Advances in RCC Circular Underground Water Tanks: Structural Integrity and Seismic Resilience

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Abstract: *This research paper presents an in-depth analysis of Reinforced Cement Concrete (RCC) Circular Underground Water Tanks, vital components in water storage and distribution infrastructure. It explores the structural advantages of their cylindrical design, particularly in distributing stresses and pressures, and their capability to withstand external forces such as soil pressure and seismic activity. The paper also discusses the construction considerations including material selection, foundation design, and environmental impact. Emphasis is placed on the necessity of these tanks in ensuring reliable water supply, especially in emergencies, and their role in fluctuating demand management. The study further delves into the seismic analysis and design considerations, highlighting the importance of these factors in the construction of water tanks. Using Staad Pro software, the paper presents a parametric evaluation of circular underground water tanks under different seismic zones and soil conditions, offering insights into their behavior under various loads. The results contribute to understanding the resilience and efficiency of these structures in modern infrastructure.*

Keywords: *RCC Circular Water Tanks, Underground Water Storage, Seismic Analysis, Structural Engineering, Water Distribution Systems.*

I. INTRODUCTION

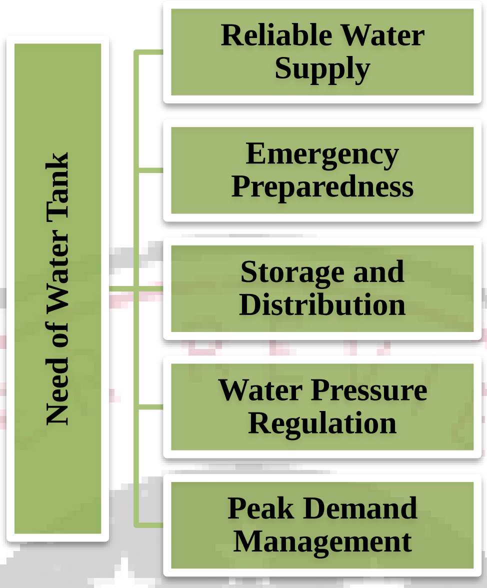
Exploring RCC Circular Underground Water Tanks offers a holistic insight into these pivotal structures, crucial within water storage and distribution systems. Crafted to reside beneath the earth's surface, these tanks optimize spatial utilization, assuring a dependable water reservoir catering to diverse applications such as residential, industrial, and firefighting demands. RCC Circular Underground Water Tanks are characterized by their cylindrical shape, which offers several advantages. The circular design allows for efficient distribution of stresses and pressures, making them well-suited to withstand external forces, including soil pressure and potential seismic loads. This shape also minimizes the potential for corners or edges, reducing stress concentration points that could lead to structural vulnerabilities.

Figure 1 RCC Circular Underground Water Tanks

The construction of these tanks involves careful consideration of various factors, including soil conditions, water table levels, and potential environmental impacts. The tanks are typically constructed using reinforced concrete, a material known for its durability and strength. The concrete walls are reinforced with steel bars, enhancing their ability to resist both internal and external forces.

A. Need of Water Tank

The need for water tanks is driven by the imperative to secure and efficiently manage the supply of water for diverse societal requirements. These tanks serve as pivotal reservoirs, storing water for distribution to homes, industries, agriculture, and commercial establishments. This reservoir function becomes crucial during periods of water scarcity or high demand, ensuring a continuous and reliable water supply. Moreover, water tanks play an instrumental role in emergency preparedness, offering accessible water sources for firefighting, sanitation, and survival during disasters. They also aid in managing fluctuating water demands by storing surplus water during low-demand periods and releasing it during peak times. In remote or off-grid areas, water tanks become lifelines, providing localized access to water. By capturing rainwater and alternative sources, these tanks also foster sustainability and conservation efforts, making them indispensable components of modern infrastructure that address water security, basic needs, and urban growth challenges.



- Reliable Water Supply: Water tanks ensure a consistent supply of water even during periods of high demand, water scarcity, or emergencies, promoting overall water security.
- Emergency Preparedness: Water tanks serve as essential reservoirs for firefighting, disaster response, and sanitation during emergencies, contributing to community resilience.
- Storage and Distribution: They store and distribute water for various purposes, including domestic use, industrial processes, agriculture, and commercial activities, facilitating efficient water management.
- Water Pressure Regulation: Elevated tanks help maintain optimal water pressure in distribution systems, ensuring adequate flow and water accessibility to consumers.
- Peak Demand Management: Tanks store surplus water during low-demand periods and release it during peak consumption times, aiding in managing fluctuating water demands.

B. Circular Water Tanks and Their Structural Considerations

Circular water tanks are cylindrical structures designed to store and distribute water for various purposes, such as domestic, industrial, and firefighting needs. Their distinct shape provides several structural advantages, making them a popular choice in water storage systems. Here's an overview of circular water tanks and the key structural considerations associated with their design:

Shape and Properties

Circular water tanks are characterized by their cylindrical shape, which offers inherent structural stability. The symmetrical design ensures uniform distribution of forces and stresses, contributing to enhanced load-bearing capacity and resilience against external pressures.

Figure 2 Cylindrical Shape

Structural Considerations

Designing circular water tanks involves several critical considerations to ensure their structural integrity, durability, and operational efficiency:

- Material Selection: The choice of construction material, such as reinforced concrete or steel, is essential in determining the tank's strength and durability. Engineers consider factors like corrosion resistance, cost-effectiveness, and the tank's intended service life.
- Foundation Design: Proper foundation design is crucial to distribute the tank's weight evenly and prevent settlement. Soil characteristics, bearing capacity, and potential for settlement under varying loads are assessed to ensure stable support.
- Hydraulic Loadings: Circular tanks experience hydraulic loads due to the weight of stored water, which can be substantial. Engineers must calculate the hydrostatic pressure and ensure that the tank walls, base, and foundation can withstand these loads without deformation or failure.
- Seismic Resilience: Circular water tanks located in earthquake-prone regions must be designed to withstand seismic forces. Engineers analyze the tank's response to ground motion, considering factors like the seismic zone, soil conditions, and potential ground acceleration.
- Wind Loads: Circular tanks are exposed to wind forces, especially when located in open areas. Engineers evaluate wind speed, local topography, and building height to calculate wind loads and ensure structural stability.
- Stress Distribution: The cylindrical shape of these tanks results in consistent stress distribution along the wall and base. Engineers analyze hoop stress (circumferential stress), axial stress (parallel to the tank's axis), and radial stress (perpendicular to the symmetry axis) to ensure they remain within safe limits.
- Design Codes and Standards: Circular water tanks must adhere to relevant design codes and standards that govern construction practices, material specifications, and safety factors. Codes like IS 3370 (Part II) and IS 456 provide guidelines for designing water-retaining structures.
- Waterproofing: To prevent leakage and maintain water quality, proper waterproofing methods are crucial. Engineers must ensure that the tank's walls and base are effectively sealed to prevent water infiltration and potential structural damage.
- Accessories and Appurtenances: Design considerations also extend to tank accessories and appurtenances, such as inlets, outlets, valves, and overflow provisions, which must be integrated into the tank's design without compromising its structural integrity.

C. Significance of Seismic Analysis and Design

Seismic analysis and design hold immense significance in the realm of civil and structural engineering, particularly in regions prone to earthquakes. The process involves assessing the potential impact of seismic forces on structures and designing them to withstand these forces. The significance of seismic analysis and design can be understood through several key points:

- Safety of Structures and Lives: The primary goal of seismic analysis and design is to ensure the safety of structures and the people who inhabit or use them. Earthquakes can exert tremendous forces on buildings, bridges, dams, and other infrastructure, leading to catastrophic failures if not properly accounted for in design. Seismic-resistant structures can minimize the risk of collapse and prevent loss of life during earthquakes.
- Protection of Property: Beyond human safety, seismic analysis and design also protect property and assets. Buildings, facilities, and infrastructure represent substantial investments, and their failure during an earthquake can result in significant financial losses. Proper seismic design helps minimize damage, repair costs, and business interruptions.
- Resilience of Infrastructure: Seismic analysis and design contribute to the resilience of infrastructure. By considering seismic forces, engineers create structures that can withstand the impact of earthquakes and continue to function afterward. This is especially crucial for critical facilities like hospitals, emergency response centers, and water supply systems that need to remain operational during and after disasters.
- Legal and Regulatory Compliance: Many regions have building codes and regulations that mandate seismic-resistant design for certain structures. Compliance with these regulations is not only a legal requirement but also ensures that structures are designed to withstand the potential seismic forces in the area, reducing vulnerability and liability.
- Long-Term Durability: Seismic analysis and design also contribute to the long-term durability of structures. By accounting for seismic forces, engineers prevent premature wear and tear, ensuring that structures remain functional and safe for extended periods. This longevity reduces the need for frequent repairs and replacements.

II. LITERATURE REVIEW

Z Yang et. al. [1] In this study, the impact of different water tank shapes on thermal energy storage capacity and thermal stratification in static laminar natural convection conditions is investigated. The research utilizes a newly constructed experimental setup and a numerical model to simulate heat transfer and fluid flow within the water tank. Computational simulations align closely with experimental data. Among the ten water tank shapes analyzed, spherical and barrel-shaped tanks exhibit optimal thermal energy storage capacities, while cylindrical tanks are least favorable. The storage capacity is closely tied to the tank's surface area. Based on velocity and temperature field characteristics, the shapes are categorized into three groups: those with sharp corners, hemispherical shapes, and horizontal plane surfaces. Sharp-cornered shapes show the highest degree of thermal stratification, while horizontal plane surfaces exhibit the lowest. Hemispherical shapes lie in between. The thermal stratification patterns are influenced by the flow at the tank's bottom and heat transfer to the environment.

AE Kabeel et. al. [2] This study focuses on enhancing the performance of pyramid solar stills through additional components. Circular copper fins and a phase change material (PCM) tank are integrated into the conventional pyramid solar still design to prolong water production after sunset. Comparative experiments are conducted on three setups: conventional pyramid solar still, pyramid solar still with hollow circular fins, and pyramid solar still with fins and PCM. The results reveal that the utilization of hollow circular fins increases daily productivity by 43%, while adding PCM further enhances it by 101.5%. The modified pyramid solar still outperforms previous designs in terms of productivity and efficiency.

H Huang et. al. [3] This paper proposes a system combining phase change material (PCM) thermal storage with a water tank for solar heating systems. The system's configuration and a composite PCM are investigated for their impact on efficiency. A system model is developed using TRNSYS software, and a numerical calculation program is compiled to account for supercooling in the PCM unit. The study identifies optimal PCM parameters through simulations, ultimately selecting sodium acetate trihydrate mixtures as the PCM. The combined use of the PCM unit and water tank improves the heat storage system's efficiency, increasing the solar fraction by around 30% compared to a single water tank system. Furthermore, the series system demonstrates a 5%-12% enhancement in solar fraction compared to a parallel water tank-PCM unit system.

A Dahash et. al. [4] Large-scale seasonal thermal energy storage (TES) is a promising component in future renewable-based district heating systems. Simulation-driven assessments are crucial to design and plan such systems efficiently. This work reviews the development and validation of numerical models for advanced TES applications, considering multi-physical aspects and dynamic energy flows.

MY Abdelsalam et. al. [5] A numerical model is developed to simulate the performance of sensible and hybrid energy storage integrated into solar domestic hot water systems. The study explores direct and indirect heat exchange configurations. Comparisons based on solar fraction, indicating solar thermal energy contribution to the load, are made between both systems. Direct heat exchange systems exhibit larger solar fractions, and adding phase change material modules to the water tank can reduce storage volume by 40%. The choice of PCM melting temperature is vital for optimal energy storage in the latent form and temperature stability.

ST Summerfelt et. al. [6] This study involves a comprehensive survey conducted to investigate the characteristics of large circular or octagonal culture tanks used in the production of Atlantic salmon smolt and post-smolt by major Norwegian salmon production companies. The survey covers various aspects, including tank geometry, operating parameters, and other key features. The research focuses on both land-based hatchery locations and sea-based tanks. The results reveal that a total of 55 large tanks were reported at seven land-based sites, averaging around 7.9 tanks per site. The culture volume of these tanks ranged from 500 to 1300 m3, and they exhibited diverse dimensions and flow rates. The study highlights trends such as tank diameters, maximum depths, flow rates, hydraulic retention times, and feed loads, providing insights into the evolution of tank designs and their operational aspects.

M Shan et. al. [7] The pursuit of energy efficiency has led to the promotion of solar energy heating systems in China. In an effort to overcome challenges faced by these systems, an integrated space heating system incorporating passive sunspace, active solar water heating, and air-source heat pump (ASHP) was developed and tested in a cold climate zone. This study analyzes the performance of each subsystem within this integrated system and evaluates its efficiency in maintaining a stable indoor thermal environment during winter. Notably, the integrated system showed promising results in terms of energy consumption and thermal comfort. However, the study also identified certain limitations and proposed recommendations to optimize the system's performance. The research emphasizes the potential of such integrated systems for energy savings and emission reductions in rural buildings, contributing to broader energy targets.

C Makropoulos et. al. [8] The escalating issue of water scarcity due to urbanization and climate variability has prompted societies to explore water reuse as a solution. This paper delves into the ongoing discourse between centralized and decentralized water reuse methods, considering efficiency and economic viability. The concept of 'sewer-mining' emerges as an intermediate scale water reuse option, demonstrating potential benefits in problematic wastewater treatment plant locations and involving Small Medium Enterprises (SME) in the water market. The study presents a pilot sewer-mining application in Athens, Greece, integrating treatment technologies and an information and communications technology (ICT) infrastructure. The results highlight the performance of the pilot and underline the potential of sewer-mining as a significant component of the circular economy for water.

K Shubhangi et. al. [9] The profound significance of water is evident from the historical settlements around water sources, often characterized by architectural marvels such as step wells. This paper focuses on the exemplary step wells found in the region of Chanderi town, Madhya Pradesh, India. These step wells, dating back several centuries, continue to serve their original purpose of water collection and storage. The paper emphasizes the architectural and aesthetic significance of these structures, highlighting their cultural, functional, and recreational value. The unique relationship between water and architectural typologies is showcased through the examples from Chanderi, showcasing the remarkable contributions of Indian Water Architecture.

H Yuk et. al. [10] Sea animals like leptocephali possess transparent hydrogels in their tissues, allowing for agile movement and natural camouflage underwater. This study introduces hydrogel-based actuators inspired by leptocephali, capable of high-speed, high-force actions, and optical and sonic camouflage in water. Unlike existing osmotic-driven hydrogel actuators, these hydraulic actuators exhibit exceptional performance and robustness, even maintaining functionality over multiple actuation cycles. The study presents innovative applications of these agile and transparent hydrogel actuators, showcasing their capabilities in swimming, interacting with objects, and even catching live fish underwater. This research demonstrates the potential of these hydrogel actuators for diverse fields..

III. OBJECTIVES

Objectives of the Research

- To study the behaviour of circular underground water tank for different parameter
- Comparison results of behaviour of underground circular water tank with Seismic load and load applied on the structure for two different Zone iv and iii and different parameter with soft soil.
- To study the behaviour of base shear, shear forces, axial force and displacement.

IV. METHODOLOGY

This studies is targeted towards presenting the parametric evaluation of circular under ground water tank considering seismic zones of iv and soil type -soft to recognize the behaviour of the structure while dead load, live load and seismic load are carried out at the structure. The modelling and analysis are completed using staad. pro software program.

Geometrical Specifications for circular water tank for model 1(d=8.73m)

Table 1 Geometrical Specifications of the Structure

Geometrical Specification	
Component	Size
Shape of tank	Circular tank
Capacity of tank	300000 litre
Diameter of tank	8.74m
Height of tank	5m
No of bays	8
No of circular bays	20
Plate Thickness	2m
Free Board	400mm
Bearing capacity of soil	300KN/m2
Soil density	18KN/m2
Water density	10
Grade of concrete	M30
Grade of steel	415

The "Geometrical Specification" provided offers a comprehensive insight into the essential characteristics and dimensions of a circular water tank, crucial for its successful design and construction. Configured in a circular shape, the tank is optimized for efficient water storage and distribution, ensuring uniform stress distribution and structural stability. With a substantial capacity of 300,000 liters, the tank can cater to a wide array of applications ranging from domestic usage to industrial processes and emergency water supply. Its diameter of 8.74 meters defines its width, while a height of 5 meters determines the vertical water storage capacity. Divided into 8 bays and further subdivided into 20 circular sections, the tank's geometry allows for efficient construction and maintenance. The 200mm plate thickness guarantees structural integrity and prevents leakage, while a freeboard of 400mm acts as a safeguard against overflowing. Grounded on soil with a bearing capacity of 300 kilonewtons per square meter and a soil density of 18 kilonewtons per cubic meter, the tank's foundation aligns with its load-bearing requirements. Water density at 10 kilonewtons per cubic meter, along with the use of M30 grade concrete and 415-grade steel, collectively contribute to the tank's robustness, durability, and functionality.

These specifications collectively underpin the tank's design, ensuring it meets safety standards, accommodates its intended capacity, and withstands operational demands.

Properties of Seismic

Table 2 Properties of Seismic

Properties of Seismic	
Zone Factor (z)	0.24 and 0.16
Importance Factor (I)	1.5
Response Reduction Factor	3
Soil type	Soft
Damping Factor	0.05

Steps of the Modelling and Analysis for circular water tank

STEP 1 Research paper from different authors is summarized in this section who have focused towards Analyzing the water tank structure considering seismic loads with zones iii and iv and soft soil.

STEP 2 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. Here in this case, 20 bays in considered in along circular bays and 8 bays in considered in along width. structure is considered with diameter of tank is 8.73m , height of the tank is 5m.

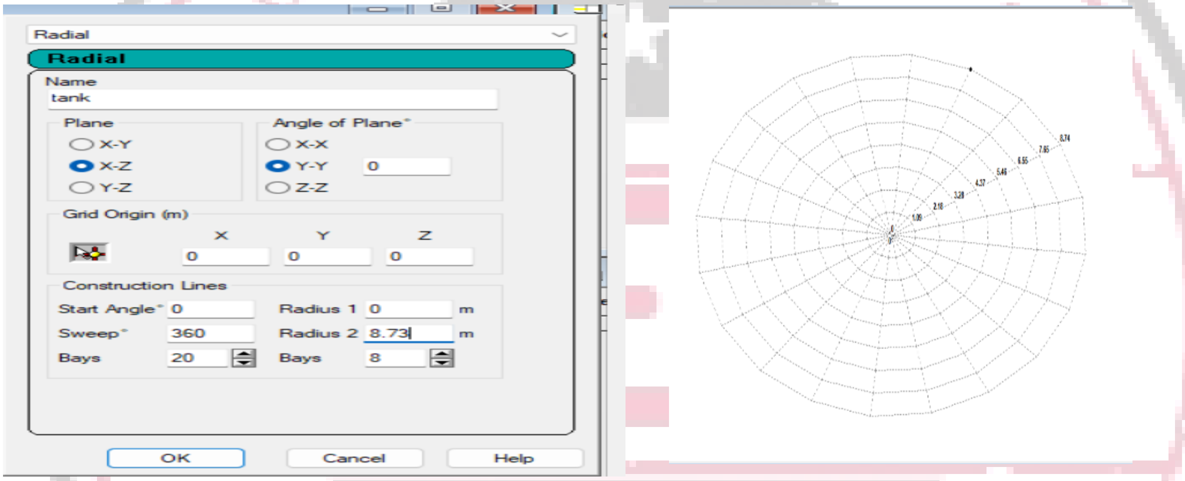


Figure 3 Property defining of circular water tank in staad pro

Step-3: Property Definition: Using General-Property command define the property as per size requirement to the respective Structure on staad-Pro. So, thickness of plate have been generated after assigning to selected plate.

Defining section properties for plate, size of plate thickness 2m, is considered in the study.

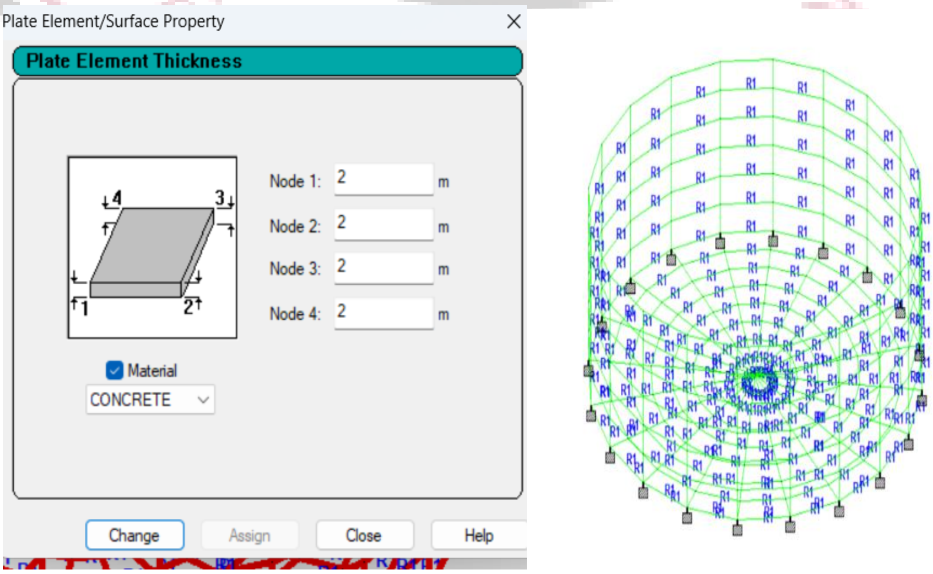


Figure 4 Property defining of thickness of plate element

Step 5 Defining Load

Step 5 Defining Load cases for dead load, live load and seismic analysis

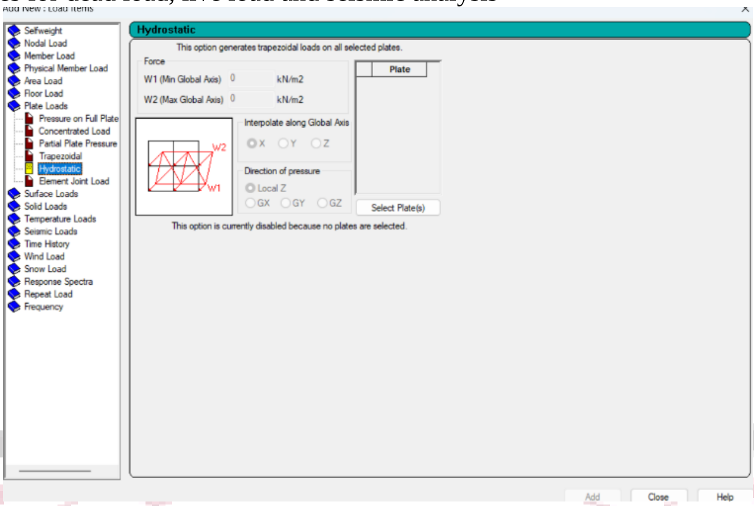


Figure 5 Defining hydrostatic pressure

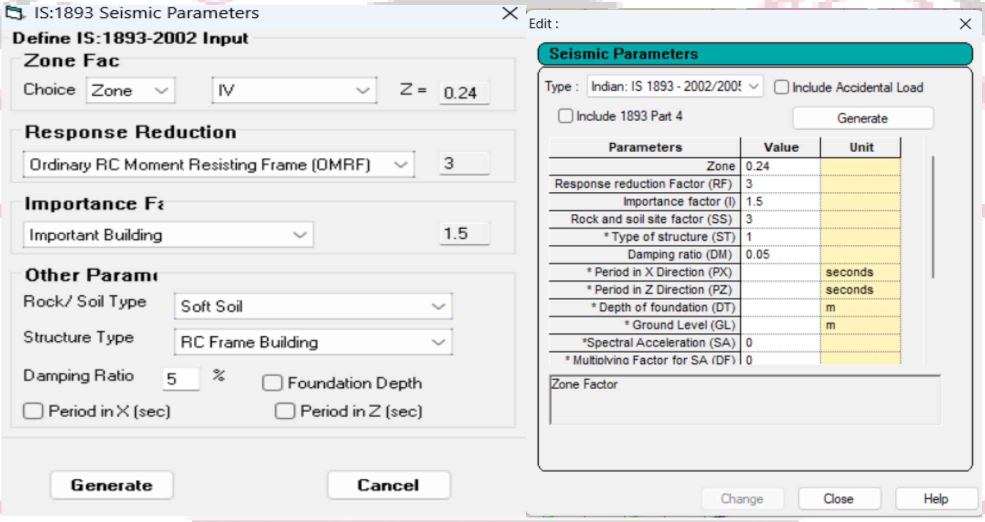


Figure 6 Defining Seismic Analysis as per IS 1893-2002 For Soft soil for zone iv

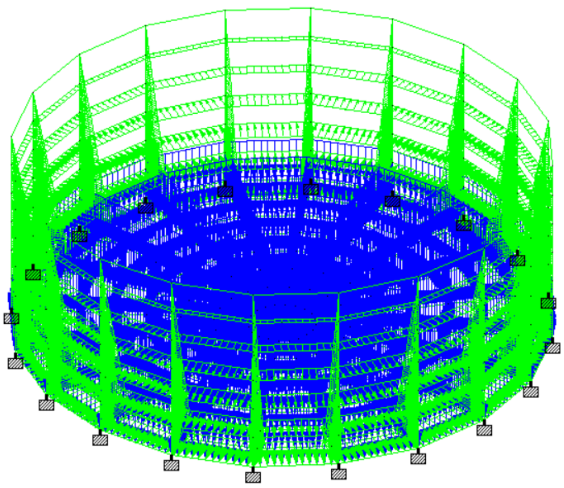


Figure 7 Defining surface pressure

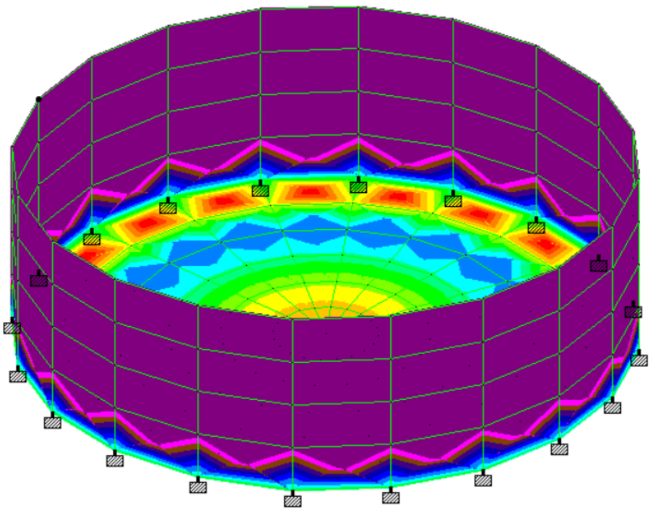


Figure 8 Load on plate due to dead and live load

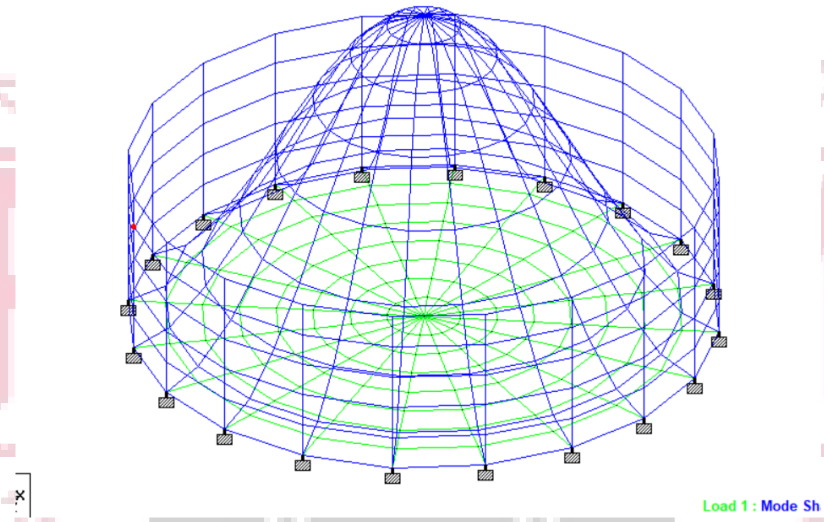


Figure 9 Displacement in water tank structure

RESULTS AND DISCUSSION

General

The comparative study of base shear, maximum shear force ,maximum axial force and displacement of response spectrum analysis is performed. The results obtained from analysis are given below and comparative study is carried out which is stated below.

Results for model 1 (d=8.75) in zone III and IV

Results of shear force for model 1 in zone III and zone IV

shear force

Table 3 Maximum value of shear force

SR. NO	Condition of water tank	Types of Zones	Shear force in KN
1	Empty	ZONE III	207
		ZONE IV	325
2	Full	ZONE III	233
		ZONE IV	520

Results of axial force for model 1 in zone III and zone IV

Axial force

Table 4 Maximum value of axial force

SR . NO	Condition of water tank	Types of model	Axial force in KN
1	Empty	ZONE III	1198
		ZONE IV	1200
2	Full	ZONE III	1198
		ZONE IV	1198

Results of base shear for model 1 in zone III and zone IV

Base shear

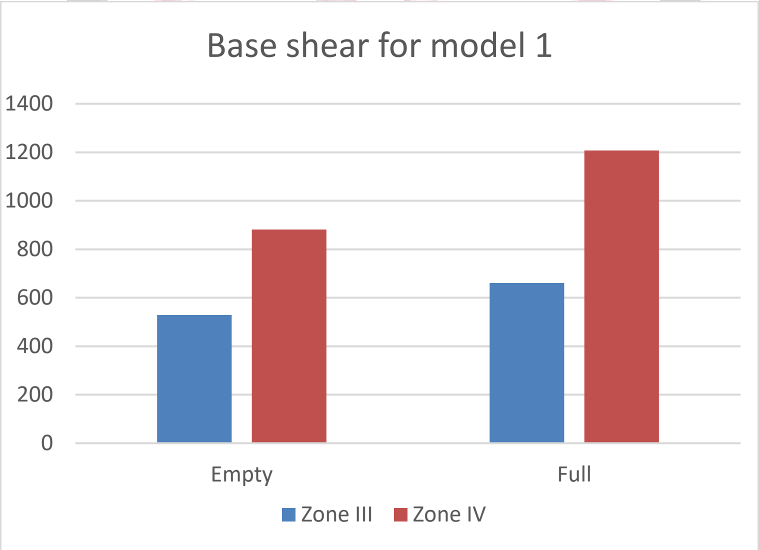


Figure 10 Base shear for model 1 in zone III and IV

Results of displacement for model 1 in zone III and zone IV

displacement

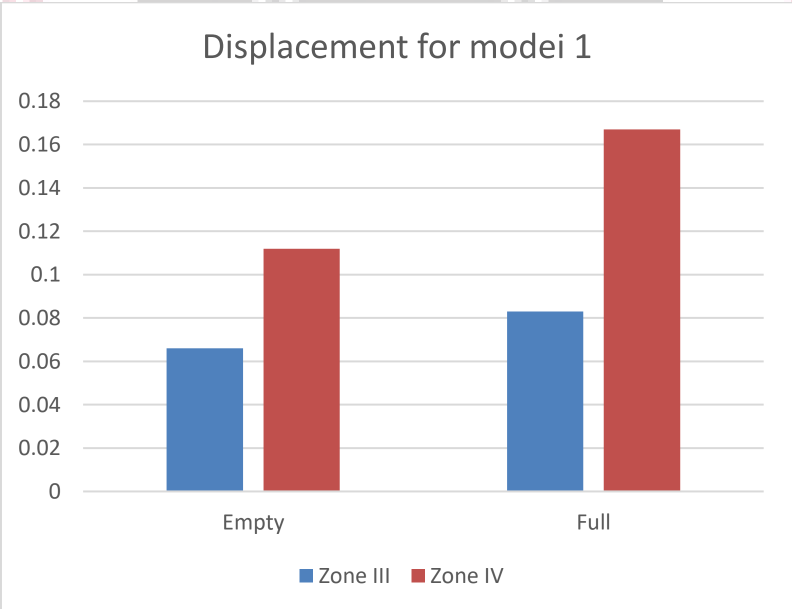


Figure 11 Displacement for model 1 in zone III and IV

Results for model 2 (d=7.12m) in zone III and IV

Results of shear force for model 2 in zone III and zone IV

shear force

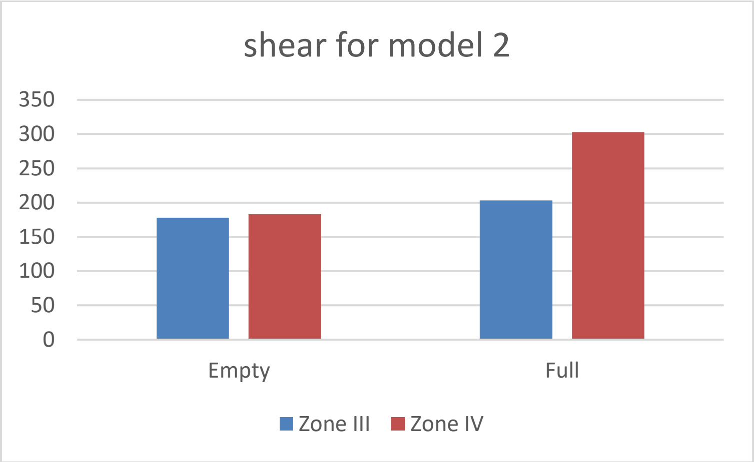


Figure 12 Shear force for model 2 in zone III and IV

Results of axial force for model 1 in zone III and zone IV

Axial force

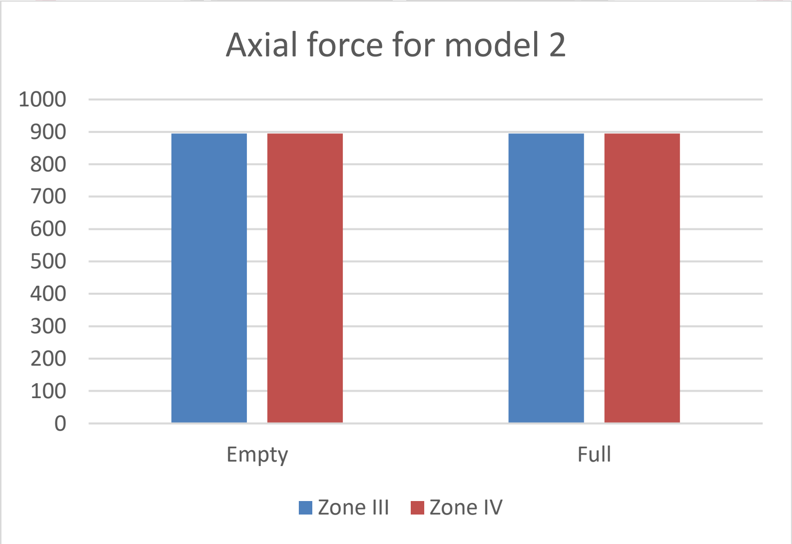


Figure 13 Axial force for model 2 in zone III and IV

4.3.3 Results of base shear for model 1 in zone III and zone IV

Base shear

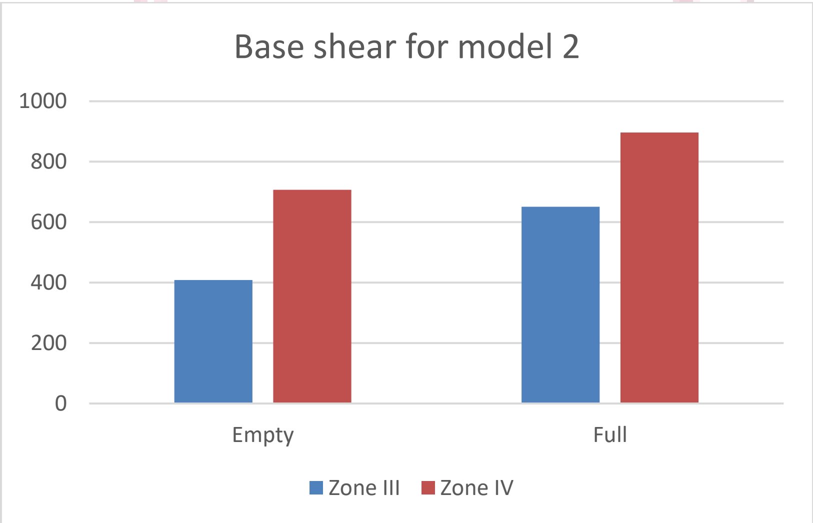


Figure 14 Base shear for model 2 in zone III and IV

Results of displacement for model 1 in zone III and zone IV

displacement

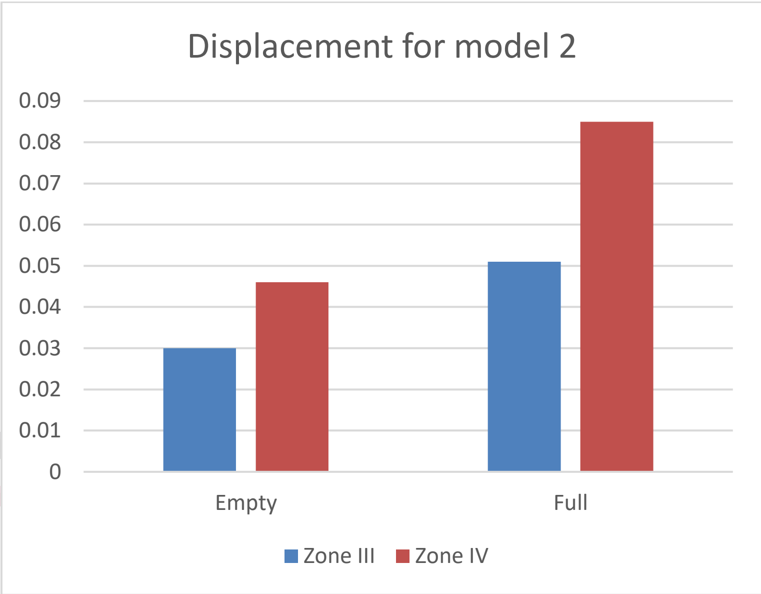


Figure 15 Displacement for model 2 in zone III and IV

Comparatively Results of shear force, axial force, base shear and displacement for model 1 in zone III and IV.

Comparatively Results of shear force, axial force, base shear and displacement for model 1 in zone III
Comparatively Results for model 1 in zone III

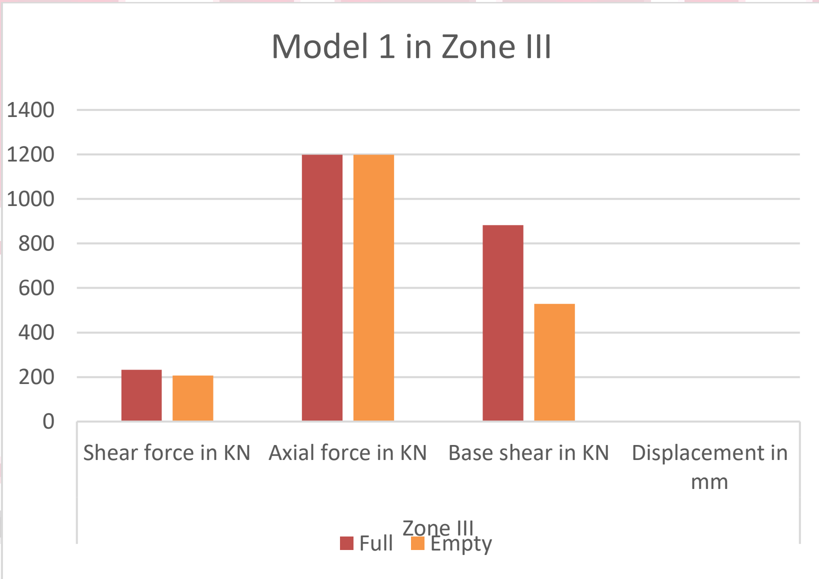


Figure 16 Comparatively Results for model 1 in zone III

Comparatively Results of shear force, axial force, base shear and displacement for model 1 in zone IV
Comparatively Results for model 1 in zone IV

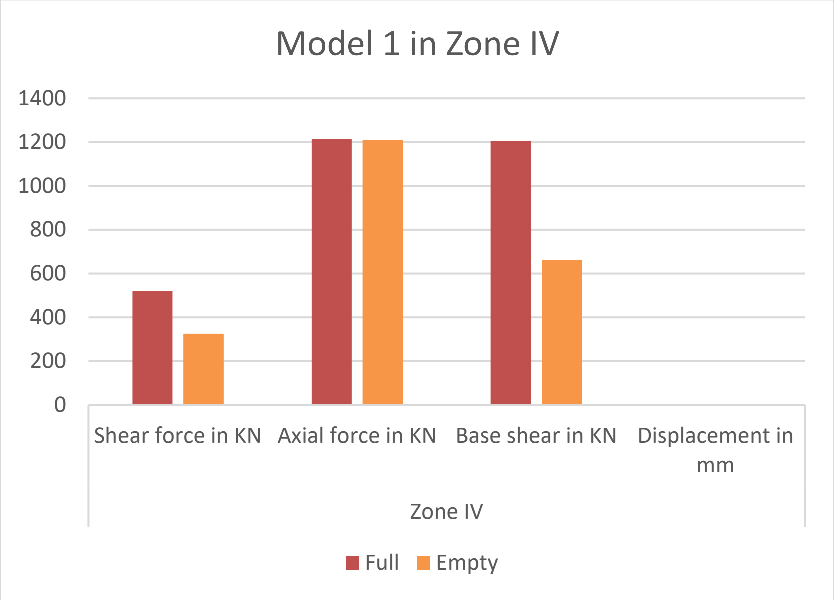


Figure 17 Comparatively Results for model 1 in zone IV

Comparatively Results of shear force, axial force, base shear and displacement for model 2 in zone III and IV.
Comparatively Results of shear force, axial force, base shear and displacement for model 2 in zone III

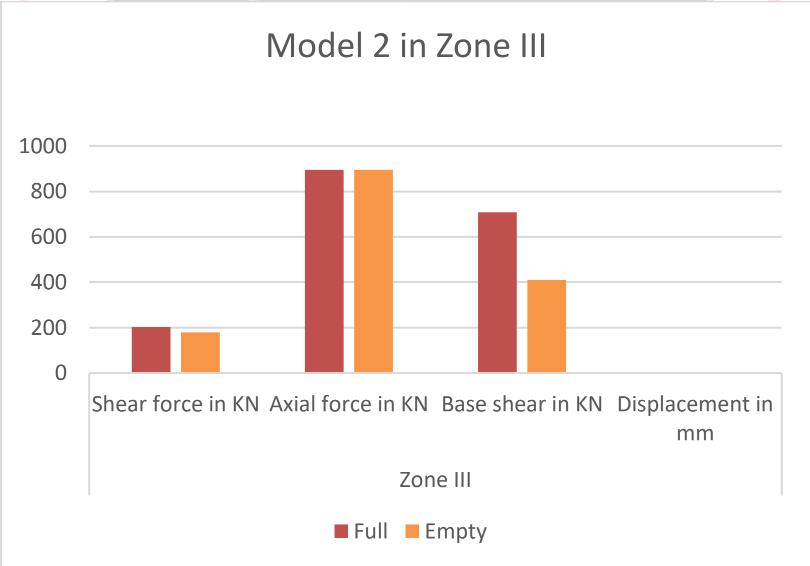


Figure 18 Comparatively Results for model 2 in zone III

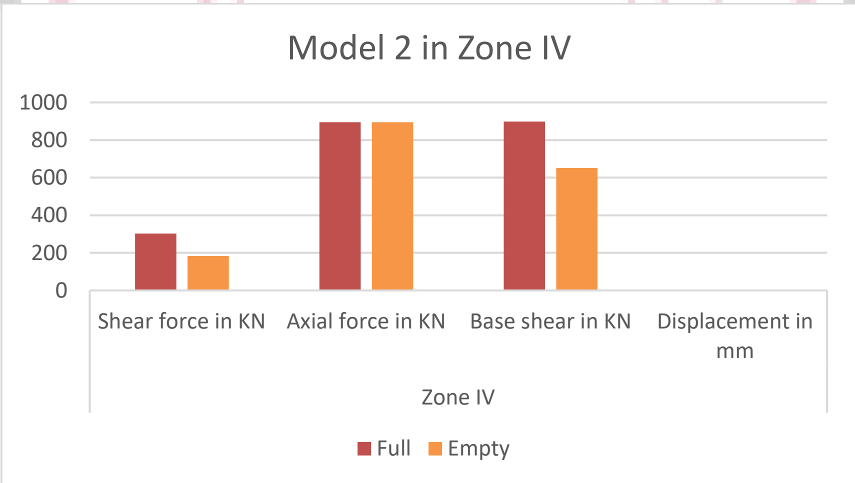


Figure 19 Comparatively Results for model 2 in zone IV

V. CONCLUSION

The research conducted on RCC Circular Underground Water Tanks underscores their crucial role in modern water distribution systems, demonstrating their structural efficiency and resilience. The cylindrical design offers significant advantages in stress distribution, making these tanks highly suitable for areas prone to seismic activity. The comprehensive analysis, including seismic considerations and load-bearing capacities, provides valuable insights into their robustness. These findings are instrumental for engineers and urban planners in designing and implementing effective water storage solutions. The study not only highlights the technical aspects but also emphasizes the broader impact of these tanks in ensuring reliable water supply and contributing to sustainable urban infrastructure. Overall, the research contributes significantly to the field of structural engineering and water management, paving the way for more resilient and efficient water storage systems.

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