Dynamic Analysis of RCC Elevated Water Tank Considering Effect of Conventional and Composite Staging

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Abstract. The raised water tank is the most significant building for storing huge amounts of water at a certain elevation to distribute the water in the surrounding area for survival purposes and to develop pressure for the distribution system. As elevated tanks are commonly utilized in seismically active areas, their seismic design must be thoroughly examined. The sloshing of the water during an earthquake may be one of the most important aspects for specific proportions of the tank and construction. The fluid-structure interaction complicates the dynamic analysis of a liquid-filled tank. As a result, there is a need to concentrate on the seismic safety of lifeline structures in terms of seismic design systems that are both safe during earthquakes and can sustain higher design forces. In this study, an elevated water tank is analyzed under seismic loading by considering conventional RCC staging and composite staging. The main focus of the study was to reduce the damage to the water tank under dynamic loading and to know the effect of composite member staging on the design performance of the water tank. The results were collected in terms of maximum base shear, overturning moment, displacement of tank etc. After performing the study, it was seen that composite columns in the staging of overhead water tanks improve the performance under seismic loading and help to control the roof displacement of the overhead water tank due to more stiffness provided by composite columns.

1 Introduction

Elevated water tanks serve as vital structures in storing and pressurizing water for various purposes such as municipal water systems, firefighting, and industrial applications [1–3]. Their integrity is paramount as damage during earthquakes can disrupt the drinking water supply, trigger fires, and lead to significant economic losses. Unfortunately, many of these tanks have collapsed or suffered severe damage due to insufficient understanding of their support systems. Failures range from buckling to sloshing damage of the ceiling, pipe breakage, and impulsion from sudden content loss. Therefore, there's a pressing need to prioritize seismic safety by exploring alternative support methods for these lifeline structures [4]. The liquid retaining structures sometimes contain water, and if these structures are used for environmental reasons, they are used for wastewater treatment plants, as these structures contain untreated sewage and wastewater. If an earthquake occurs, the underground structure

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*Corresponding author: adadtiwary15@gmail.com may be damaged, and if the structure collapses, the untreated water in the liquid Storage structure will discharge into the environment [5]. As a result, it is critical to analyze liquid storage structures using seismic analysis so that earthquake-resistant forces can be established and earthquake-resistant structure design may be carried out using those forces [3,6] . The container, staging, and base are the primary components of a reinforced concrete raised water tank in terms of analysis. Containers might be round, rectangular, intz, spherical, or any other form. When the water tank's necessary capacity is quite high, however, an intz kind of form is preferable since it requires less reinforcement than other varieties. This kind is very popular and widely used due to its efficient load-balancing design [7–10].Support structures for elevated water tanks encompass a variety of designs including RC-braced frames, steel frames, RC shafts, and masonry pedestals. Among these, frame types are the most commonly employed in practical applications. The pressure exerted by the water is borne by the walls, with the base supporting the combined weight of the water, walls, and roof. These structures must withstand the load of a full tank while also enduring wind forces. Reinforced concrete water towers offer numerous benefits: they are resilient to weather, resistant to leaks, provide added stability, and can be tailored to suit specific design requirements [11]. A frame staging consists of multiple columns symmetrically aligned on the girder's edge. It normally consists of the following components. Peripheral girder, columns, and braces to reduce column effective length [12,13]. The raised water tank's frame construction must be able to handle axial loads, moments, and shear forces induced by lateral loads. These forces are determined by the structure's overall weight, which varies based on the amount of water in the tank container [4]. Fluid-holding structures have undergone revision. The limit state design technique has been added in the updated edition. Before being assessed for serviceability, the structure is designed to collapse to the greatest extent possible. IS 3370:2009 uses the limit state design technique, with certain restrictions. The criteria that control fracture width are used in the limit state design procedure [22-24].

Water is necessary for putting out flames that may break out during earthquakes, causing damage and deaths. As a result, raised water tanks should continue to work after the earthquake . The considerable social and economic consequences of previous earthquakes in metropolitan areas have raised awareness of the possible seismic hazard and the accompanying susceptibility of the existing elevated storage water tank, which is essential for seismic risk estimation. Nowadays, the majority of buildings are erected with composite structures at maximum height, resulting in improved seismic performance. The performance of a raised composite water tank was investigated for the same purpose . For decades, researchers have been studying the dynamic reaction of liquid storage tanks. The seismic performance of liquid storage tanks is influenced by various factors including the tank's fixity (self or mechanically-anchored), potential base uplifting, roof configuration (open or fixed/floating), tank shape (circular, rectangular, or spherical), and other parameters [14]. This research focuses on conducting a seismic analysis of an elevated water tank, considering both RCC and composite staging beneath the tank. The objective is to assess how composite staging impacts the design and behavior of the overhead water tank [15]. The study evaluates parameters such as base shear, displacement, overturning moment, and period, comparing results with those obtained from the RCC staging model.

The objective of this study is to do the seismic analysis of the RCC overhead water tank by using Etabs software, to get the response of the RCC overhead tank under dynamic loading in terms of displacement, base shear, overturning moment etc., to check the effect of staging on performance of the overhead tank, and to compare the effect of RCC and composite staging on the design of the Overhead water tank.

2 Methodology

A rectangular overhead water tank of dimensions 10 × 10 × 5m is considered for the required study. A freeboard of 0.2m is provided at the top. The modelling of the water tank with staging was done in ETABS software. Six models were prepared for doing the study. The first three with RCC staging and the other three with composite columns in the staging with different heights of staging viz. 9m, 12m and 15m. The framed staging is considered for the required study. The model undergoes response spectrum analysis to evaluate the dynamic behavior of the water tank. Table 1 outlines the model configuration, including loading and other relevant factors considered for the study. Six distinct models were scrutinized during the investigation, as presented in Table 2.

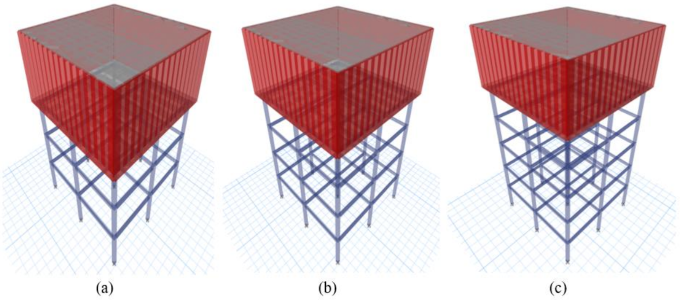

Fig. 1. 3d view of overhead water tank with different staging heights (a) 9m, (b) 12m, (c) 15m

Table 1. Model configuration

Model Description	
Plan dimensions	10m × 10m
Staging storey height	3m
Height of tank	5m
Free board	0.2m
No. of storey	Three, Four, Five
Total height	14m, 17m, 20,
Member Properties	
Beam size in staging	230mm × 230mm
Column size in staging	300mm × 300mm
Composite column size	250mm × 250mm
Tube thickness for composite column	6mm
Thickness of bottom slab	300mm
Thickness of tank wall	250mm
Thickness of top slab	150mm
General Loadings [14]	
Water Pressure	47 kN/m^2
Floor Finish Loading	1.5 kN/m^2
Material Properties	
Grade of Concrete	M25 and M20
Grade of Steel	FE500
Seismic Properties [15]	
Zone Factor	0.24 (zone IV)
Importance Factor	1
Response Reduction Factor	5
Soil Type	Medium
Damping Factor	0.05

Table 2. Types of models considered

Type of model	*Description about model*
M1	RCC Square overhead water tank with RCC staging of height 9m.
M2	RCC Square overhead water tank with RCC staging of height 12m.
M3	RCC Square overhead water tank with RCC staging of height 15m.
M4	RCC Square overhead water tank with composite column staging of height 9m.
M5	RCC Square overhead water tank with composite column staging of height 12m.
M6	RCC Square overhead water tank with composite column staging of height 15m.

2.1 Response spectrum analysis

Most structural designers opt for this type of analysis due to its user-friendly nature and quick completion time. Response spectrum analysis is a linear dynamic analysis method that disregards the structure's nonlinearity. While static analysis suffices for low-rise structures, taller structures necessitate dynamic analysis for a more accurate response to seismic loads. Dynamic analysis has proven to be more efficient than static analysis, leading to cost savings in design. Base shear is calculated in response spectrum analysis similar to static analysis, but for determining design spectral acceleration, IS 1893 provides specific tables based on soil type and the structure's fundamental time period [16]. Upon completing the analysis, the results from all analyzed building models were compiled and compared. The primary objective of the study was to assess the dynamic response of the various models mentioned above and juxtapose the analytical findings to evaluate the effectiveness of composite columns, along with the pros and cons of the models under consideration.

3 Results and Discussions

Dynamic analysis was employed to investigate the behaviour of the overhead water tank under seismic loading using RCC and composite column staging. The study primarily gathered findings regarding base shear, time period, displacement, and other relevant parameters. These results were then visually depicted through graphs in this section.

3.1 Maximum Displacement

Fig. 2 shows the plot of maximum displacement at the different levels of staging for all the models. From the graph it can be seen that the value of displacement for all the models at the lower levels is almost the same i.e., for overhead water tank supported at a higher height will show maximum roof displacement. Model M1, M2, M3 shows more displacement than M4, M5, M6 respectively. This is due to using composite columns instead of RCC members in models M4, M5, and M6. Composite columns provide more stiffness to the staging of the overhead water tank which prevents staging from moving under the effect of lateral loading, thus displacement of staging levels reduces.

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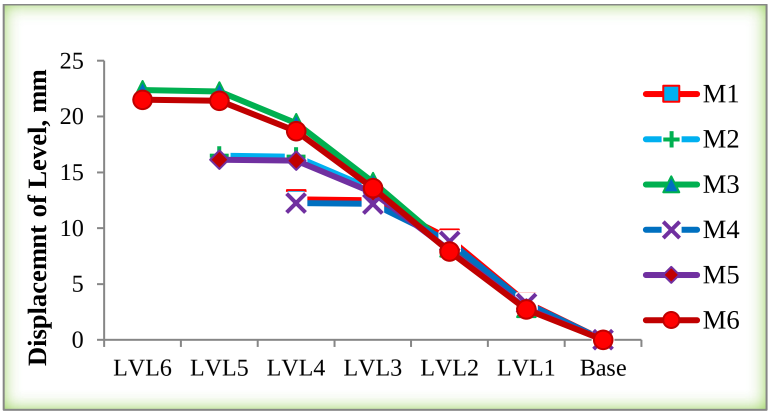

Fig. 2. Maximum storey displacement plot for all models

3.2 Maximum Drift

Fig. 3 shows the drift values between levels for all the models at different levels of staging. Drift value results also show the same impression i.e., at the lower heights of staging all models show similar values of drift or in other words as the staging height increases the drift values increase. M3 shows the maximum value of drift at the top of the water tank roof slab. Here also composite column models i.e., M4, M5, and M6 show lower values of drift than conventional RCC columns staging due to more rigidity provided by the composite sections. However, the effect of composite columns in reducing the drift is very small as can be seen from the graph in Fig. 3.

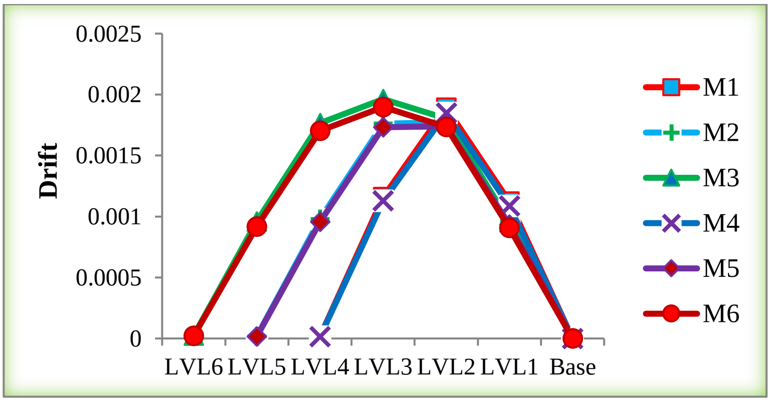

Fig. 3. Maximum storey drift plot for all models

3.3 Maximum Shear

Fig. 4 shows the plot of the maximum shear at different levels of the staging of the overhead water tanks for all models. Model M4 shows a maximum value of shear at LVL1 than all other models. For the lower height of the staging shear values are more than at higher values. This is due to the reason that at the lower height, staging becomes stiffer and attracts more seismic forces which result in higher values of shear at lower staging levels. As the height of staging grows, flexibility enters the picture, resulting in a lower value of shear. When the composite section is included in the staging, the shear values increase because M4, M5, and M6 have higher shear values than M1, M2, or M3. This is because composite columns add weight to the staging, increasing the structure's seismic weight and shear values.

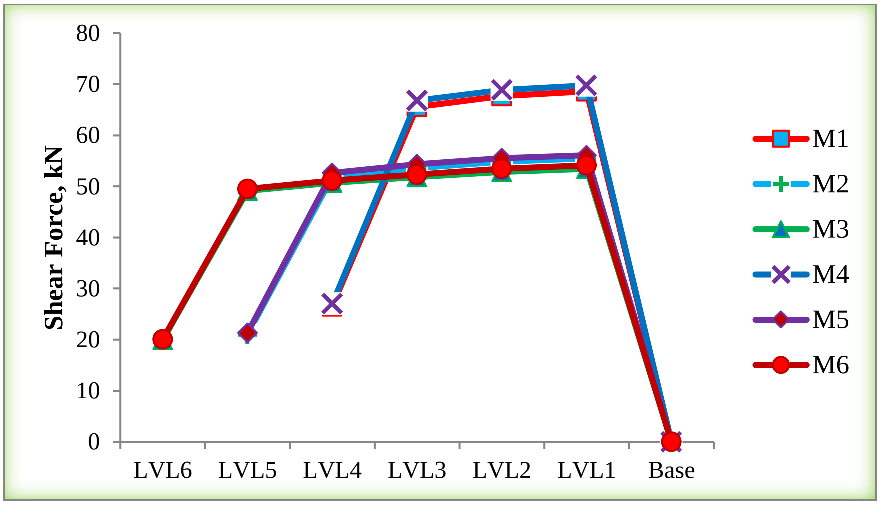

Fig. 4. Maximum storey shear plot for all models

3.4 Base Shear

Figure 5 illustrates the base shear plots for all models under investigation. The graph indicates that model M4 exhibits a higher base shear value compared to the other models, while M3 demonstrates a lower base shear value. The addition of composite sections in M4 raises the structure's weight and shear values at various levels, resulting in a high base shear value. Also, as its staging height was lower more stiffness of staging attracts more forces in seismic events and base shear value increases. In M3 only RCC members are there, so, its base shear value will be less than the composite column model. Also, as the height of the staging in this case was higher than other models staging behaves as a long-laced column which reduces the stiffness of the staging resulting in less attraction of seismic forces and resulting in lower value of base shear than other models.

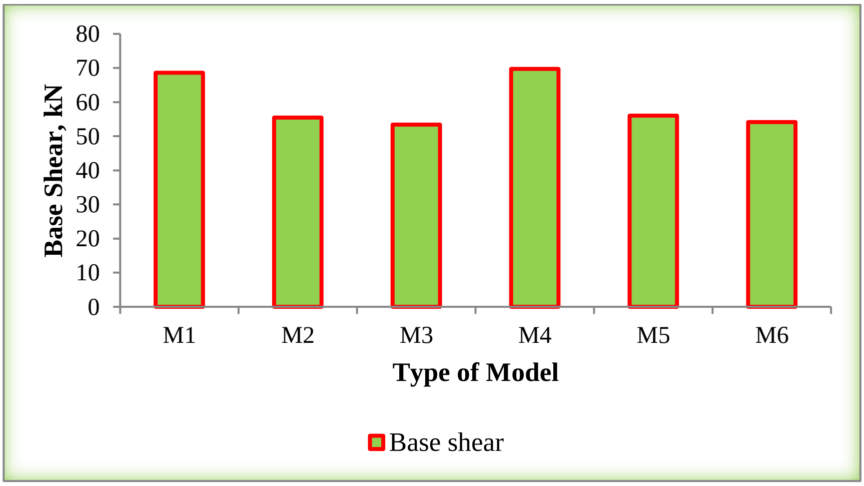

Fig. 5. Base shear plot for all models

3.5 Fundamental Time Period

Fig. 6 shows the fundamental time period values for all the models considered. The graph shows that model M3 has a more fundamental time period and M4 has less value of the fundamental time period among other models. In model M3 as only RCC sections were there in staging and its height was also higher than other models, it resulted in more flexible staging than other models. Because of the low stiffness of the staging, its frequency of motion during seismic excitation is reduced, resulting in a greater fundamental time period for the structure. Because of the weight of the composite columns and the increased stiffness they give, as well as the lower height of staging, the structure's rigidity increases, resulting in a higher frequency of motion during earthquake loading. Because of this period, the model shrinks.

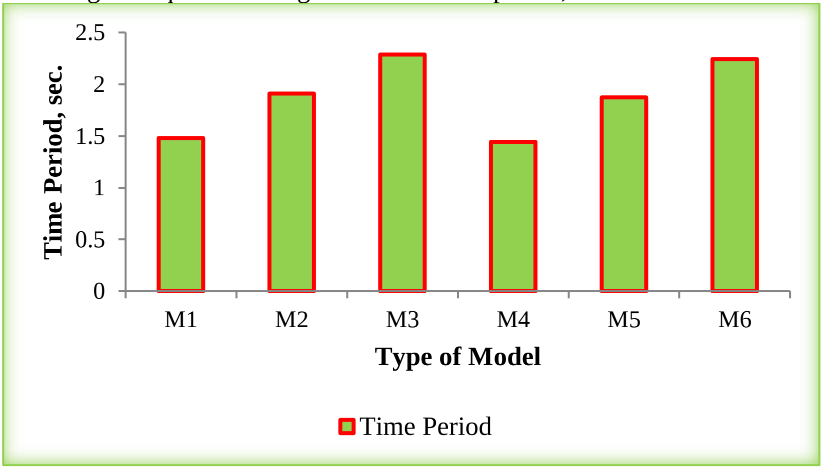

Fig. 6. Fundamental time period plot for all models

4 Conclusion

In the above seismic analysis of overhead water tanks with RCC and composite column staging was performed with different staging heights. The primary goal of the research was to determine the impact of composite column staging on the analysis of above-water tanks. After doing the analysis and receiving results, the following key points are listed below:

- The displacement of the overhead water tank is determined by the height of the staging. As the height of the staging grows, so will the displacement value. Composite columns stiffen the structure and aid in reducing the roof displacement of the overhead water tank. M3 increases the displacement value by approximately 78%, whereas M4 reduces the displacement of the overhead water tank's roof level by 2.6% compared to model M1.
- Drift value at various levels of staging also depends on the height. With the increase in the height of the staging, the drift first increases then its value goes on decreasing. The composite column section in the staging also helps in reducing the drift of level. However, the reduction is very small. Model M4 results in approx. 8% reduction in drift values and M3 shows 3.7% more drift values than model M1.
- Shear force at various levels of staging also depends on staging height. For higher heights of the staging, the shear force will decrease and vice-versa. The use of composite

parts in the staging of the above water tank increases shear force values due to the additional weight given by composite sections. Model M3 reduces storey shear values by 22.12%, whereas M4 increases maximum shear force by 1.7% compared to model M1.

- Because base shear is simply the sum of storey shear values at each level, it is also affected by staging height; as the height of staging increases, base shear values drop, and vice versa. When the composite section was employed instead of the RCC column to stage the overhead water tank, base shear values rose. Models M2, M3, M5, and M6 exhibit 19%, 22%, 18%, and 21% reductions in base shear value, respectively. In addition, M4 shows a 1.67% increase in base shear.
- The fundamental time period is contingent upon the stiffness of the structure. With increasing stiffness, the fundamental time period decreases. Similarly, as the height of the staging increases, the fundamental time period also increases. However, the presence of composite columns with greater rigidity leads to a decrease in the structure's time period. M4 has a 2.4% shorter fundamental time period of the above water tank than M1. Model M3 yields a 54.5% greater time period value than M1.

The study revealed that composite column staging is successful in reducing drift and displacement, but it also increases base shear and shortens the structure's life period. However, composite column staging beneath an above-water tank performs better in seismic loads.

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