Performance Evaluation of Elevated Storage Reservoir Subjected to Earthquake Forces

Sameer S Mulani[1], S. S. Kadam[2], G. D. Lakade[3]

[1]Research Scholer, Dept. Civil Engineering, SKN Sinhgad College of Engineering, Maharashtra, India
[2]Prof. Dr, Dept. Of Civil Engineering, SKN Sinhgad College of Engineering, Maharashtra, India
[3]Prof, Dept. Of Civil Engineering, SKN Sinhgad College of Engineering, Maharashtra, India

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Abstract - *An Elevated water tanks are lifelines of our water supply systems. However, earthquakes pose a important hazard to their stability [2]. This study investigates into the seismic response of a reinforced concrete (RC) elevated water tank using advanced computer models. The investigation focuses on a specific tank design with a 50 cubic meter capacity. We created a detailed numerical model incorporating its dimensions and assigned realistic material properties. Staad Pro software was then used to perform a time history analysis, simulating the tank's behavior under earthquake ground motions. Two historical earthquakes, Bhuj and Uttarkashi, were chosen to represent different seismic scenarios. The analysis yielded valuable data on the tank's dynamic response under these varying conditions. This data includes roof displacement, velocity, acceleration, the force at the base (base shear), and the tank's natural frequencies of vibration. A key takeaway is the significant influence of water level on the tank's seismic behavior [15]. The study highlights how a full or partially filled tank reacts differently compared to an empty one. This knowledge is crucial for understanding critical failure mechanisms during earthquakes. Ultimately, this research contributes valuable insights into the seismic vulnerability of elevated water tanks. It covers the way for developing effective retrofitting strategies and improved design guidelines.*

Key Words: Seismic response, Elevated water tank, Reinforced concrete (RC), Time history analysis, Water level

1. INTRODUCTION

Elevated storage reservoirs play a critical role in ensuring reliable water supply to communities, industries, and various other sectors [3]. However, their structural integrity and resilience under seismic events are of paramount importance, particularly in regions prone to earthquakes [3]. The seismic vulnerability of elevated storage reservoirs necessitates thorough evaluation and analysis to mitigate potential risks and ensure the safety of water supply systems [6].

The seismic performance of elevated storage reservoirs depends on various factors such as design considerations, material properties, structural configuration, and dynamic response characteristics [20]. Understanding how these factors interact under seismic loading conditions is essential for developing effective design guidelines and retrofitting strategies to enhance the resilience of existing structures [2].

In recent years, advancements in structural engineering, computational modeling, and seismic analysis techniques have facilitated more comprehensive assessments of the seismic performance of elevated storage reservoirs. Researchers and practitioners have employed sophisticated numerical simulations, experimental testing, and field investigations to evaluate the behavior of these structures under seismic forces.

This paper aims to contribute to the existing body of knowledge by conducting a systematic performance evaluation of elevated storage reservoirs subjected to earthquake forces. Through a combination of numerical modelling and experimental validation, the seismic response of elevated storage reservoirs will be investigated, with a focus on understanding critical failure mechanisms, dynamic characteristics, and the effectiveness of retrofitting measures.

The outcomes of this study are expected to provide valuable insights into the seismic vulnerability of elevated storage reservoirs and inform the development of robust design guidelines and risk mitigation strategies. By enhancing our understanding of the seismic behaviour of these structures, we can better safeguard water supply systems against the devastating impacts of earthquakes, ensuring the resilience and reliability of critical infrastructure in earthquake-prone regions.

2. METHODOLOGY

2.1 Model Description

A RC Elevated water tank having storage capacity of 50 m3 is considered in this study. The container has a square base of side 5m and the height is 2m with a slab. The support structure consists of 4 columns having cross section 0.4m x 0.3m. For study purpose tank full condition is considered, the structure is subjected to two earthquake ground motions (Bhuj and Uttarkashi).

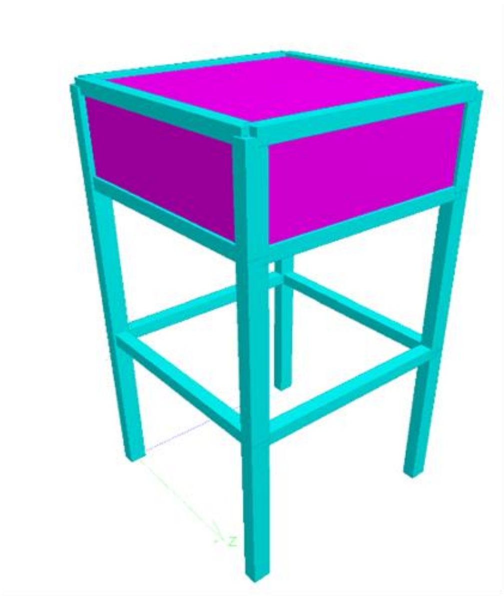

Fig -1: Model of Elevated RC Water Tank

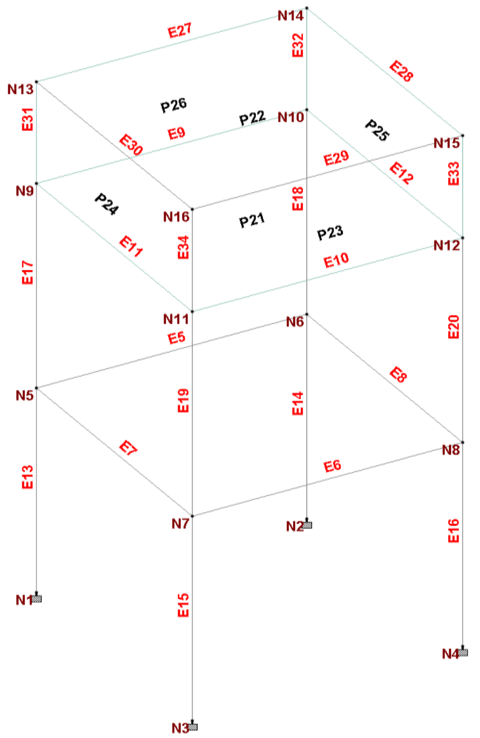

Fig -2: The model of structure with all the beams and nodes

2.2 Selection of ground motion

Ground motion is the basic and prime input for time history analysis of structure. The real ground motion records can be obtained from the records of previous earthquake events are preferred. Real ground motion are actual records of seismic shaking produced by earthquakes. For current study purpose total two real ground motions are considered for the dynamic analysis of the elevated water tank. Finite element model is modelled in StaadPro software.

Table -1: Parameters of selected ground motion

Sr. No.	Earthquake	PGA g	Magnitude (Richter scale)	Duration (sec)
1	Bhuj, JAN 26, 2001	0.38	6.9	137
2	Uttarkashi, OCT 20,1991	0.24	6.8	45

2.3 Assigning the material

Following the structural modelling of beams and columns, material assignment constitutes a pivotal stage in the design process. In the context of this project, characterized by concrete design specifications, the beams and columns have been designated with concrete material properties.

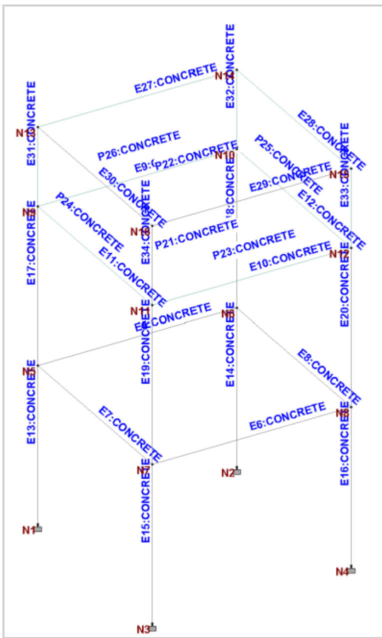

Fig -3: Assigning concrete material to structure

2.4 Time History analysis

The study of time history analysis is to understand the actual behavior of a structure at every addition of time, when it is subjected to a ground motion. The technique of time history analysis represents the most sophisticated method of dynamic analysis for the structure. The mathematical model of the structure is subjected to acceleration from earthquake at the base of the structure. Time history analysis consists of a step-by-step direct integration over a time interval, the equation of motion is solved with the acceleration, velocities and displacements of the previous step serving as initial function. The two earthquake ground motions selected are considered as an input motion for the time history analysis and applied at the base of the structure. The seismic performance of the elevated water tank under two different selected earthquake records will be examined for tank full tank. StaadPro v8i software is used for time history analysis of the structure.

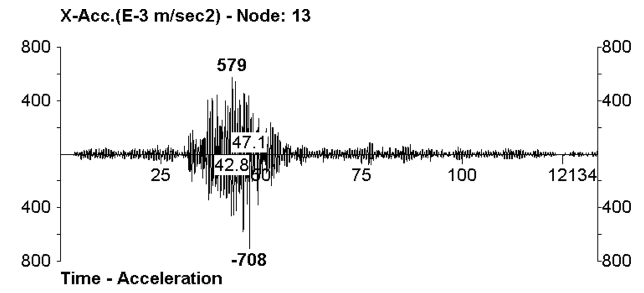

Chart -1: Acceleration Graph for Bhuj earthquake data

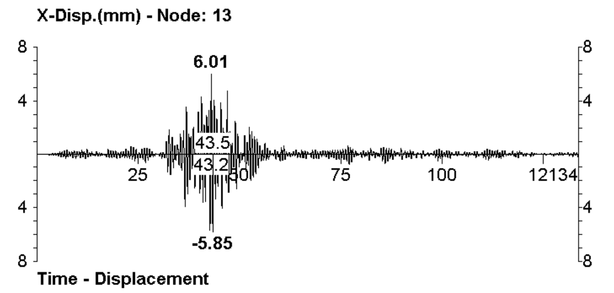

Chart -2: Displacement Graph for Bhuj earthquake data

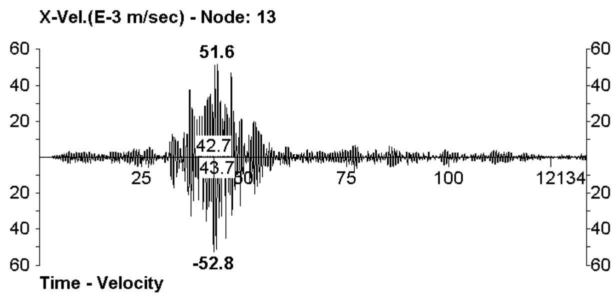

Chart -3: Velocity Graph for Bhuj earthquake data

3. RESULTS AND ANALYSIS

The time history analysis is carried out for the tank with full tank condition using above mentioned parameters. For each earthquake separate model is prepared.

The results are noted down in form of tank Roof displacement, velocity, acceleration, Base shear, frequency. The value of roof displacement, velocity and acceleration is taken by considering a node (node no.#13) in the roof of the structure.

3.1 Roof Displacement

Roof displacement is an important serviceability criterion for any structure. Maximum roof displacement has been observed under Uttarkashi Earthquake ground under half tank condition and minimum roof displacement observed under Bhuj Earthquake ground record under empty tank condition.

Table -2: Roof Displacement comparison

Earthquake	Displacement (mm)		
	Empty Tank	Half Tank	Full Tank
Bhuj	6.01	6.42	6.4
Uttarkashi	10.2	10.3	8.73

Table 2 provides data on roof displacement measured at a structure during the Bhuj and Uttarkashi earthquakes. The table highlights the importance of considering the weight of water tanks on roof displacement during seismic events. The Bhuj earthquake resulted in higher displacements compared to Uttarkashi, potentially due to a combination of factors like earthquake intensity and the specific structural characteristics.

3.2 Roof Velocity

Table -3: Roof Velocity comparison

Earthquake	Velocity (E-3 m/sec)		
	Empty Tank	Half Tank	Full Tank
Bhuj	52.8	50.5	54.2
Uttarkashi	105	112	116

Table-3 complements the displacement data (Table-2) by showing the roof velocity measured at a structure during the Bhuj and Uttarkashi earthquakes. Both displacement and velocity data emphasize the importance of considering the weight of water tanks on the seismic response of structures. The higher velocities observed in Bhuj compared to Uttarkashi might be due to a combination of factors like earthquake intensity and structural characteristics.

3.3 Roof Acceleration

Table -4: Roof Acceleration comparison

Earthquake	Acceleration (E-3 m/sec2)		
	Empty Tank	Half Tank	Full Tank
Bhuj	708	697	581
Uttarkashi	1130	1740	1800

Table-4 (acceleration) alongside Tables-2 (displacement) and 3 (velocity) provide a comprehensive overview of the roof's response under different earthquake scenarios and water tank fill levels. While a trend of increased response with higher water weight is generally observed, the Bhuj data for acceleration shows an anomaly where the full tank has a lower value compared to the half tank. Further investigation with a larger dataset and analysis considering factors like structural properties and water tank dynamics is recommended.

3.4 Base Share

Table -5: Base Share comparison

Earthquake			Bhuj			Uttarkashi		
			x	y	z	x	y	z
Base Share	Empty Tank	Time	43.154999	43.134998	36.625000	6.240000	3.160000	3.840000
		Value	-3.106708E+01	1.907349E-06	-2.328306E-10	4.958914E+01	-9.536743E-07	-2.328306E-10
	Half Tank	Time	43.549999	46.910000	44.474998	6.260000	6.260000	6.520000
		Value	3.199498E+01	-9.632111E-05	-1.147219E-04	4.808244E+01	-2.613068E-04	-1.540098E-04
	Full Tank	Time	43.580002	46.910000	45.724998	6.280000	6.260000	6.560000
		Value	3.201888E+01	-3.895760E-04	6.094886E-04	4.741825E+01	-1.016617E-03	-7.393046E-04

Base shear is an estimate of the maximum expected lateral force that occurs due to seismic ground motion at the base of the structure. The base shear depends in probability of significant ground motion and the level of ductility and over strength associated with various structural configurations and the total weight of the structure.

- The base shear values for both earthquakes (Bhuj and Uttarkashi) seem to vary across different time points during the event.
- In most cases, the base shear appears to be higher for the full tank scenario compared to the empty or half tank scenarios, suggesting that the increased weight of the water affects the shear forces at the foundation.
- Table-5 explores the influence of water tank fill level on base shear at the foundation during earthquakes. The data suggests a potential correlation between increased water tank weight and higher base shear values, particularly for the Bhuj earthquake. Further studies with a larger dataset and various structural configurations are necessary to validate this observation and its implications for design."
- Table-5 provides base shear data for different earthquake scenarios and water tank fill levels. This data can be valuable for validating analytical models used to assess the seismic response of structures with water tanks. Including more earthquake data and structural details would allow for a more comprehensive analysis of the impact of water tank weight on base shear.

3.5 Natural Frequency

Table -6: Natural Frequency comparison

Mode	Natural frequency		
	Empty Tank	Half Tank	Full Tank
1	1.332	1.300	1.244
2	1.603	1.558	1.496
3	1.645	1.602	1.535
4	9.060	8.978	9.030
5	9.877	9.793	9.856
6	11.871	11.721	11.820

The modal analysis determines the vibration characteristics such as natural frequencies and corresponding mode shapes. For dynamic loading conditions, the mode shapes and natural frequencies are important parameters in the design of a structure. From the above table 6, it is observed that the natural frequencies of the structure generally decrease as the fill level increases, indicating a decrease in overall stiffness due to added mass. This trend is observed for modes 1, 2, and 3. However, mode 4 exhibits minimal variation in natural frequency across different fill levels. possible explanations for this behaviour is Localized Vibration Pattern: Higher modes, like mode 4, often involve more localized vibration patterns. In a rectangular tank, mode 4 might primarily involve vibrations in specific areas, such as the corners, where the added liquid mass has minimal influence compared to its effect on the overall structure in lower modes.

3. CONCLUSIONS

- Time history analysis was performed for the full tank condition subjected to two different earthquake ground motions (Bhuj and Uttarkashi).

- The analysis results included roof displacement, velocity, acceleration, base shear, and frequency for each earthquake and fill level (full, half, empty).
- A comparative study highlighted the significant influence of water tank fill level on the structural response during earthquakes. Key observations include:
  - Higher roof displacement, velocity, and acceleration were observed in full tank scenarios compared to empty or half tank scenarios.
  - Base shear values generally increased with increased water weight, indicating a greater force exerted on the foundation during earthquakes [5].
  - Natural frequencies tended to decrease with higher fill levels (except mode 4), suggesting a reduction in overall stiffness due to the added mass of water.

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