Seismic Performance of G+ 7 Framed Buildings with Overhead Water Tanks: Dynamic Effects and Design Strategies

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Abstract. This study investigates the dynamic response of G+7 storey reinforced concrete framed building with overhead water tank emphasizing the dynamic effects of liquid sloshing during earthquakes. Using ANSYS Workbench for finite element modelling and applying equivalent static analysis as per IS 1893:2014, the study evaluates structural behaviour under hydrodynamic loading. Results show that the impulsive sloshing mode generates a significant base shear of 1166.97 kN at a time period of 0.813 seconds, indicating the need for strong lateral load-resisting systems. The convective mode, with a longer time period of 1.797 seconds and base shear of 23.84 kN, contributes to prolonged vibrations that require effective damping strategies. Modal analysis highlights Mode 6 as the most critical, with maximum deformation of 0.19995 mm. Storey drift is highest at the lower levels and reduces with height, suggesting the need for targeted seismic design approaches. This research emphasizes the importance of integrating water sloshing effects into the seismic design of buildings and offers practical recommendations for enhancing resilience in earthquake-prone regions.

1. Introduction

Roof-top water tanks play a crucial role in urban infrastructure, serving critical functions as potable water storage, irrigation, and fire protection. However, when placed atop multistorey buildings, they introduce complex seismic behaviours due to fluid-structure interaction and sloshing effects. These interactions can significantly intensify seismic demands, making it essential to examine their impact on structural stability.

Extensive literature underscores the need to address such interactions. Titiksh emphasized the influence of tank aspect ratio on dynamic behavior [1]. A researcher reported that sloshing increases base shear and deformation in tall tanks [2]. Similar research [3-4] highlighted damping as a key mitigation strategy, while [5] found rectangular tanks more stable than cylindrical ones. Most of these studies, however, focused on standalone tanks.

Research on tank-building interaction is limited but growing. Findings of research [6-7] highlighted that sloshing amplifies structural responses like base shear and vibration frequencies. Numerical studies by [8-10] emphasized the importance of hydrodynamic modelling. Studies by [1] advocated for integrating structural and fluid dynamics.

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To address these gaps, this study uses ANSYS Workbench to simulate the dynamic behaviour of a G+7 storey RC framed building with an overhead water tank in Seismic Zone III. The modeling incorporates sloshing effects, base shear, deformation, and time period analysis in accordance with IS 1893:2014.

2. Methodology

It was observed that the authors have calculated the sloshing effect on the liquid tank, limited focus has been directed toward structural response resulting from sloshing effect. The present investigation examines structural response due to oscillatory effects in liquid storage structures by analysing time period, base shear, total deformation, frequencies and storey drift. This study addresses these gaps by conducting a comprehensive analysis of a G+7 framed building with an overhead water tank, located in Mumbai's seismic Zone III. Using advanced computational modeling in Ansys Workbench, the research investigates the interaction between sloshing effects and structural responses, focusing on parameters such as base shear, time periods, frequencies, and deformations.

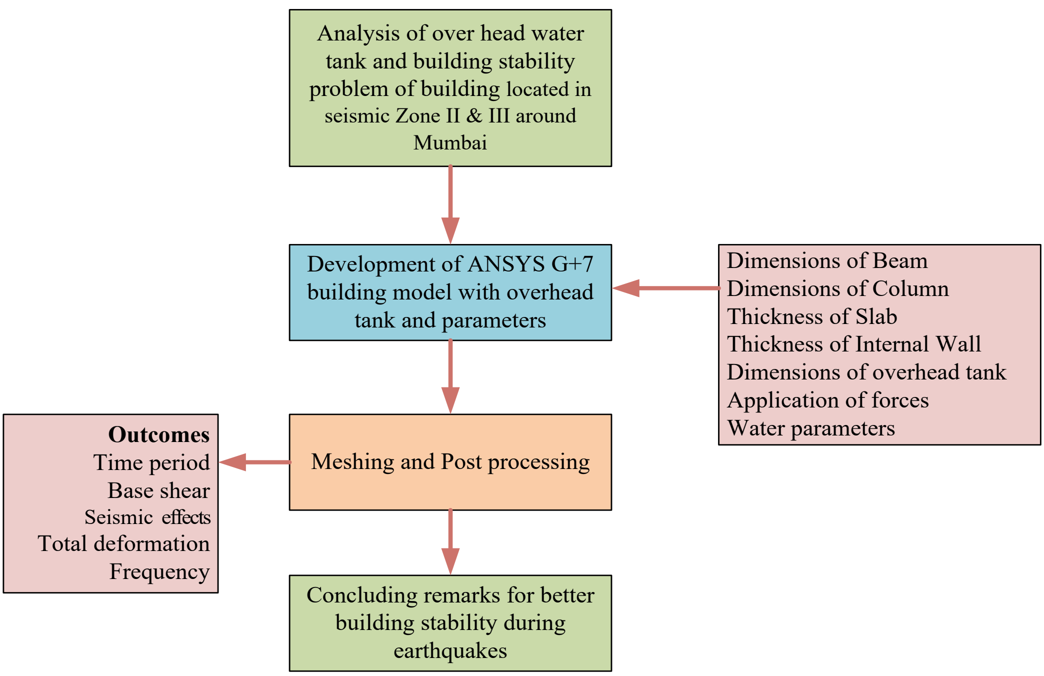

Fig. 1. Proposed methodology

In pre-processing meshing i.e. discretization of the G+7 storey structure has been done by using hexahedral elements. Then, setting up is done by applying the boundary conditions, i.e. fixed Support and loading conditions on the mesh model. Seismic analysis is done by using equivalent static analysis Table 1 data is used to model the structure.

Table 1. Preliminary Building Data for Analysis

Building Type	**Residential Building**
Storeys	G+7
Type of frame	R.C.C. Framed Structure
Seismic Zone	III
Importance Factor (I)	1.0
Zone Factor (Z)	0.16
The Response Reduction Factor (R)	3 (OMRF)
Floor Area	9X9=81 m^2
Wall material	syporex wall (deisity-6.5kN/m^2)
Grade of Concrete	M30
Grade of Steel	Fe 415
Size of Beam	230x400 mm
Size of Column	300x300 mm
Slab Thickness	150 mm thick
Internal Wall Thickness	150mm thick
Live Load	2kN/m^2
Floor Finish	1kN/m^2
Height of water tank	3m
Width of water tank	3m
Length of water tank	3m

2.1 Seismic Analysis: Equivalent Static Method

Time period & base shear has been calculated for impulsive mode and in convective mode in accordance with IS 1893:2014 (part II [12] and part I [13]), the different calculations in both modes are shown in table 2. In this mass of structure (Ms) is considered as addition of Lumped mass of empty water tank (m1) and one third mass of lumped mass of building (clause 4.2.2.3 IS code 1893:2014 part II). The total mass of water in full tank condition is 27000 Kg . The impulsive mass Mi =21600 Kg , and convective mass Mc =7020 Kg of water were calculated under clause 4.2.3 IS 1893: 2014 part II & stiffness of structure Ks =16260 kN/m has been calculated from FEA analysis in Ansys software.

Table 2. Total seismic weight of structure

Property	Number of items	Value	Unit
Total Seismic Weight of building/lumped mass of building		6718.893	kN
Weight of tank wall		141.75	kN
Weight of base slab		40.8375	kN
Weight of water (a)		264.87	kN
self-weight of beam		2.3	kN
weight of longitudinal beam	2 nos.	11.96	kN
Weight of transverse beam	2 nos.	12.742	kN
Weight of columns	4 nos	9	kN
lumped weight of water tank without water (b)		216.2895	kN
lumped weight of tank with water ($a+b$)		481.1595	kN
lumped mass of empty water tank ($m1$)		22047.86	Kg
lumped mass of building (m2)		684902.4	Kg
$Ms = (m1 + (\frac{m2}{3})$ [Mass of structure = mass of empty water tank+(lumped mass of building/3)]		250348.7	Kg
Mass of water		27000	Kg

Table 3. Total seismic base shear of structure

Total seismic Base Shear V	Impulsive Mode		Convective Mode		
Description of Item	**Quantity**	**Unit**	**Quantity**	**Unit**	**Remarks**
Time Period Ti , Tc (in X & Y direction; in X & Z direction respectively)	0.81268	Sec	1.79725	Sec	*Clause 4.3.3.2, IS 1893 (Part 2):2014*
Base Shear Calculation in Impulsive and Convective Mode Vi and Vc					*Clause 4.6.2; IS 1893(Part 2):2014*
Ah = Design Horizontal Seismic Coefficient, W = Weight of the Building					*Clause 4.5.1, IS 1893:2014(Part 1)*
Zone Factor (Z)	0.16		0.16		*For Zone III*
Importance Factor (I)	1		1		*For normal Building*
Response Reduction Factor (R)	3		3		*For OMRF*
Spectral Acceleration (Sa/g)	1.67348		0.75682		*Figure 2; IS 1893:2014, (Part 1)*
$(Ah)i$	0.04463		0.03532		

Seismic Weight $(Mi+Ms)$ for impulsive and (Mc) for convective mode	2665.10	kN	68.80	kN	*From Weight Calculation Sheet*
Base Shear for Impulsive and Convective Mode Vi and Vc	**1166.73**	kN	**23.84**	kN	
Total Base shear at the base of building (V)	**1166.97**	kN			*Clause 4.6.3, IS 1893(Part 2):2014*

3. Results and Discussion

3.1 Time Period

Time periods of 0.813 sec (impulsive mode) and 1.797 sec (convective mode) in the X-Y, and X-Z directions respectively highlight the building's dynamic behavior. The shorter impulsive period indicates rapid lateral forces, while the longer convective period underscores the importance of damping

Lu [2] reported time periods for elevated water tanks that varied depending on tank height and capacity. Their findings align with the impulsive mode values in this study, emphasizing rapid dynamic responses. A researcher [9] observed similar trends in the convective mode, where prolonged oscillations required specific damping mechanisms. This study's time periods validate established ranges for seismic response in multi-storey structures with overhead water tanks.

3.2 Base Shear

The analysis of base shear indicates that the impulsive mode contributes a dominant 1166.97 kN, while the convective mode adds only 23.84 kN, as shown in Figure 2. This confirms that over 97% of the total base shear originates from impulsive forces, requiring structures to be designed for high-magnitude, short-duration lateral loads. The findings are consistent with earlier studies by [5] and [11], who reported similar base shear trends in elevated tanks

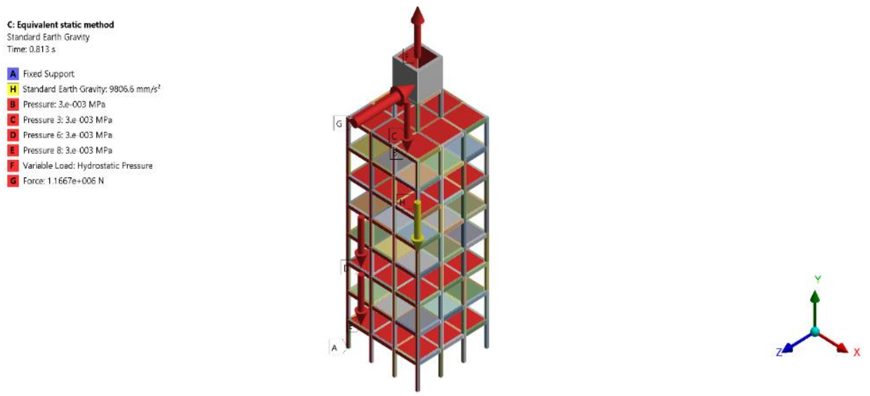

Fig. 2. Total Base Shear V

3.3 Hydrostatic Pressure

Figure 3 displays a linear hydrostatic pressure distribution, with the maximum pressure of 22.43 kN/m² observed at the tank base due to the water column and external loads. n additional hydrodynamic pressure of 1.575 kN/m², as per IS 1893 (Part 2):2014[12], further intensifies lateral loading. These combined pressures demand proper reinforcement and adequate wall thickness to ensure structural integrity under static and seismic conditions.

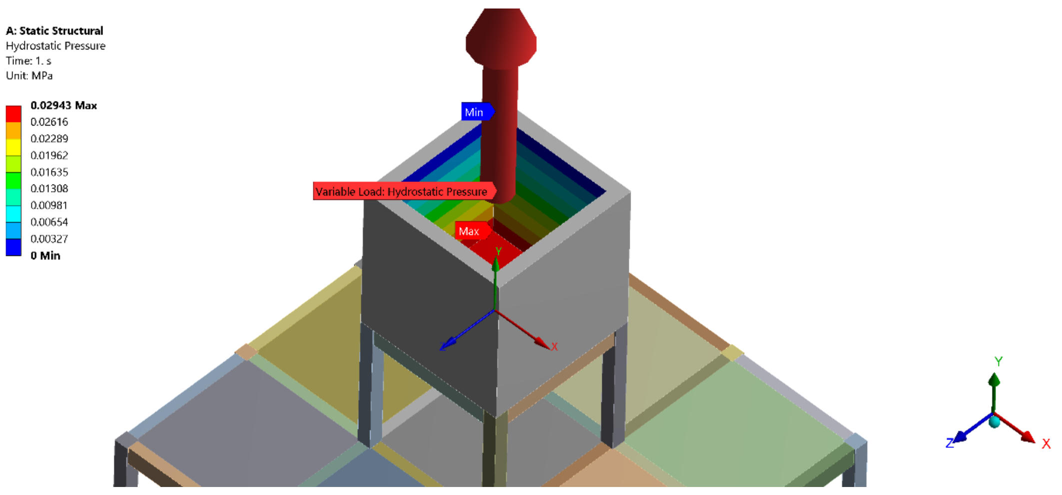

Fig. 3. Hydrostatic Pressure

3.4 Total Deformation and Frequencies.

Modal analysis reveals that Mode 1 has the lowest frequency (1.2691 Hz) and smallest deformation (0.0757 mm), representing the fundamental mode. Mode 6 has the highest frequency (6.9491 Hz) and maximum deformation (0.1999 mm), reflecting a more dynamic response.

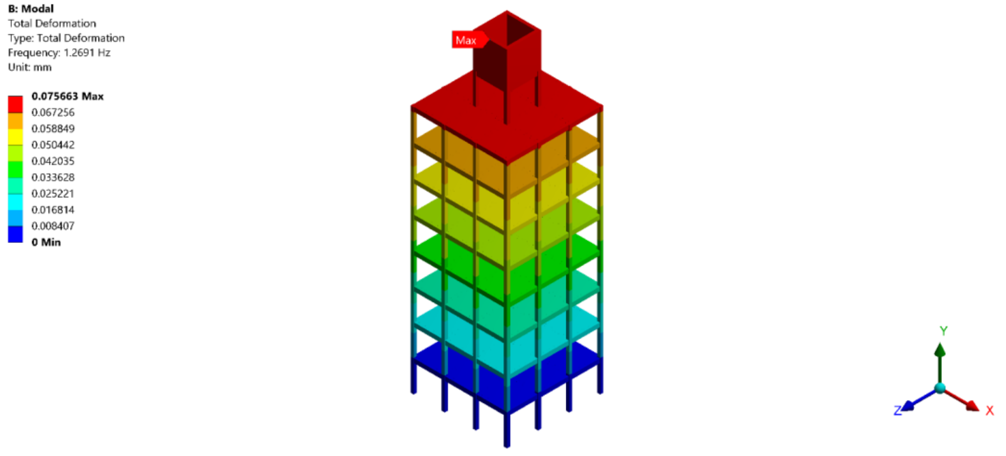

Fig. 4. Total Deformation-Mode 1

Figure 5 shows a consistent increase in frequency across modes, with Mode 5 slightly exceeding Mode 6 in deformation. This behaviour aligns with observations by [7] and [9], who emphasized the importance of higher modes due to their influence on localized structural stresses.

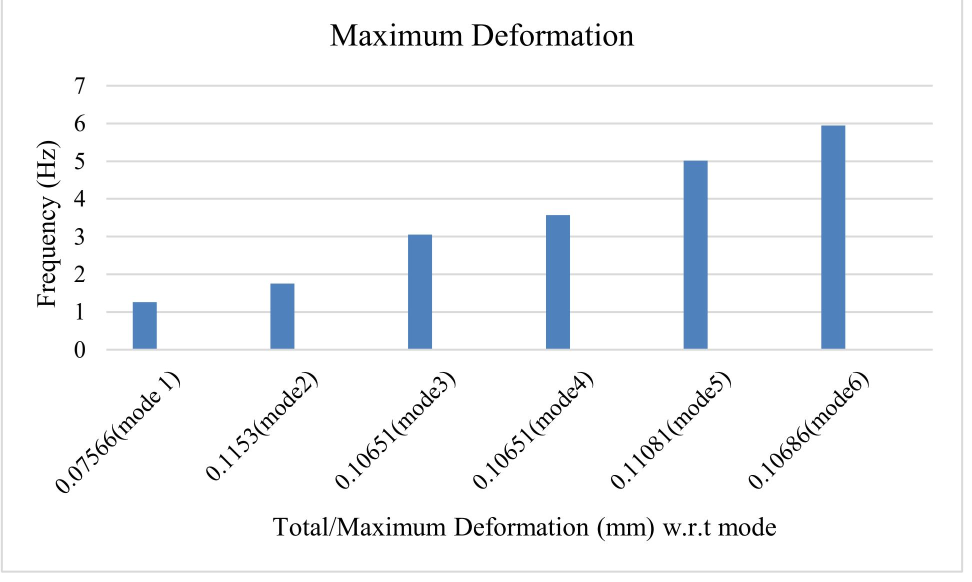

Fig. 5. Frequency vs total/maximum deformation

The findings emphasize the critical role of higher modes in dynamic analysis, aligning with conclusions from earlier research.

3.5 Storey Drift

Storey drift, or the relative displacement between consecutive storeys, is a key parameter in evaluating seismic flexibility. As depicted in figure 6, the highest drift (9.087 mm) occurs between the ground and first storey, while the minimum storey drift (0.602 mm) is at the 7th storey. This behavior results from mass concentration, base flexibility, and sloshing-induced inertial forces.

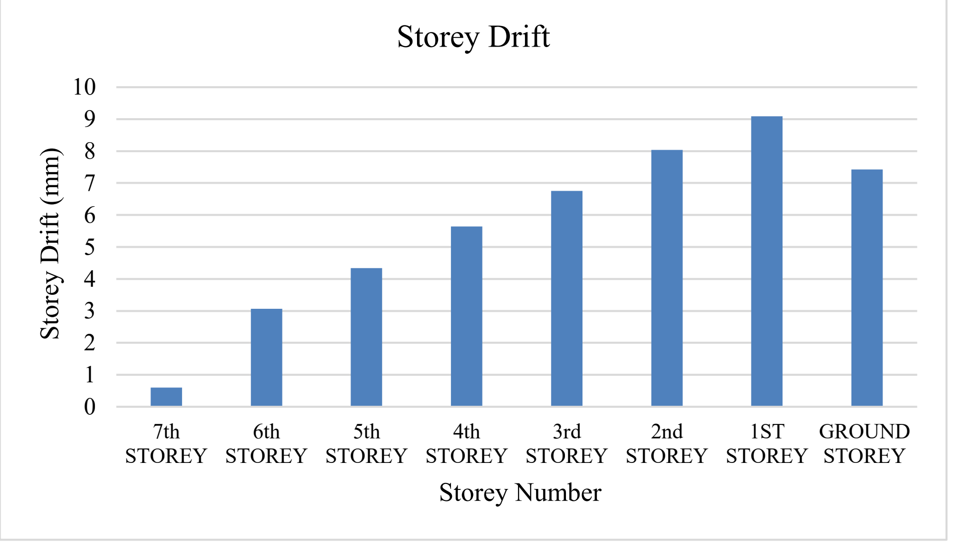

Fig. 6. Storey Drift vs Storey Number

While all values remain within IS 1893:2014 limits [12, 13], the results underscore the need for enhanced reinforcement, energy-dissipating devices, and base strengthening to control drift in lower storeys.

4. Conclusion

This research evaluated the dynamic response of a G+7 storey reinforced concrete frame structure incorporating an overhead water tank, situated within Seismic Zone III of Mumbai. Key findings indicate that the impulsive mode is the primary contributor to base shear, while the convective mode influences sustained vibrations. Higher modes significantly impact deformation, and storey drift is highest at lower levels, underscoring the need for focused structural reinforcement.

The results validate the ANSYS Workbench simulation and align with existing research. The study recommends incorporating smart damping systems (TMDs, MRDs), high-performance materials (HPC, CFRP), and seismic isolation techniques to enhance resilience. These strategies offer practical solutions for improving the seismic safety of water tank-supported structures.

Future work should explore the application of these technologies across different building configurations and seismic zones to promote safer infrastructure design.

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