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Original Research Article

RESPONSE OF ELEVATED WATER TANKS SUBJECTED TO LATERAL LOADS

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Abstract

During previous earthquakes around the world, it was discovered that elevated water tanks were severely damaged or collapsed. As a result, structural engineers are concerned about the analysis of these structures to gain a better understanding of the effects of seismic loads on elevated water tanks. In the current study, E-Tabs software, which is based on finite elements, is used to model various shapes of elevated water tanks along with various staging patterns. The higher stiffness of the supports in cross staging tanks makes them better than normal staging tanks, according to the results of the analysis. Furthermore, circular tanks perform better than other tank shapes when subjected to seismic loads. The study looks at water tanks subjected to static seismic loads. More research is needed to determine the analysis results for the dynamic seismic loads applied to the structure. All the analysis results are derived from the software's tank analysis results.

Keywords: elevated water tank, staging pattern, E-Tabs model, seismic load, equivalent static method

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1. INTRODUCTION

Elevated water tanks are a type of elevated liquid tank that is used in many cities as a vital town service. During strong earthquakes, their safety performance is a major concern for engineers as well as the public. They should not collapse in the event of an earthquake so that they can be used for critical uses such as preparing drinking water and putting out fires. The collapse of these structures and falling water perils occurred for people and their health in the city due to a lack of water for drinking or a disturbance in cooling fire during critical conditions. The seismic behavior, analysis, and design of tanks, particularly in-ground tanks, have been the subject of numerous studies. The majority of these studies have focused on elevated tanks in the last decade. Many elevated water tanks in the past have been severely damaged by earthquakes. As a result, structural engineers are concerned about analyzing these critical structures for seismic loads.

1.1 Literature Review

Various research scholars have previously conducted studies on water tank analysis. To better understand the behavior of elevated water tanks during seismic activity, researchers used software as well as manual analysis and design. In her research, Latha M.S. compared rectangular and circular overhead water tanks. According to the findings of her research, circular tanks are better for high-capacity tanks, while rectangular elevated water tanks are better for lower-capacity tanks[1]. Soheil Soroushnia investigated the seismic performance and damage patterns of frame-staged RC-raised water tanks in 2011. The reasons for reservoir damage during previous earthquakes were first investigated in the paper, and then alternative patterns for structural damage were proposed[2]. Bhavana Valeti studied the seismic response of an elevated aqueduct in 2016 while taking hydrodynamic and soil-structure interactions into account. The results of this investigation are presented in a paper that explains the seismic behavior of an elevated aqueduct under a variety of modelling assumptions[3]. In 2018, Alessandra Fiore conducted research on the seismic performance of spherical liquid storage tanks. The seismic behavior of a butane-filled spherical pressure vessel was studied, taking into account the effects of sloshing and the soil-structure interaction[4]. Kashyap N. Patel published a case study in 2018 on performance-based evaluation of the response reduction factor of an RC elevated water tank while considering soil flexibility. The findings show that the supporting soil's flexibility has a significant impact on the water tank's response reduction factor, period, and overall performance, implying that the idealization of fixity at the base could be misinterpreted as soft soils[5]. Shaikh Saddam Chandpasha investigated vibration control in an elevated water tank using various staging patterns and discovered that when using an alternative bracing design in staging, the base shear value decreases[6]. Tayyaba Anjum studied the efficiency of an overhead water tank under seismic stress and discovered that as the water level rises, base shear increases[7]. Neha S. Vanjari designed the circular overhead water tank. Her study demonstrates how to use the limit state method to design an overhead circular tank[8]. S S Quadri performed the seismic analysis of RC-raised water tanks for various staging patterns. For a 0.7 h/d ratio, the cross-staging type is found to deliver the best results when compared to alternative staging patterns for lateral displacement, axial force, moment-y, moment-z, and moment-x[9]. Sagar Mhamunkar et Al. did the analysis and design of the overhead water tank at Phule Nagar, Ambernath in 2018. In the study, the comparison of manual design of elevated water tanks and staad pro design is done[10]. Tejaswini and Mamtha used E-Tabs software to analyze and design elevated water tanks using the equivalent static and response spectrum methods. The area of steel required for the structure increases in the limit state method, according to the results. The limit state method is more effective and cost-effective than other reinforcement methods[11]. Kalyani Ravindra Bachhav performed dynamic analysis of elevated water tanks for seismic zones III and V according to IS:1893 2002, (part 2). The tanks were examined both manually and using the software. The study's main goal was to investigate the dynamic behavior of elevated water tanks when subjected to earthquake loading. According to the study's findings, elevated circular tanks outperform elevated rectangular tanks[12]. The parametric study of underground water tanks was carried out by Anshuman Nimade et al. using the finite element method. The paper includes a parametric study of a UG Rectangular tank to see how stress, node displacement, and base pressure are produced when the tank is empty or full, with varying length and width ratios (L/B) and a constant stem height using the Staad Pro V81[13]. After condition ranking using non-destructive testing, Chittaranjan Nayak and Sunil Thakare evaluated the seismic performance of an existing water tank. The purpose of this paper was to develop a systematic investigation of metrology for condition ranking procedures based on the analytical hierarchy process (AHP) and bolstered by various retrofitting strategies. The elevated service reservoir's ranking was determined using a variety of non-destructive tests (NDTs). The condition index of the elevated service reservoir was determined using the DER (degree extent relevancy) rating technique (ESR). After determining the existing structure's condition ranking, an analysis was conducted using SAP 2000 to determine the current seismic requirements using IS codes. Finally, the findings were used to address some of the most pressing concerns about the retrofitted structure's seismic response. Finally, the findings were used to address some of the most pressing concerns about the seismic response of the retrofitted structure in terms of period, model shapes, base shear, story displacement, acceleration, and velocity. The findings of a seismic retrofit case study for an existing elevated water tank confirm that a relatively simple retrofitting method is successful in maintaining the tank functional after an earthquake [14].

2. METHODOLOGY

Many steps are involved in the software's structure analysis. The first step is to model the structure. The finite element-based E-Tabs software is used to model a variety of elevated water tanks. The finite element analysis is performed in the software's backend. The material properties and sectional properties input for various elements of the structure are also included in the modelling. These material and sectional properties are discussed in detail in the modelling section of the paper. The loading conditions and boundary conditions are added after the modelling is completed. Finally, there's the structural analysis. Modeling of the structure, input properties, load input, and analysis are the steps in the structure analysis process.

3. MODELLING

Modelling is the first and most significant stage in completing a software study of any structure. E-Tabs, a finite element-based software, is used to model various designs of elevated water tanks. The following elevated water tanks are modelled in the software:

Model 1: Circular elevated water tank with Cross Staging (Fig),

Model 2: Rectangular elevated water tank with Cross Staging (Fig**Błąd! Nie można odnaleźć źródła odwołania.**),

Model 3: Square elevated water tank with Cross Staging (Fi),

Model 4: Circular elevated water tank with Normal Staging (Fig. **1**),

Model 5: Rectangular elevated water tank with Normal Staging (Fig),

Model 6: Square elevated water tank with Normal Staging (Fig).

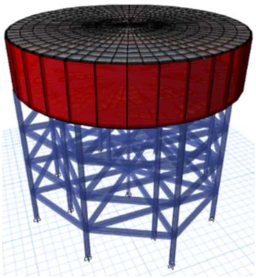

Fig. 1. Cross Staging Circular Water Tank

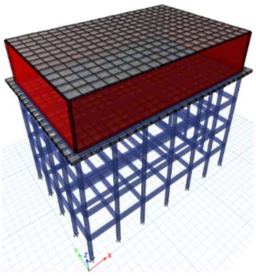

Fig. 2. Cross Staging Rectangular Water Tank

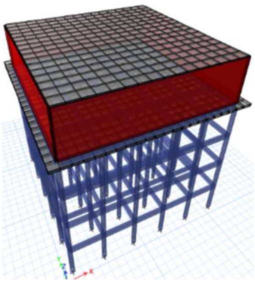

Fig. 3. Cross Staging Square Water Tank

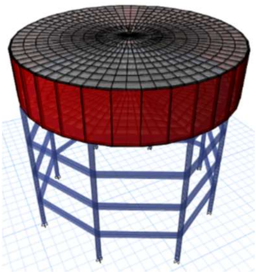

Fig. 1. Normal Staging Circular Water Tank

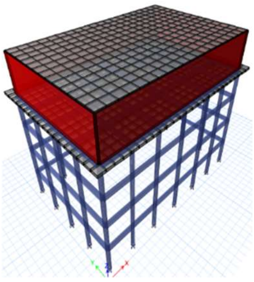

Fig. 5. Normal Staging Rectangular Water Tank

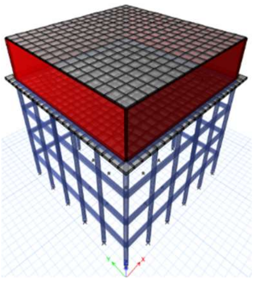

Fig. 6. Normal Staging Square Water Tank

The dimensions of various tanks are selected such that the volume of all the elevated water tanks remain almost the same. The staging height of all the tanks is 16m and the tank height is 5 m, including the freeboard. Table **1Błąd! Nie można odnaleźć źródła odwołania.** shows the dimension configuration of various shapes of tanks modelled for comparison analysis. The two types of staging for which the tanks are compared are cross staging and normal staging. The diagram of cross and normal staging is shown in the figure below (Fig and Fig).

Table 1. Dimension Configuration of Various Elevated Water Tanks

S. No.	Shape	Rectangular	Square	Circular
1.	Plan Dimension (m x m)	25x16	20x20	23 φ
2.	Height of tank	5	5	5
3.	Capacity in lakh (L)	20	20	20.77
4.	Staging Height (m)	16	16	16
5.	Bottom slab thickness (mm)	300	300	300
6.	Top slab thickness (mm)	150	150	150
7.	Sidewall thickness (mm)	300	300	300
8.	Column Dia. (mm)	500	500	500
9.	Bracing Size (mm x mm)	350 *500	350 *500	350 *500

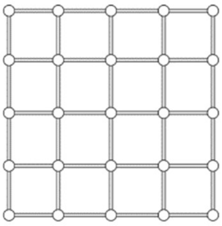

Fig. 7. Cross Staging

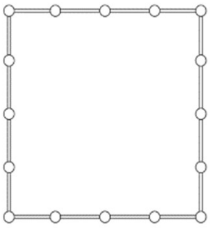

Fig. 8. Normal Staging

3.1 Material Properties

For the aim of analysis, the various parameters of concrete and steel are entered into the software. Concrete is believed to be homogenous, isotropic, and elastic in nature. M25 and M30 concrete were used, as well as Fe415 steel. Table **1** shows the various material properties used for the analysis.

Table 2. Material Properties

S. No.	Material Grade	Concrete M30	Concrete M25	Steel Fe415
1.	Specific weight γ (kN/m^3)	25	25	76.97
2.	Density ρ (kg/m^3)	2550	2550	7850

3.	Modulus of Elasticity E (MPa)	2.7x10^{4}	2.5x10^{4}	20x10^{4}
4.	Poisson’s ratio μ	0.2	0.2	----------
5.	Coefficient of Thermal Expansion α (1/°C)	5.5x10^{-6}	5.5x10^{-6}	11.7x10^{-6}
6.	Shear Modulus G (MPa)	11.4x10^{3}	10.4x10^{3}	----------

3.2 Section Properties

The sectional properties of various elements are entered in the software. Beams, supporting columns, top slab, bottom slab, and side walls are among the various elements. Table **1** already shows the sectional properties of these elements.

3.3 Boundary Condition

The bottom supports are fixed is the only boundary condition being applied in the model.

3.4 Loading Conditions

Elevated water tanks are the raised structure which are prone to various loads. Dead load, live load, water pressure, and seismic loads are the various forces which are applied on the models in the software. The software directly calculates the dead load of the structure. The live loads are applied according to IS:875 (part 2)- 1987 (reaffirmed 2008). The seismic load is applied according to IS:1893 (part 2)- 2014. The various seismic coefficients whose values are entered in the software are shown in the Table **3** below.

Table 3. Seismic Load Coefficients

Importance factor (I)	1.5
Response reduction factor(R)	2.5
Zone Factor (z)	0.16
Soil Type	1 (Medium Soil)

4. Result and Discussion

The outcomes of various tank shapes and staging are compared. The reactions that are examined for comparison of various tank forms and staging are maximum story displacement, maximum story drift, and maximum base shear.

4.1 Maximum Base Shear

Base shear is a calculation of the greatest predicted lateral stress on a structure's base due to seismic activity. The equivalent static technique uses IS:1893 2016,

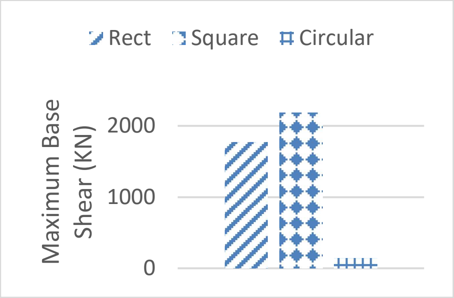

Fig. 9. Comparison of Maximum Base Shear for Various Cross Staging Tanks

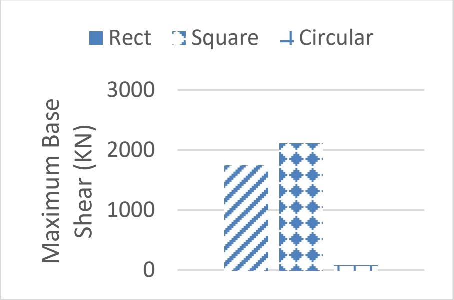

Fig. 10. Comparison of Maximum Base Shear for Various Normal Staging Tanks

Part 1 to building code seismic zone, soil material, and building code lateral force equation (1).

$$Base\ Shear = A_H \times W \qquad (1)$$

Here,
A_H = Design Horizontal Earthquake Acceleration Coefficient,
W = Seismic Weight of the Building

To understand the behaviour of various shapes and staging of elevated water tanks under the action of seismic loads, various graphical figures are created.

Fig and Fig depict graphs comparing rectangular, square, and circular tanks for cross staging and normal staging patterns, respectively. According to the charts, circular-shaped tanks have the lowest maximum base shear, whereas rectangular and square tanks have roughly the same maximum base shear.

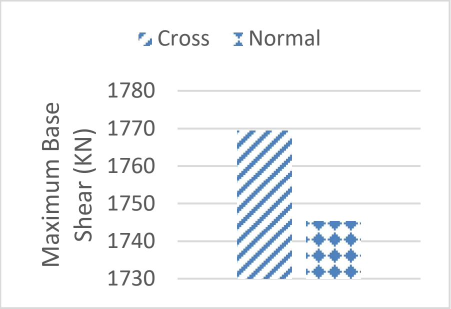

Fig. 11. Comparison of Maximum Base Shear for Various Staging of Rectangular tank

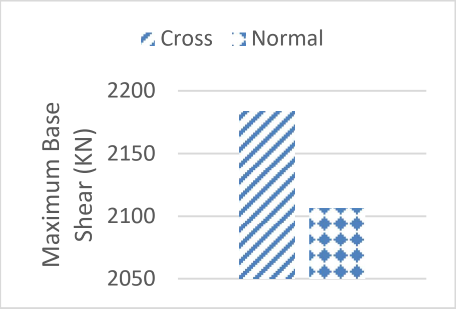

Fig. 12. Comparison of Maximum Base Shear for Various Staging of Square tank

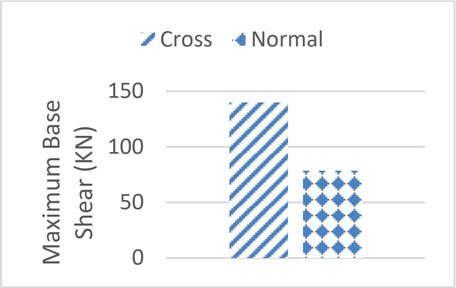

Fig. 13. Comparison of Maximum Base Shear for Various Staging of Circular Tank

The maximum base shear comparison of the cross and normal staging for rectangular, square, and circular tanks is shown in Fig, Fig, and Fig. According to the graphs, cross-staging tanks have a greater maximum base shear value than normal staging tanks, which is because of the higher stiffness in cross-staging tanks' staging due to the increased number of bracing columns.

4.2 Maximum Story Displacement

The absolute value of story displacement under the operation of lateral forces is called story displacement. It is the lateral displacement of the story about the structure's foundation. To understand the variation of maximum story displacement for various shapes of tanks and staging patterns under the action of seismic loads, various graphical figures are drawn.

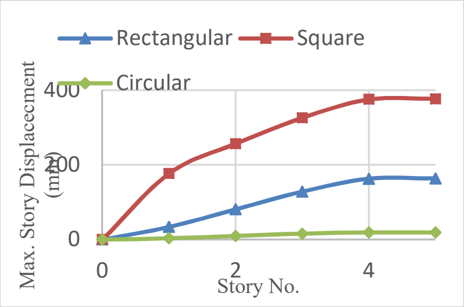

Fig. 14. Comparison of Maximum story displacement for Various Normal Staging Tanks

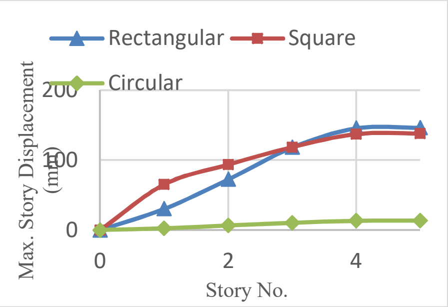

Fig. 15. Comparison of Maximum Story Displacement for Various Cross Staging Tanks

Fig and Fig show graphs comparing cross staging and normal staging patterns in rectangular, square, and circular tanks. From the curves, circular-shaped tanks have the least maximum story displacement while the story displacement value of the square tank is the highest. The maximum story displacement for the cross-staging tank is about the same for square and rectangular tanks.

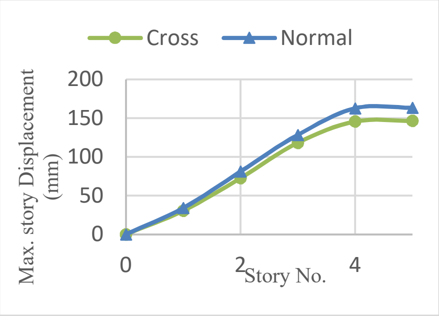

Fig. 16. Comparison of Maximum Story Displacement for Various Staging of Rectangular tank

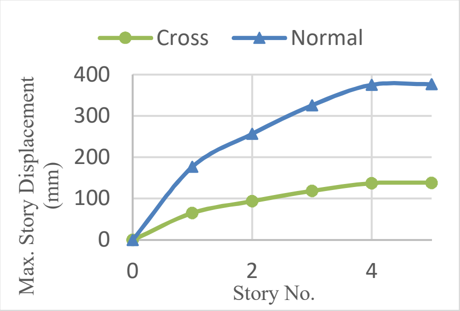

Fig. 17. Comparison of Maximum story Displacement for Various Staging of Square Tank

For maximum story displacement, the cross and normal staging tanks are compared in Fig, Fig and Fig. The graphs show that the cross-staging tanks have the lower story displacement for all the shapes of tank. This is because cross staging has a higher number of supporting columns, making the structure's support stiffer.

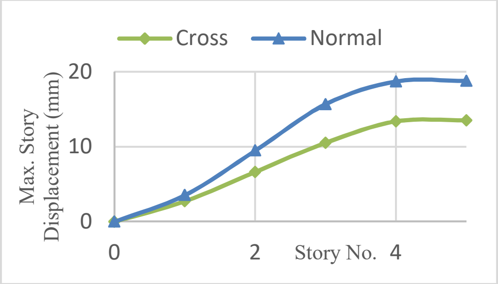

Fig. 18. Comparison of Maximum Story Displacement for Various Staging of Circular Tank

4.3 Maximum Story Drift

Story drift is the relative displacement of one-story relative to another story. For comparing the maximum story displacement values for various shapes and staging of tanks, graphical figures are drawn.

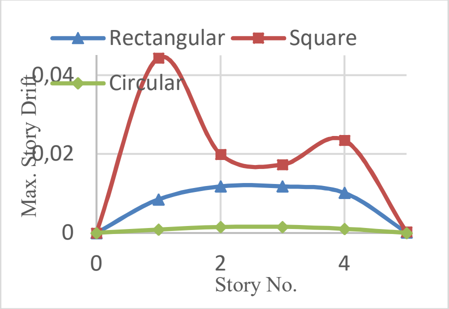

Fig. 19. Comparison of Maximum Story Drift for Various Normal Staging Tanks

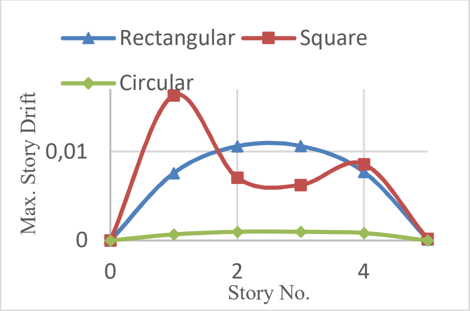

Fig. 20. Comparison of Maximum Story Drift for Various Cross Staging Tanks

Fig and Fig provide the comparison of cross staging and normal staging patterns for maximum story drift values in rectangular, square, and circular tanks. According to the curves, circular-shaped tanks have the least maximum story drift. For lower floors, the square tank's story drift value is the highest, while for the higher stories, i.e., for the tank container, the maximum story displacement for the cross-staging tank is near about the same for square and rectangular tanks.
For maximum story drift, the cross and normal staging tanks are compared in Fig, Fig, and Fig. The graphs show that the cross-staging tanks have the least story drift for all the tank shapes which is because cross staging has a higher number of supporting columns, making the structure's support stiffer

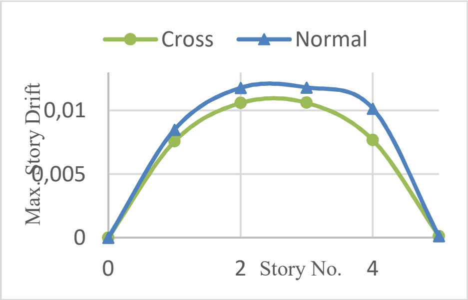

Fig. 21. Comparison of Maximum Story Drift for Various Staging of Rectangular Tank

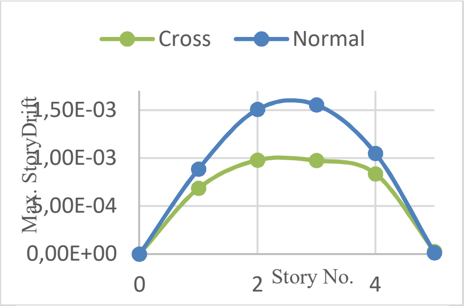

Fig. 22. Comparison of Maximum Story Drift for Various Staging for Circular Tank

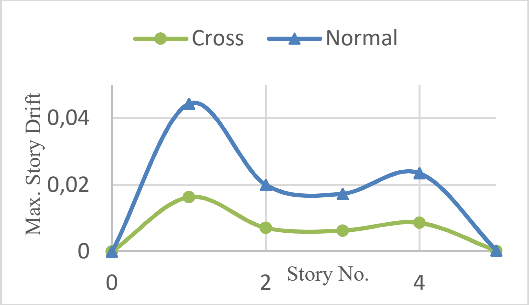

Fig. 23. Comparison of Maximum Story Drift for Various Staging of Square Tank

5. CONCLUSIONS

The elevated tanks are the structure which should be made considering various loads acting on it. The present study has presented the comparison of various shapes and staging of elevated water tanks. Following are the conclusions that can be drawn after reviewing the various analysis results:

- Cross-staging tanks have lower story displacement and drift than normal staging tanks in all shapes of the tank. As a result, under the action of seismic loads, cross-staging tanks are more stable than normal staging tanks. The reason for this is that the cross-staging tank has a higher stiffness than the normal staging tank. Thus, cross staging tanks are more effective in seismically prone areas than normal staging tanks in terms of stability.

- For seismic loading, square-shaped tanks have higher story displacement and story drift than other types of tanks due to their shape. Compared to other tank shapes, circular tanks have less story displacement and drift. In seismically prone areas, circular shaped tanks should be preferred over the other two shaped tanks.

6. ACKNOWLEDGMENT

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