A Comprehensive Analysis of Column Optimization for Circular Elevated Water Tanks in Seismic Environments

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Abstract. Water storage is critical everywhere, especially in places where there is a severe water shortage. Understanding its vital significance, water storage projects are receiving more attention in an effort to guarantee regular availability to this resource that is necessary for daily existence. The study explores the complex dynamics of raised water tanks and describes the structural details of slabs, beams, columns, and footings. These element channel loads carefully to the soil sub-grade, allowing their complex interaction. The study focuses into many load types, including seismic, living, and dead, and as a result, the analytical framework reveals the dynamic behaviours of the water tank. The main aim of this research project is to perform a thorough hydrological investigation of circular water tanks. Furthermore, the study presents the findings from a thorough analysis of round raised water tanks, with a focus on column optimisation. The research examines different column arrangement with capabilities that remain constant across the range, from 10 to 14 columns. In the context of Zone II seismic conditions, the study preserves relative integrity by keeping heights and diameters constant. By conducting a detailed analysis of crucial structural considerations, such as maximum bending moment, maximum displacement, and base shear, the study aims to clarify the subtle performance characteristics present in circular elevated water tanks under seismic loading scenarios.

Keyword-: load distribution, column optimization, analytical frame work, hydrological investigation, soil sub-grade.

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1 Introduction

Elevated water tank serves as a reservoir for storing water under gravitational flow. The work is focused on high-height water tanks that shall offer insights into designing structures that are both reliable and cost-effective, while prioritizing safety. To understand the optimisation principles of such tanks it is of utmost importance to focus on the existing literature and [1]. This study delineates various design criteria influencing the structural strength and support, ensuring the safety and cost-effectiveness of tank construction [2-3]. The design pertains to an elevated or overhead tank featuring reinforced concrete as the primary material for the liquid containment structure. It incorporates seismic assessment and wind analysis for the liquid-holding component, adhering to Indian standards such as IS: 3370(1965) and IS: 1398. Additionally, it references IS: 875, IS: 1893 part-3, and IS: 1398 standards [5-6]. Despite the imperative role of water storage tanks in post-earthquake scenarios for maintaining water supply to communities, there remains a scarcity of research on tank design and analysis. The principal objective of this study is to develop an elevated water tank resilient to seismic events, addressing the pressing need for enhanced earthquake resilience in water infrastructure [4-6]. Water storage is very important all throughout this globe, especially in places where there is a shortage of water. Initiatives to save water are therefore becoming more and more important in order to provide constant access to this resource that is necessary for daily life. One significant development in design guidelines for liquid-retaining structures is the introduction of the limit state design method. Using this method, structures are designed to survive collapse in limit states, and then their accessibility is evaluated. A modern and thorough approach to structural design is demonstrated by IS3370:2009's adoption of the limit state design method [7]. A prime example of this methodology in action is the design of raised rectangular RC water tanks. In order to maintain sufficient pressure in water distribution systems, elevated water tanks serve as significant storage containers designed to hold water at particular heights. Municipalities and businesses use these tanks a lot to store different chemicals, volatile liquids, and water [8-10]. Because to their essential role, high water tanks might sustain damage during seismic events that compromise drinking water supply, fail to contain large fires, and cause large-scale financial losses. Elevated water tanks are often used in seismically active areas; consequently, it is critical to assess their seismic design in detail [11]. The numerous instances in past of tank collapses or significant damage because of earthquakes suggest the urgent necessity of giving seismic safety top priority while designing important lifeline structures. Maintaining the structural stability of infrastructure, especially crucial utilities like water storage structures, is crucial in regions subjected to seismic activity [12]. Among those, circular elevated water tanks are vital to providing a regular supply of potable water, especially in areas with limited water resources. But there is still cause for problem approximately how they characteristic during earthquakes, which necessitates rigorous examination and optimisation. The main aim of the proposed research is to conduct a complete analysis of column optimisation for circular raised water tanks located in seismic zones. The goal of this study is to examine the effects of various column layouts at the seismic performance and structural strength of these important water storage structures [13-16]. The study intends to reduce potential damage and improve the tanks' resistance to seismic loads through optimising column design. One of the number one targets of the look at is to have a look at the effects of different column arrangements, along with the quantity and placement of columns, on critical structural statistics [17]. Among these measurements are base shear, displacement, and maximum bending moment; these are important markers of the way the tank will react to seismic loading. Through the use of state-of-the-art structural evaluation techniques such as dynamic simulation and finite element modelling, the study evaluates how the tanks react to seismic events which are simulated [18]. Similarly, the quality column arrangement that maximises earthquake resilience while reducing production costs and material utilisation may be decided by means of parametric calculations. Through undertaking these exhaustive studies, the observe hopes to provide significant insights into enhancing the seismic resilience of circular improved water tanks. Better design techniques for this creation are expected to be guided by means of the study, ensuring its dependability and safety in seismically lively locations. The project's closing goal is to boom our understanding of structural optimisation techniques and promote the development of greater earthquake-resistant water infrastructure [19-23].

2 Methodology

The study clarifies the complex structural elements relating to slabs, beams, columns, and footing and explores the complex dynamics seen in raised water tanks. These component help distribute loads in an orderly manner by directing them into the soil's subgrade [24]. Because the study includes three different sorts of loads—seismic, live, and dead—the water tank's complex behaviours are explained by the analytical framework. One of the main goals of this academic endeavour is to perform an extensive hydrostatic examination of circular water tanks [25]. Furthermore, the study presents the results of a thorough analysis of circular raised water tanks, with a focus on column optimisation techniques. The goal of this study is to provide a thorough analysis of the performance traits displayed by raised circular water tanks during seismic activity. Under Zone II seismic circumstances, the study examines column optimisation scenarios involving 10, 12, and 14 columns in a circular elevated water tank with a capacity of 2 lakh litters, all while maintaining constant height and diameters [26-29]. The major objective is to understand how these structures respond to a combination of dead, live, and seismic loads. With the Staad. Pro programme, the water tank are carefully modelled and analysed. This study looks at the structural performance under different earthquake condition in an effort to provide insight into the dynamic behaviour of elevated circular water tanks. This will help us understand these tanks' reaction processes better [30].

2.1 Analysis of Circular Elevated Water Tank with Different No. of Column 10, 12, and 14

Staad pro provides the option of modelling the structure with an easy option of quick template where the bays can be defined in X and Z direction [31]. The modelling process for this specific situation takes into account 20 bays surrounding the perimeter and a range of columns, from 10 to 14. In addition, the geometric parameters of the tank are as follows: the height is 5 metres, the staging height is 12 metres, and the radii are 3.5 meters [32-35]. By carefully utilizing the Quick Template function, modelling accuracy and efficiency are enhanced by accurately representing structural components. As such, it permits a full analysis of the elevated circular water tank's behaviour under various loads and situations, which advances our understanding of its structural integrity and performance

Shown in Table 1 detail in table the circular elevated water tank with a 2-lakh litter capacity. The circular tank shape and precisely defined dimensions of this tank guarantee its structural soundness and functionality [36]. It contains specifications for the thickness of the tank wall, floor slab and roof slab in addition to the size of the floor and bottom beams. The diameter and height of the tank, the number and size of columns, and the staging height. Important elements include the type of staging, free board, steel and concrete grades, seismic zone, response reduction factor, importance factor, and damping coefficient detail in table. In effort to properly plan and build the water tank, ensure that it satisfies safety regulations, can survive seismic activity, and efficiently stores and distributes water, engineers and designers need to know these parameters.

Table 1: Specifications of the Circular Elevated Water Tank

Property	Specification
Shape of tank	Circular
Size Capacity	2 lakh litters
Roof Slab Thickness	120 mm
Tank Wall Thickness	200 mm
Floor Slab Thickness	300 mm
Bottom Beam Size	500 mm x 600 mm
Floor Beam Size	300 mm x 450 mm
Number of Columns (8 Nos)	700 mm x 700 mm
Number of Columns (10 Nos)	700 mm x 700 mm
Number of Columns (12 Nos)	700 mm x 700 mm
Height of Tank	5 meters
Diameter of Tank	7 meters
Staging Height	12 meters
Type of Staging	Frame Staging
Free Board	0.3 meters
Grade of Concrete	M30
Grade of Steel	Fe 500
Earthquake Zone	III
Response Reduction Factor	5
Importance Factor	1.5
Coefficient of Damping	0.05

3 Results and Discussion

The comparatively analysis of elevated water tanks, shedding light on their structural complexities encompassing slabs, beams, columns, and footings. These elements enable the methodical distribution of loads, directing them systematically to the soil sub-grade. With the study's inclusion of diverse load types—dead, live, and seismic. This study investigates how well a circular elevated water tank performs when various column optimisation procedures are used. Configurations with 10, 12, and 14 columns, for example, are all examined under zone II conditions while using constant height and diameter measurements. This research present is to behavior a comparative evaluation of critical structural parameters, focusing specifically on maximum displacement, natural time period and maximum base shear. The results obtained from this analysis are meticulously presented below, providing a comprehensive evaluate of the tank's behaviour across different column optimization schemes and capacities. This comparison analysis gives a deeper understanding of ways every tank type impacts commonplace stability and resilience under place II seismic conditions by illuminating the diffused variances in structural response.

Table 2: base shear of elevated circular water tank in zone II

Storey	Peak Storey Shear in KN		
	No of 10 Column	No of 12 Column	No of 14 Column
4	272	305	315
3	296	334	346
2	312	354	378
1	318	365	396
BASE	318	365	396

This Table 2 representation gives a comprehensive analysis of the height storey shear forces measured in round increased water tanks with various column numbers (10, 12, and 14). Kilonewtons (KN) are used to measure the peak storey shear forces, which can be representative of the lateral forces that the tanks stumble upon at different levels. at the topmost tale (stage 4), after those studies the peak storey shear increases from 272 KN for tanks with 10 columns to 315 KN for tanks with 14 columns. In addition, this trend is determined throughout all tiers, with higher numbers of columns correlating with higher top storey shear values. This comparison highlights the influence of column optimization at the structural response of the tanks, indicating that increasing the number of columns enhances the tanks' capability to withstand lateral forces and improve overall stability.

Table 3: Results of displacement of elevated water tank for 2 Lakh litters in zone II

Storey	**Displacement in mm**		
	No of 10 Column	**No of 12 Column**	**No of 14 Column**
Top	33.4	28.6	22.9
4	31.7	26.9	21.1
3	24.9	21.1	16.9
2	15.5	12.3	10.0
1	5.6	4.9	4.1
BASE	0.00	0.00	0.00

This Table 3 predict comparatively analysis of the displacement observed at different tale levels in circular elevated water tanks based on the number of columns—10 columns, 12 columns, and 14 columns. During this research the displacement values are measured in millimetres (mm) and represent the extent of movement or deformation experienced by the tanks at various levels. At the topmost level, the displacement decreases from 33.4 mm for tanks with 10 columns to 22.9 mm for tanks with 14 columns, indicating that increasing the number of columns results in reduced displacement at the top of the tank [1]. The process is found to be continued across all levels, with higher numbers of columns associated with lower displacement values. However the comparison made in the study highlights the impact of column optimization on reducing structural deformation and improving the overall stability of the tank as a result.

Table 4. Results of Natural Time Period of Elevated Water Tank for 2 Lakh litters in Zone II

Mode	**Period (Sec)**		
	No of 10 Column	**No of 12 Column**	**No of 14 Column**
1	0.8385	0.7418	0.6590
2	0.8305	0.7356	0.6581
3	0.5968	0.5274	0.4703
4	0.3376	0.3370	0.3365
5	0.2122	0.2065	0.2001
6	0.2086	0.2035	0.1989

The Table 4 showing that the mode shapes and their corresponding periods for circular elevated water tanks with different numbers of columns: 10 columns, 12 columns, and 14 columns. Each mode shape represents a distinct pattern of structural vibration, and the period indicates the time taken for one complete cycle of vibration. As observed, the period decreases as the mode number increases, indicating higher-frequency vibrations for higher modes. The tanks with 10 columns generally exhibit slightly longer periods compared to those with 12 or 14 columns across all mode shapes. This trend continues for subsequent mode shapes, with the periods decreasing gradually. The variations in period among different tank configurations demonstrate the influence of column optimization on the dynamic characteristics of circular elevated water tanks.

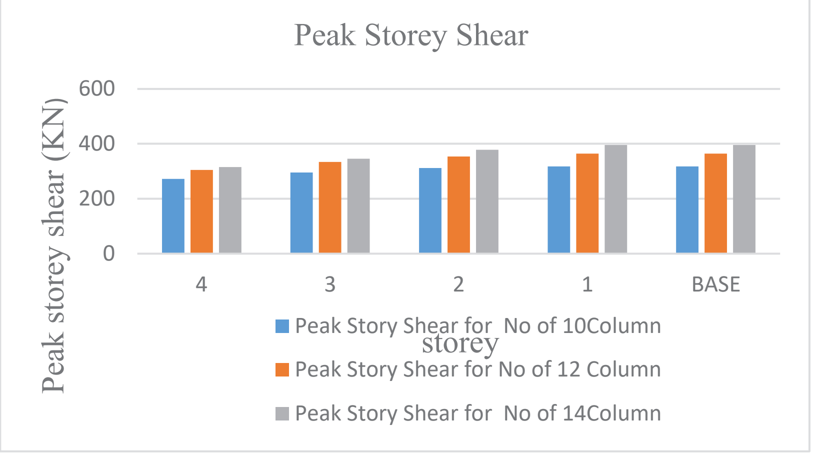

Fig. 1: comparative results of peak storey shear for circular elevated water tanks with 10, 12, and 14 columns

Fig. 1 showing that the peak storey shear forces across different configurations of circular elevated water tanks with varying column numbers reveals intriguing insights into their structural behaviour. After this research the peak storey shear forces tend to increase as the number of columns in the tank increases from 10 to 14. This trend persists consistently across all storey levels, indicating a proportional relationship between columns numbers and the magnitude of peak storey shear forces. Moreover, at the base level, all configurations with 12 and 14 columns demonstrate identical peak storey shear forces of 365 kN, slightly higher than the configuration with 10 columns, reinforcing the impact of column number on shear force distribution throughout the tank structure. The focus of the work is on the importance of column optimization in enhancing the structural resilience and stability of circular elevated water tanks under seismic loading situations.

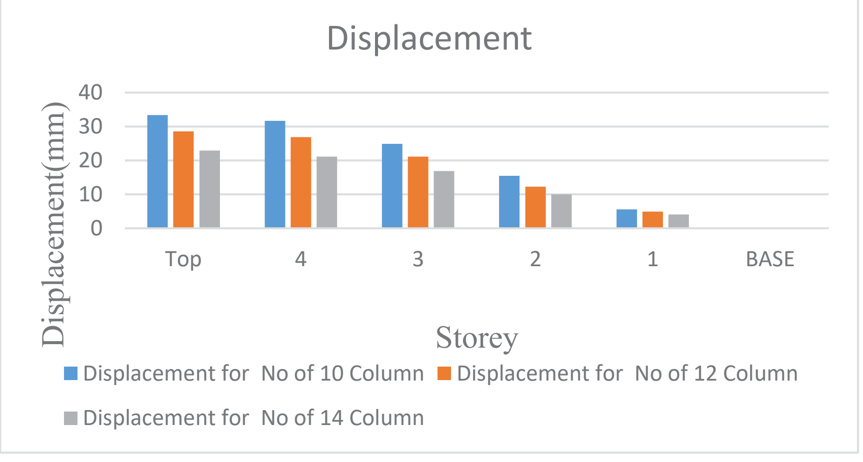

Fig. 2: Comparative results of displacement for circular elevated water tanks with 10, 12, and 14 columns

The study shown in Fig. 2 represents the displacement across different configurations of circular elevated water tanks with various column numbers that provides valuable insights into their structural response under seismic. During this research at every storey level, the displacement decreases because the number of columns in the tank increases from 10 to 14. This trend continues consistently across all storey levels, indicating a reduction in displacement with an increase within the number of columns furthermore, at the bottom level, all configurations display zero displacement, emphasizing the stability of the tank's foundation no matter the number of columns. Overall, this comparative evaluation highlights the position of column optimization in minimizing displacement and enhancing the structural integrity of round elevated water tanks subjected to seismic loading.

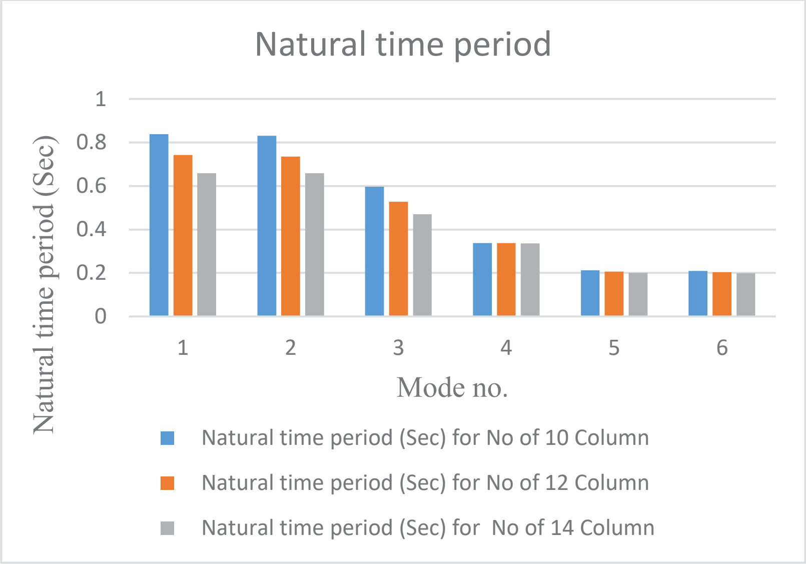

Fig. 3: comparative results of natural time period for circular elevated water tanks with 10, 12, and 14 columns

The mode shapes and their respective periods for circular elevated water tanks with varying numbers of columns: 10 columns, 12 columns, and 14 columns. Each mode shape represents a completely unique sample of structural vibration, and the duration indicates the time taken for one complete cycle of vibration in showing in Fig. 3. This trend persists at some point of the subsequent mode shapes, with the durations gradually decreasing. The variations in duration among distinctive tank configurations highlight the impact of column optimization on the dynamic behaviour of circular elevated water tanks. Mainly, the variety of columns appears to persuade the natural frequencies of vibration, with fewer columns commonly resulting in longer periods and lower-frequency vibrations.

5 Conclusion

The comparative analysis conducted on circular elevated water tanks with various numbers of columns provides valuable insights into their structural behaviour under seismic loading situations. The results of a thorough parametric inquiry into a circular elevated water tank, providing column optimization with 10, 12, and 14 columns under zone II conditions, maintaining consistent height and diameters, are elucidated. This investigation basically concentrates at the comparative evaluation of pivotal structural parameters, including maximum displacement, natural time period, and maximum base shear.

- Increasing the number of columns from 10 to 14 outcomes in higher height shear forces across all storey levels. Configurations with 12 and 14 columns exhibit slightly better shear forces at the base level as compared to those with 10 columns. The number of columns affects the magnitude of peak storey shear force.
- Displacement decreases with an increase the number of columns. Tanks with 14 columns show the lowest displacement across all storey levels. Zero displacement is observed at the base level for all configurations, highlighting foundation stability.
- Column optimization significantly impacts shear force distribution, enhancing structural resilience and stability. and minimizes displacement, improving structural integrity under seismic loading.
- Periods reflect the dynamic behaviour of tanks with varying column numbers. Tanks with fewer columns exhibit longer periods and lower-frequency vibrations. Longer periods indicate lower-frequency vibrations, while shorter periods suggest higher-frequency vibrations.
- The number of columns influences the natural frequencies of vibration, emphasizing the importance of column optimization in ensuring structural stability.

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