therefore the OTM has been calculated for the said conditions only.

Type of Tank	**Type of Loading**	
	Empty	**Combined**
Tank A	9,047	9,191
Tank B	10,820	19,457
Tank C	11,776	23,208

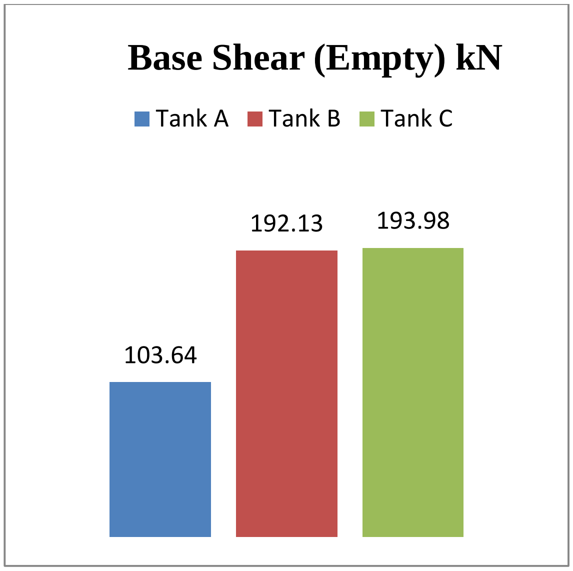


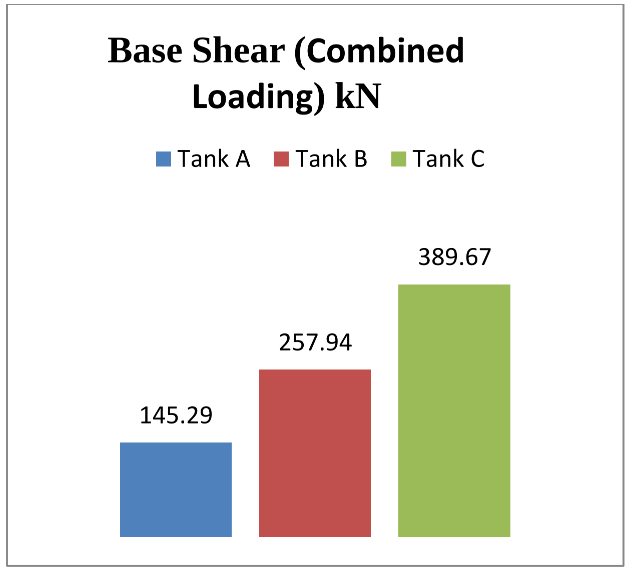


BASE SHEAR

Base shear is the total design lateral force at the base of the structure in response to the seismic forces. As shown below base shear in case of Hydrostatic and combined loading are almost the same for a particular type of tank .

Type of tanks	Base Shear (kN)				
	Empty	**Impulsive**	**Convective**	**Hydrostatic**	**Combined**
Tank A	103.64	105.21	103.86	143.93	145.29
Tank B	192.13	194.53	192.42	255.81	257.94
Tank C	193.98	212.54	195.38	368.32	389.67





Area of Steel

The area of steel in any section while working on computer program is calculated by predefined formulas as given in the Indian standard as an output results by clicking on post-processing mode. But Staad pro v8i is unable to calculate steel detailing in slab portion because this version is not compatible for slab designs. The quantity of steel in the cylindrical tank portion is the same where as some variation has been observed in the staging components which have been depicted below in the form of graphs and table. Following are the bar graphs shows area of steel for some components having Variation in area of steel.

Component	Area Of Steel (A_{st}) (mm^2)		
	Tank A	Tank B	Tank C
Top Dome	156	156	156
Top Ring Beam	320	320	320
Cylindrical Wall	516	516	516
Intze beam	470	470	470
Conical Dome	516	516	516
Bottom Dome	396	396	396
Bottom circular beam	678	540	470
Bracing	1705	1430	396
Columns	3015	2375	

The A_{st} for elements is represented per unit length. The value of A_{st} for linear members is the maximum of all the group members.

The total area of steel (Staging Portion & Linear members) in the different tanks have been shown below.

Type Of Tank	Total Quantity of Steel (tones)
Tank A	3.74
Tank B	4.98
Tank C	3.67

CONCLUSIONS AND FUTURE SCOPE

This chapter envisages the research outcomes and the possible future activities that can be undertaken. The conclusions are enlisted below:-

a) Time period in Impulsive mode in case of Shaft Type Tank is less as compared to the framed tanks which in turn ascribes high horizontal seismic coefficient (A_h).
b) Base shear for the empty and the convective mode of loading is almost similar which states that horizontal excitations will have the same effect on the tank. Also base shear has been observed as higher in the shaft type staging as compared to the frame type staging.
c) Also the increment in base shear is much higher in case of combined loading for all the three type of tanks.
d) The Hydrodynamic Pressure values remain the same for a common staging pattern irrespective of the mass of water in the tank. In fact it largely depends on the dimensions of the tank.
e) The low nodal displacement values of shaft type tank as compared to the frame type staging suggests that the frame type staging is much more flexible and is capable of returning to its original position after a large deflection from its mean position.
f) The nodal displacement values are higher in impulsive mode as compared to convective mode.
g) The shaft type staging has higher base shear values but lower nodal displacements values suggesting that the shaft type staging is brittle compared to frame type staging.
h) During designing an elevated water tank primary importance is given to the overturning moment, since large mass accumulates at the top of slender supporting system it is observed that the overturning moment for frame staging is less than that of tanks supported on shaft type staging.
i) Time period in convective and impulsive are similar for both frame type and shaft type staging.

j) Sloshing wave height is approximately same for the tanks, as it majorly depends on the capacity of the tank.
k) The new code has enhanced the overall cost of the structure by 12%.

References

a) George W. Housner (1963) The dynamic behavior of water tanks Bulletin of the Seismological Society of America. Vol.53, No. 2, pp. 381-387.
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c) IS:1893-2002(PartII) Criteria for Earthquake Resistant Design of Structure (Liquid Retaining Tanks), Bureau of Indian Standards, New Delhi.
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