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Performance-Based Seismic Evaluation of Elevated Water Tanks in Moderate Seismic Zones

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Abstract:

Water tanks have been the most vital lifeline structures. They serve as an essential component for most water supply schemes in urban and rural areas. Water storage is generally based on overhead water tanks since the required pressure in the water delivery process is achieved by gravity in elevated tanks rather than the need for large pumping systems. These elevated tanks consist of a large water mass at the top supported by a tall staging which is extremely weak against horizontal forces caused due to earthquakes. The selection of a suitable staging system plays a major role in the behaviour of elevated water tanks during earthquakes since these tanks are often utilized in seismically active regions. Design procedures available in the present seismic codes indirectly address the inelastic behavior, and they showed the overestimates of the actual strength. Proper selection of a staging system and engineering demand parameters are the key elements of the elevated water reservoir design. In the present work, we performed a non-linear time history analysis on the models prepared about the data of existing elevated water tanks available within the Nanded region (Maharashtra-India). The obtained engineering demand parameters were used to predict the efficacy of elevated water tanks.

Keywords — Earthquake, Elevated water tanks, Non-linear Time history analysis, Seismic analysis,

1.0 INTRODUCTION

Elevated water storage tanks are usually classified according to the shape of the container, the type of stage, and the materials used to build it. In India, RC elevated tanks with circular or rectangular shape of container are widely used [1]. This is based on the RC type of stage frame or the RC shaft stage type Elevated water tanks are considered a living structure and therefore, their earthquake safety is a matter of great concern. Water storage tanks should continue to function after the earthquake to ensure access to drinking water in the earthquake-affected areas and to address the need for firefighting. To design a structure to remain elastic or undamaged is uneconomical and difficult to justify for an infrequent earthquake type loading [2]. Instead, it is common design principle to accept some structural as well as non-structural damage during severe earthquake in a structure, provided it does not lead to collapse of structure. The primary basis for construction of structures for strong ground shaking is that it shall not collapse. An effective and realistic District Disaster Management Plan with full proof communication, authentic and accurate data base, documented and rehearsed to be activated in the shortest possible time with minimum simple orders and procedures ensuring active participation both by Government, Community and Volunteers at all levels making optimum utilisation of men, material and available resources with no gaps or no over laps to prevent loss to lives and minimise loss to property ensuring fastest approach for rescue, rehabilitation and to avert further miseries of the calamity stricken people [3]. There is a saying that a friend in need is a friend indeed. The DDMP like a true friend will obviously guide the entire machinery engaged for relief operation and input courage among the community to face the eventuality boldly India in general is one of the most hazard prone countries in the world. 60% of the country is prone to earthquakes of moderate to high intensity, 40 million hectares is prone to floods, 5,700 km long coast is prone to cyclones and tsunamis and the whole of Himalayas are prone to landslides [4]. The state of Andhra Pradesh in particular is one of the multi-hazard prone districts in India. As a result, it was important to develop a plan that improves district's response to disasters while improving its ability to mitigate the disaster risks and increasing community's resilience by implementing the preparedness plan [5]. It was deemed important to put a plan in place for dealing with disasters in an organized way with all the stakeholders well-aware of their role in responding to or preparing for disasters, as the district is responsible for responding to disasters through its Incident Response Team in the disaster site, while the State and the Centre is responsible for providing extended support, guidance, external resources or additional help as required in case of any major disasters and upon the request of support from the district [6].

Scope of the study:

The scope of the study is to observe the response of the elevated water tank when subjected to seismic effect considering the effects of SSI. Further, the behaviour of water tank when resting on different soil conditions such as soft, medium, and hard during seismic actions need to be observed. Since sloshing phenomena increases severe oscillations, sloshing effect is also considered.

2.0 LITERATURE REVIEW

[7] Atul Jadhav et al. (2015) that had studied and provided the theoretical background of an "A review paper on analysis of elevated water storage tank in a high seismic zone by using staad-pro software" he had presented the study of seismic performance of the elevated water storage tanks for high-intensity seismic zones of India for various section of elevated water storage tanks for various circular shape (dome concrete floor, flat concrete floor).[8] Dr. Ramakrishna Hegde, Yogesh G (2018) They had studied about "Comparative study on rectangular and circular water tank using staad pro software" This paper made the Comparison between the circular water tank and rectangular water tanks. It was concluded that the total amount of materials required for constructing the circular tank is lesser than the construction of a rectangular tank. Hence circular shape tanks were more favored selection over a rectangular shaped tank. [9] Krishna Rao M.V (2015) that they had presented a study about the "Seismic Analysis of overhead Circular water Tanks-A Comparative Study" during this paper, he had compared the results of seismic analysis of overhead circular water tank administered by following under IS: 1893- 1984 and IS: 1893-2002 (Part-2) draft code. The analysis was finished with an elevated circular tank of 1000 Cu m capacity, located in four seismic zones (Zone-II, Zone -III, Zone-IV, Zone-V) and three different soil types (Hard rock, Medium soil, Soft soil) [10] Manish N. Gandhi, Prof.A. Rajan (2014) They studied the "Necessity of Dynamic Analysis of Elevated Water Storage Structure Using Different Bracing in Staging" to understand the behavior of different staging, under different loading conditions and strengthening the traditional sort of staging, to offer the higher performance during the earthquake. This study aimed to understand the necessity of analyzing the conventional staging system of an elevated water storage tank with various bracing types in a staging system for the elevated water storage tank.

3.0 METHODOLOGY

The methodology includes performing the nonlinear dynamic analysis (Time History Analysis) by IS: 1893(2002) draft code for the selected water tank. This work proposes to study the Circular and Intze shape of a tank with different capacities and staging height. The analysis is carried out for tanks with empty, half, and full water level and considers the sloshing effect and hydrostatic effects. The finite Element Model (FEM) is used to model the elevated water tank using Staad-Pro software.

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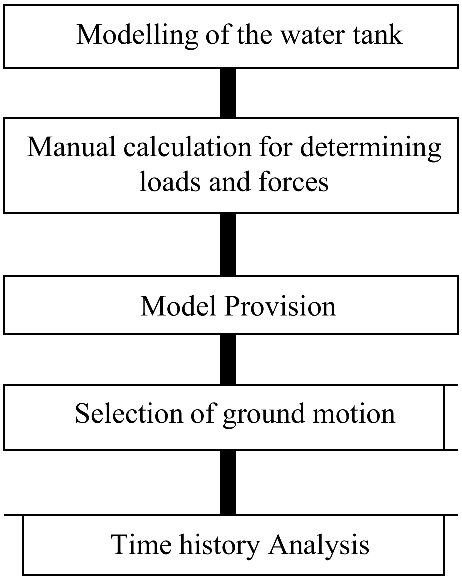
- With the available data, the geometry of the tank has been created in the STAAD-Pro software
- Manual calculations were done to know various loads and forces acting on the structure.



Description of Elevated Storage Reservoir (ESR)

In this study, the existing ESR located in the ongole region of the elevated water tank's circular & Intze shape is considered. Table 1 and Table 2 shows the dimensions and various parameters of circular and Intze elevated water storage tank.

Table 1: Parameters of Circular ESR

Component	**Size**
Capacity	42 m^3
Location of ESR	Ongole region
Diameter of Tank	4.3 m
Roof Slab Thickness	120 mm
Tank Wall Thickness	200 mm
Floor Slab Thickness	200 mm
Floor Beam size	250mm X 650 mm
Size of Braces	250mm X 350 mm
Column Diameter	450 mm
Number of Columns	4
Height of Tank	3 m
Staging Height 16 m	16 m
Type of Staging	Frame Staging
Free Board 0.3 m	0.3 m
Grade of Concrete	M25, M30
Grade of Steel	Fe 415
Earthquake	Zone III
Response ReductionFactor	2.5
Importance Factor	1.5

Coefficient of Damping	0.05
Soil Type	Hard Strata

Table 2. Parameters of Intze ESR

Component	**Size**
The capacity of the Tank	207 m^3
Location of ESR	Ongole region
Grade of Concrete	M20, M30
The thickness of Top Dome	0.120 m
Rise of Top Dome	0.880 m
Diameter of Tank	8.8 m
Height of Cylindrical wall	2.65 m
The thickness of the Cylindrical wall	0.2 m
The thickness of the Conical shell	0.2 m
Rise of the Bottom dome	1.020 m
The thickness of the Bottom dome shell	0.2 m
Number of Columns	6
Number of Bracing levels	4
Size of Bottom ring Beam	0.5m x 0.6m
Distance between Intermediate bracing	3.6 m
Height of staging above Foundation	15 m
Diameter of Columns	0.45 m
Size of Bracing	0.3m x 0.35m
Type of Staging	Frame staging
Free Board	0.3 m
Grade of Steel	Fe 415
Earthquake	Zone II
Response Reduction Factor	2.5
Importance Factor	1.5
Coefficient of Damping	0.05
Soil Type	Medium Soil

Time History Analysis

The study of time history analysis is to understand the actual behavior of a structure at every addition of time when 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 an earthquake at the structure's base 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 the initial function. The

Northridge earthquake ground motion is considered an input motion for the time history analysis and applied at its base. The seismic performance of the elevated water tank under selected earthquake records will be examined for tank empty, half full, and full condition for both the type of tank. For time-history analysis, Staad pro v8i software is employed for the structure

4.0 RESULTS AND DISCUSSION

The Time history analysis is carried out for the tank with empty, half, and full conditions using the aforementioned parameters. For each filling condition separate model is prepared. The results are noted down in roof displacement, velocity, acceleration, Base shear, frequency, and time period. The value of roof displacement, velocity, and acceleration is taken by considering the topmost node at slab level.Fig.1 shows Selected Node for Circular and Intze ESR.

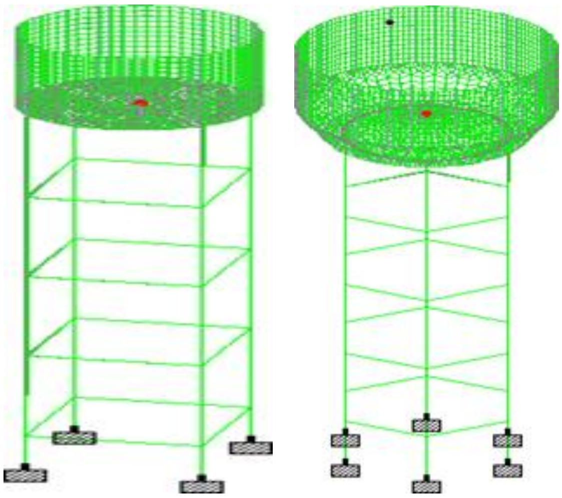
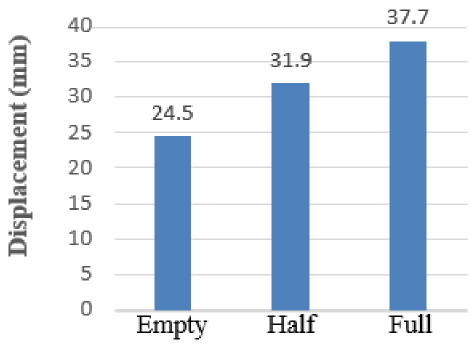


Fig 1: Selected Node for Circular and Intze ESR

Table 3. Natural Frequency and Time Period for Circular ESR

	Natural Frequency(Hz)			Time Period (sec)		
Modes	**Empty**	**Half**	**Full**	**Empty**	**Half**	**Full**
1	0.986	0.886	0.811	1.014	1.128	1.232
2	0.988	0.888	0.813	1.012	1.126	1.230
3	1.498	1.404	1.326	0.667	0.712	0.754
4	4.963	4.924	4.895	0.201	0.203	0.204
5	5.024	4.978	4.947	0.199	0.200	0.202
6	6.260	6.192	6.140	0.159	0.161	0.162



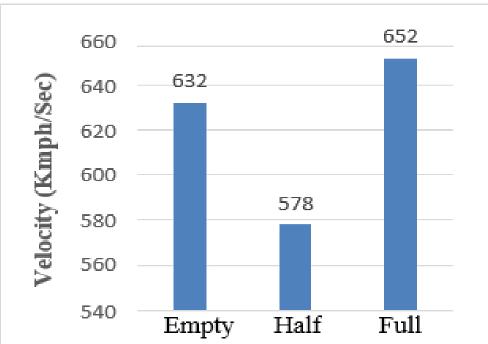


Fig. 2 Circular ESR Displacement and Velocity

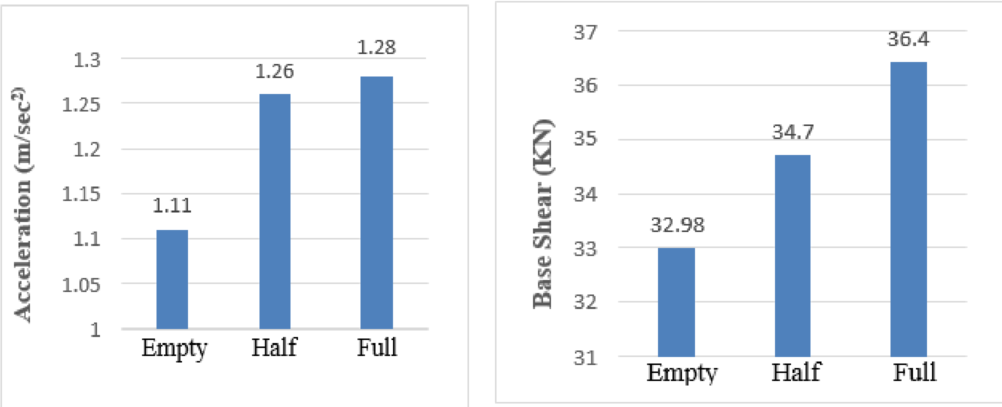


Fig. 3. Circular ESR Acceleration and Base Shear

Table 4. Natural Frequency and Time Period for Intze ESR

	Natural Frequency (Hz)			Time Period (sec)		
Modes	**Empty**	**Half**	**Full**	**Empty**	**Half**	**Full**
1	0.916	0.789	0.742	1.091	1.267	1.348
2	0.964	0.813	0.761	1.036	1.229	1.314
3	1.201	1.101	1.059	0.833	0.908	0.943
4	1.792	1.600	1.533	0.558	0.624	0.652
5	5.439	5.385	5.367	0.183	0.185	0.186
6	5.644	5.527	5.495	0.177	0.181	0.182

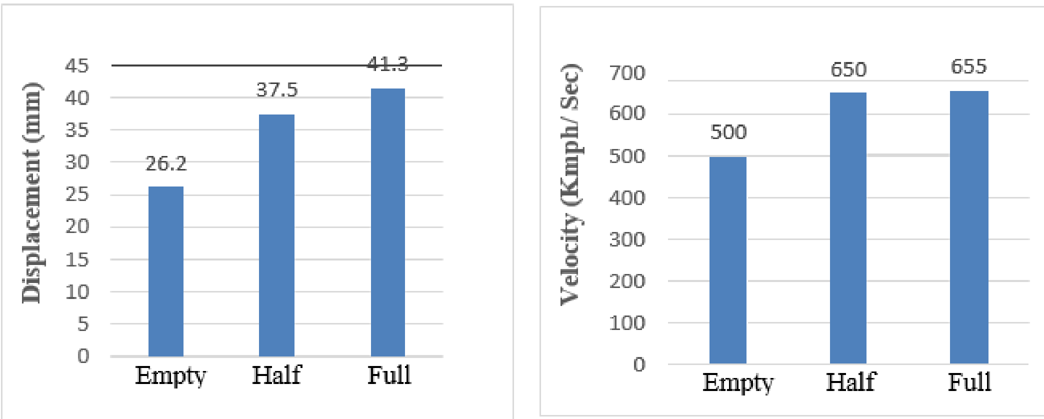


Fig. 4 Intze ESR Displacement and Velocity

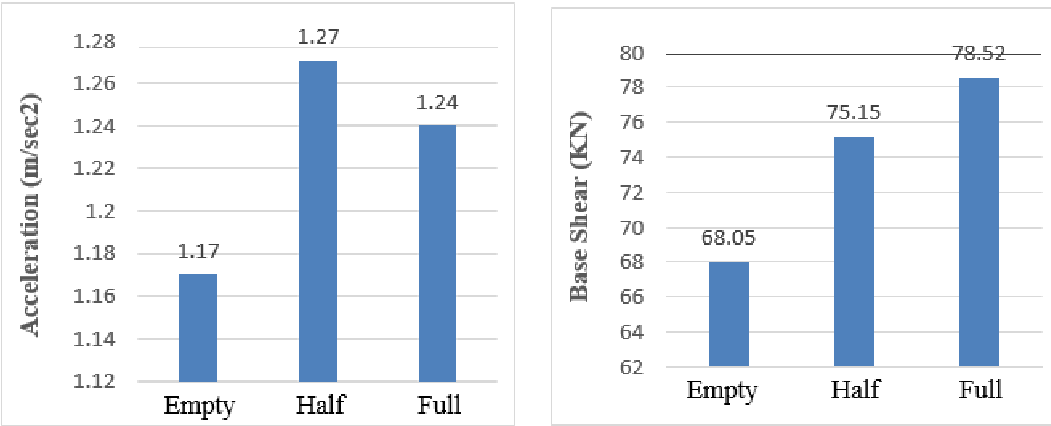


Fig. 5. Intze ESR Acceleration and Base Shear

Conclusion:

Based on the results obtained after the Time history analysis of existing Circular and Intze ESR, the following conclusions can be drawn:

- The natural frequency of the structure decreases with an increase in water storage.
- The Time period varies in-tank empty, half, and full condition. This is due to the effect of sloshing and hydrodynamic pressure.
- Base shear and base moment are increasing with an increase in the water level.
- With the increment of the seismic zone base shear value also increases.
- The nodal displacement increases with an increase in the water level.
- The critical response of the elevated water tanks doesn't always happen in full tank conditions, and it may occur even in the empty and half case of the tank depending on the earthquake characteristics.

Future Scope

Despite a wide range of studies on the dynamic analysis of the liquid containing storage structures, many design issues remain unsolved. Many researchers researched only rectangular, circular, and Intze shaped tanks, but nowadays, many new shapes of tanks are constructed.

- The present work is done on reinforced concrete water tanks of Circular and Intze shaped tank, and another study could be on considering different shapes of tanks.
- One may do work on considering a particular shape with a different capacity and staging pattern.
- Only time history analysis is considered, another work could be done by considering different seismic analysis methods.

Hence there is a vast field scope for further investigations on tanks of different shapes by varying different parameters such as the tank's height, the intensity of seismic excitation, type of staging pattern, etc.

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