COMPARISION BETWEEN DESIGN AND ANALYSIS OF ECONOMICAL CIRCULAR AND RECTANGULAR ELEVATED WATER TANK IN DIFFERENT SEISMIC ZONE USING STAAD PRO SOFTWARE.

DEEPAK SINGH[1], RAKESH GROVER[2]

[1]PG STUDENT, MASTER OF ENGINEERING, CIVIL ENGINEERING, JABALPUR ENGINEERING COLLEGE, JABALPUR

[2]ASSOCIATE PROFESSOR, DEPARTMENT OF CIVIL ENGINEERING, JABALPUR ENGINEERING COLLEGE, JABALPUR

Abstract.-

Every design comes out when there is a problem. A design is created to solve the existing problems. People in the region where there is scarcity of water, to get enough flow or speed or discharge especially those living on the upper floors in a multi-storied building. As a consequence people suffer from lack of water due to insufficient supply for compensating their daily needs. As a first solution of this problem, one needs to develop a water storage project as has been designed with the help of STAAD principles, known as Overhead Water Reservoir. The present study gives the comparison between design and analysis of economical circular and rectangular elevated water tank using STAAD.Pro Connect edition. The design involves load calculations analyzing the whole structure by STAAD.Pro Connect Edition.

Keywords: Structural Framing Model, Analysis & Design of Structure, Seismic Analysis, Quantity, Axial force and Moments.

I. INTRODUCTION

Safe drinking water is one of the basic elements for humans to sustain healthy life. Reinforced concrete overhead water tanks are widely used to provide the safe drinking water. Most water supply systems in developing countries, such as India, where urbanizing is increasing day by day rely on overhead storage tanks and hence there is need to construct more number of water tanks. Earlier design of water tanks was being done using the working stress method given in IS code. This method leads to thicker and heavily reinforced sections. This study is carried out to analyze the cost of overhead water tanks of varying capacities and having different shapes so as to determine the most economical shape of the tank. This will help the designers in making the choice for their design.

II. AN ELEVATED WATER TANK

An elevated water tank is a structure designed to store water at a height above ground level to create sufficient pressure for the distribution of water through pipelines. These tanks are typically constructed using materials like steel, concrete, or fiberglass and are supported by towers, columns, or pedestals. By utilizing the force of gravity, elevated water tanks ensure a consistent water flow and pressure without relying heavily on mechanical pumps. They are commonly used in municipal water supply systems, industrial facilities, and agricultural irrigation to meet demand during peak usage and provide a backup water supply in emergencies. Their height and capacity are engineered based on the specific requirements of the area they serve.

III. CIRCULAR ELEVATED WATER TANK

A circular elevated water tank is a type of water storage structure designed with a cylindrical shape and elevated above ground level to ensure efficient water distribution through gravity. The circular design is widely preferred due to its structural efficiency, as the shape evenly distributes pressure from the stored water, reducing stress on the walls and minimizing material usage. Typically constructed from materials like reinforced concrete or steel, these tanks are supported by columns, pedestals, or towers. The tank's height and capacity are engineered to meet the specific water demand and pressure requirements of the supply area. Circular elevated water tanks are commonly used in municipal, industrial, and agricultural applications, providing a reliable water supply while ensuring durability and ease of maintenance.

Generally circular tank rest on the ground or are elevated ones. Underground circular tanks are also constructed. The circular tanks may be designed either with flexible base connection with wall or with rigid connection between walls and base, in the former case the expansion and contraction of side walls are possible but in latter case the walls are monolithic with base. The walls of tank are subjected to hydrostatic pressure which is maximum at base and zero at top. Usually for design of circular tanks, the theory of thin cylinders is applied for design of wall thickness and for calculation of maximum hoop tension. The main reinforcement consists of circular hoops to take care of hoop tension and is placed on both faces and wall. The distribution steel is placed vertically and is tied to main reinforcement.

IV. RECTANGULAR TANK

For smaller capacities circular tanks are uneconomical and their form work is costly. Rectangular tanks are constructed when small capacity tank are required. These may be resting on ground, elevated or underground. Tanks should be preferably square in plan and it is desirable that larger side should not be greater than twice the smaller side and for rectangular tanks. Walls of tanks either resting on ground or elevated are subjected to water pressure from inside and when underground they are subjected to internal water pressure and outside earth pressure. In rectangular tanks the moments are caused in two directions, hence exact analysis is rather difficult, they are designed by approximate methods.

V. ECONOMICAL COST ESTIMATION

The cost estimation of an elevated water tank involves assessing various factors to determine the total project cost. Key components include the tank's capacity, height, and material, as these significantly influence the design and construction expenses. Material costs, such as reinforced concrete, steel, or composite materials, account for a substantial portion of the budget. Additional factors include site preparation, foundation construction, and labor costs, which vary depending on the soil condition and local labor rates. Other expenses include the installation of inlet and outlet pipes, overflow systems, water level indicators, and safety features like ladders and railings. Provisions for corrosion protection, seismic resistance, and wind load considerations may further add to the cost. Moreover, design fees, permits, testing, and commissioning expenses are also included. On average, the total cost can range widely depending on location, tank size, and complexity, requiring a detailed analysis to provide an accurate estimation tailored to specific project needs.

VI. PROCEDURE FOR DESIGNING AN ECONOMICAL ELEVATED WATER TANK

1. Identify Requirements:

- **Purpose:** Define the purpose of the water tank (e.g., municipal supply, industrial use, irrigation).
- **Capacity:** Estimate the water demand and calculate the storage capacity needed based on the daily consumption and emergency reserve requirements.
- **Pressure Requirements:** Determine the minimum height required to achieve desired water pressure in the distribution network.

2. Site Selection:

- **Location:** Choose a strategic location considering proximity to the water source, distribution area, and elevation of the terrain.
- **Soil Testing:** Conduct a geotechnical investigation to assess soil strength and stability to support the tank and its foundation.
- **Accessibility:** Ensure the site is accessible for construction, maintenance, and operation.

3. Structural Design:

- **Type of Tank:** Decide on the type of elevated tank (e.g., column-supported, pedestal, or tower tank) based on cost, capacity, and site conditions.
- **Material Selection:** Choose appropriate materials like reinforced concrete, steel, or composite materials based on durability, climate, and budget.
- **Shape:** Select the tank shape (cylindrical, spherical, or rectangular) for structural efficiency and ease of maintenance.
- **Height:** Design the height of the tank to meet the pressure requirements for the water distribution system.

The impact of different seismic zones

The impact of different seismic zones on elevated water tanks is critical to their structural safety, as these zones dictate the level of earthquake forces the tank must withstand. Seismic zones are classified based on the intensity and frequency of earthquakes in a region, and the design of elevated water tanks must account for these variations. Here’s how seismic zones impact elevated water tanks:

1. Increased Design Loads in High-Seismic Zones:

- **Impact:** Elevated water tanks in higher seismic zones (e.g., Zone IV or V in regions like India) experience greater seismic forces due to stronger ground motions.
- **Considerations:**
  - Tanks are designed to withstand higher base shear forces and overturning moments.
  - Reinforced concrete or steel structures must be used to handle dynamic loads.
  - Additional bracing or dampers may be incorporated to minimize vibrations.

2. Dynamic Behavior of Water:

- **Impact:** The water inside the tank contributes to seismic forces due to the "sloshing effect." In high-seismic zones, this dynamic behavior becomes more pronounced and can lead to structural instability.
- **Considerations:**
  - The tank's shape (circular tank better resist seismic loads) and height are optimized to minimize sloshing.
  - Designers use seismic analysis tools to model water movement and its impact on the structure.

3. Zone-Specific Seismic Coefficients:

- **Impact:** Seismic zones are assigned coefficients that influence the design forces (e.g., Zone III has lower coefficients compared to Zone V).
- **Considerations:**
  - Designers calculate forces based on the seismic coefficient, the tank’s weight (including water), and the height of the center of gravity.
  - High zones require higher safety margins, leading to increased material usage and cost.

The seismic zone significantly influences the design, material selection, and construction of elevated water tanks. In high-seismic zones, the focus is on enhancing structural stability, mitigating sloshing effects, and ensuring foundations can absorb seismic forces. Adhering to seismic design codes is essential to safeguard the tank, its surroundings, and the critical water supply system during earthquakes.

VII. ANALYSIS STAAD.PRO SOFTWARE

Staad.Pro is powerful design software licensed by Bentley. Staad stands for structural analysis and design. Any object which is stable under a given loading can be considered as structure. So first find the outline of the structure, whereas analysis is the estimation of what are the type of loads that acts on the beam and calculation of shear force and bending moment comes under analysis stage. Design phase is designing the type of materials and its dimensions to resist the load. This we do after the analysis. To calculate S.F.D and B.M.D of a complex loading beam it takes about an hour. So when it comes into the building with several members it will take a week. Staad pro is a very powerful tool which does this job in just an hour's staad pro is a best alternative for high rise buildings. Now a day's most of the high rise buildings are designed by staad pro which makes a compulsion for a civil engineer to know about this software. This software can be used to carry R. C. C, steel, bridge, truss etc., according to various country codes.

STAAD PRO has a state of art user interface, tools for visualization, well-built analysis and design software with advance finite element and capable of dynamic analysis. From model production, analysis and design to visualizing and verifying results tools. STAAD.PRO is a common choice for steel, concrete, aluminum and cold formed steel multiple-storey buildings, factories, tunnels, bridges and much more. The objective of the design is to achieve an acceptable possibility that the constructed structures will function satisfactorily during their life span. The results of these analyses generally include supportive responses, stress and movement. This information is then analyzed using criteria that indicate failure conditions. The purpose of the design is to achieve an acceptable possibility that the constructed structures will operate satisfactorily over their lifetime.

Procedure to be followed to design the structure

- Structural planning
- Loads computation
- Analysis method
- Design of members and detailing, etc.

Objectives-

Computer aided analysis and design of tank structure by using STAAD PRO

- Structural framing plan
- Model of structure in STAAD.PRO CONNET EDITION V22.
- Applications of various load combinations on vertical and horizontal members.
- Analysis of the structure Concrete quantity (cum), Steel quantity (kn) and Max axial forces (kn).
- Design of the structure

VIII. PROPOSED ANALYSIS STEPS

Elevated Water Tank Analysis:

1. **Define Structure Geometry:**
   - Model the tank, including the walls, base slab, columns, and foundation.
2. **Input Material Properties:**
   - Assign properties for reinforced concrete or steel.
3. **Apply Loads:**
   - Include dead load (self-weight), live load (water weight), wind load, seismic load, and hydrostatic/dynamic forces.
4. **Set Support Conditions:**
   - Define the foundation type (fixed, pinned, or spring supports).
5. **Run Analysis:**
   - Perform structural analysis to determine displacements, forces, stresses, and moments.
6. **Design Checks:**
   - Verify reinforcement, section strength, and compliance with seismic and wind codes.
7. **Optimize and Validate:**
   - Adjust the design for performance and cost-efficiency, and validate results against standards.
8. **Generate Reports:**
   - Export analysis results and structural drawings for implementation.

IX. SECTION DETAILS

Table 1:- Properties.

S.No.	Structure Components	Value
1	Concrete	M-30
2	Reinforcement	Fe-500
3	Zone	III/IV/V
4	Response Reduction Factor	5(SMRF)
5	Importance Factor	1.5
6	Type of Soil	Medium Soil

Table 2:- Geometry Data.

	Rectangular Data		Circular Data	
Type of Data	**Value**	**unit**	**Value**	**unit**
Volume	250	kl	250	kl
Length/Diameter	7	mtr	7	mtr
Width	6	mtr	0	mtr
Height	6	mtr	6.5	mtr

Table 3:- Rectangular Section Data.

	Rectangular Section Data	All Units in Meter		
S No.	Structure Components	Zone III	Zone IV	Zone V
1	Size of Bracing Beam	0.60x0.30	0.60x0.4	0.60x0.55
2	Size of Top Beam	0.30x0.30	0.30x0.30	0.30x0.30
3	Size of Column	0.38x0.30	0.45x0.38	0.60x0.30
4	Thickness of Base slab	0.25	0.3	0.4
5	Thickness of Side Wall	0.25	0.3	0.4
6	Height b/w Bracings	3	3	3

Table 4:- Circular Section Data.

	Circular Section Data	All Units in Meter		
S No.	Structure Components	Zone III	Zone IV	Zone V
1	Size of Bracing Beam	0.60x0.30	0.60x0.4	0.60x0.55
2	Size of Top Beam	0.30x0.30	0.30x0.30	0.30x0.30
3	Size of Column	0.40 m	0.5 m	0.60 m
4	Thickness of Base slab	0.25	0.3	0.4
5	Thickness of Side Wall	0.25	0.3	0.4
6	Height b/w Bracings	3	3	3

X. RESULTS AND ANALYSIS

STAAD.Pro is a powerful structural analysis and design software widely used for analyzing elevated water tanks. It allows engineers to model the geometry of the tank, including its walls, base slab, supporting columns, and foundation. The software enables the application of various loading conditions, such as dead loads (self-weight of the tank and structure), live loads (water weight), wind loads, and seismic forces, based on regional design codes like IS 1893-2016 and IS 456. STAAD.Pro also supports the analysis of dynamic effects such as sloshing forces due to seismic activity. After running the analysis, it provides detailed results, including stress distributions, bending moments, shear forces, and support reactions. Engineers can use these outputs to check structural safety, optimize material usage, and ensure compliance with design standards. STAAD.Pro streamlines the process of designing elevated water tanks, ensuring their stability, durability, and efficiency under various loading scenarios.

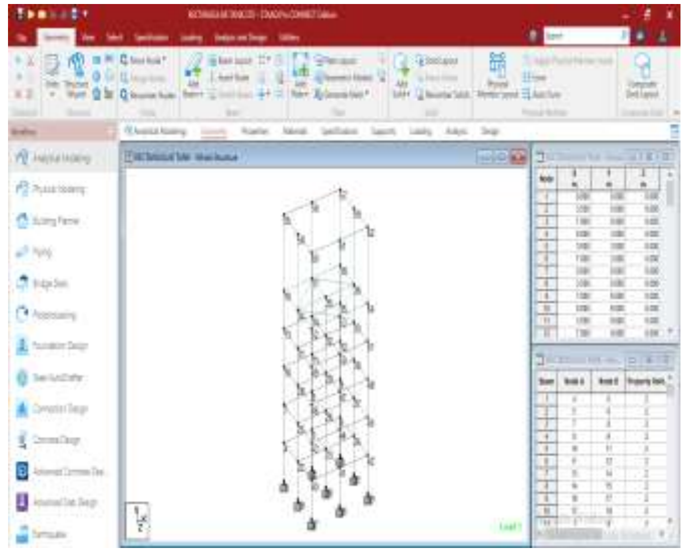

Fig.1. Rectangular tank.

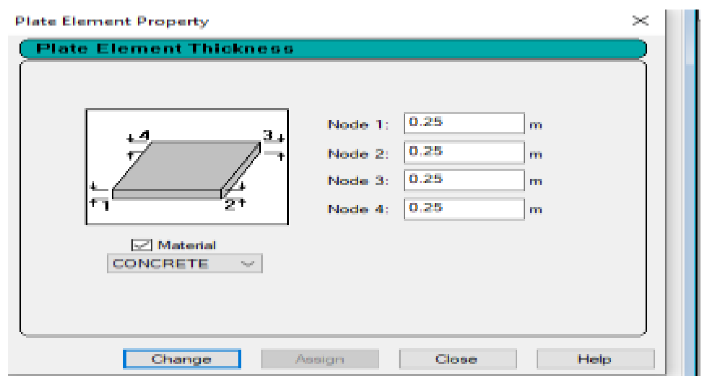

Fig.2. Plate Property.

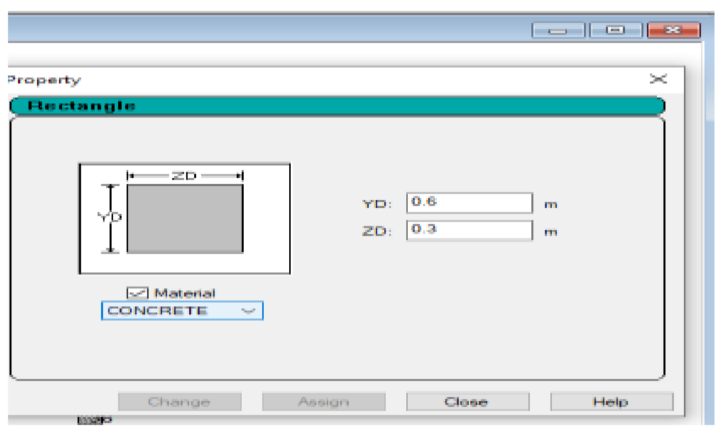

Fig.3. Rectangle Property-1.

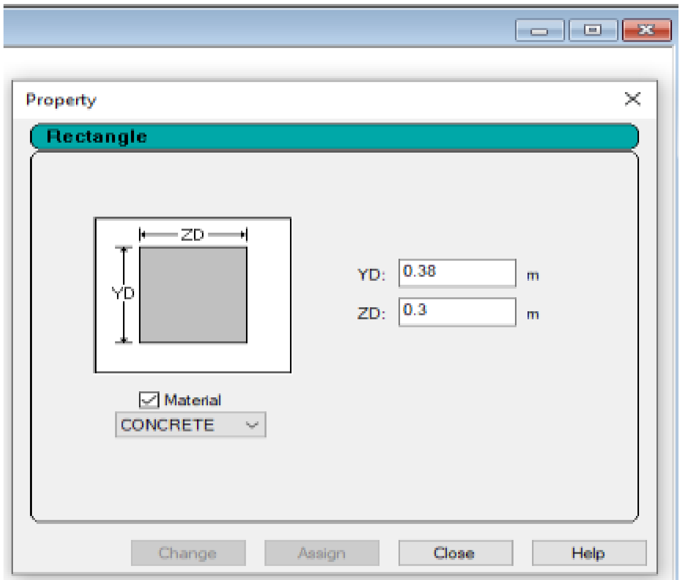

Fig.4. Rectangle Property-2.

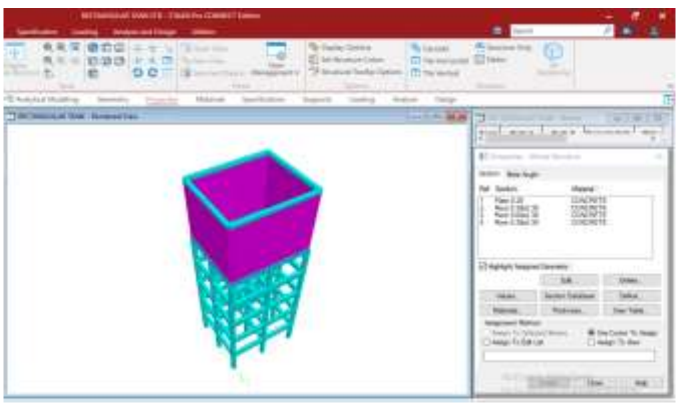

Fig.5. 3D view.

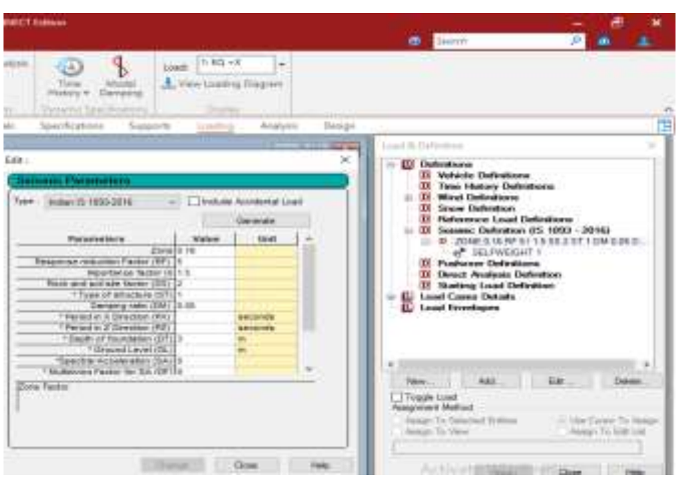

Fig.6. Seismic Property.

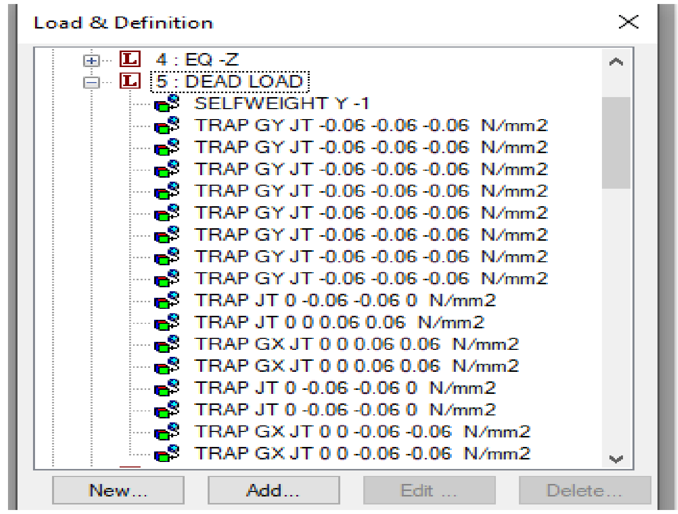

Fig.7. Dead Load Definition.

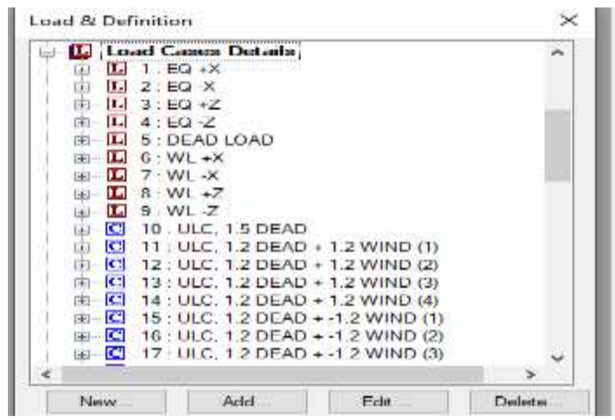

Fig.8. Load cases Details 1.

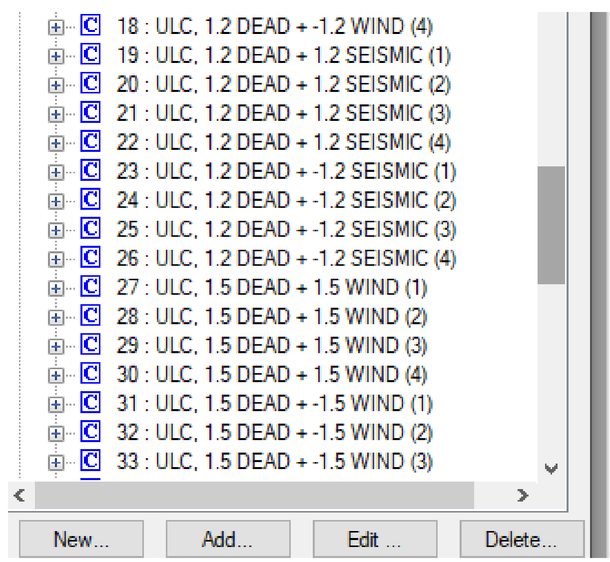

Fig.9. Load combinations 2.

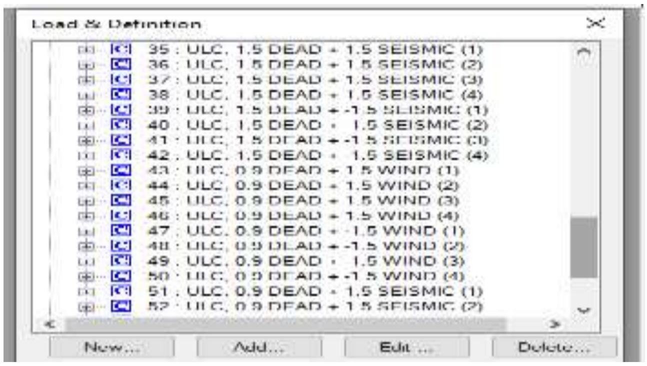

Fig.10. Load combinations 3.

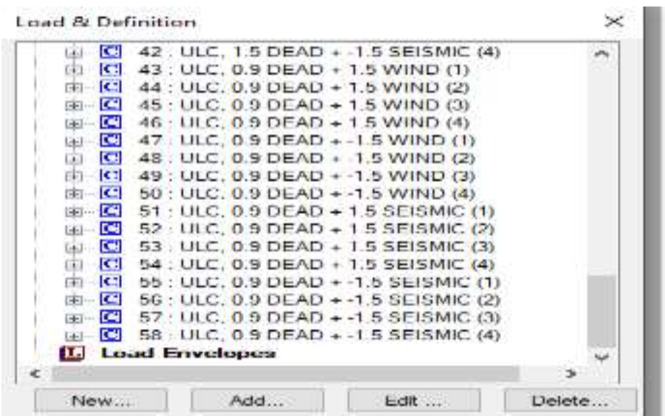

Fig.11. Load combinations 4.

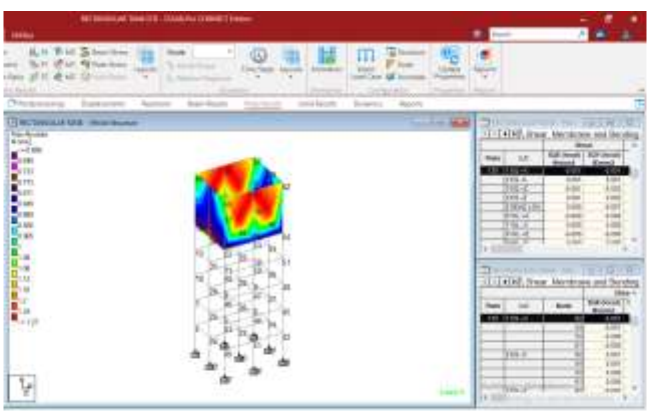

Fig.12. Load Impact on Rectangular tank.

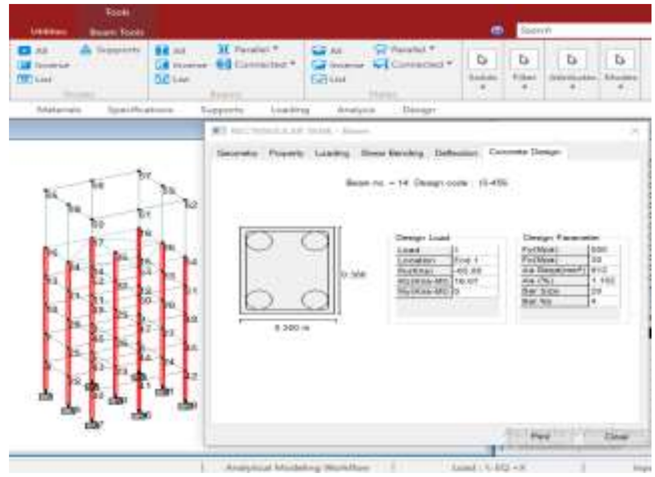

Fig.13. Column Design in Rectangular water tank

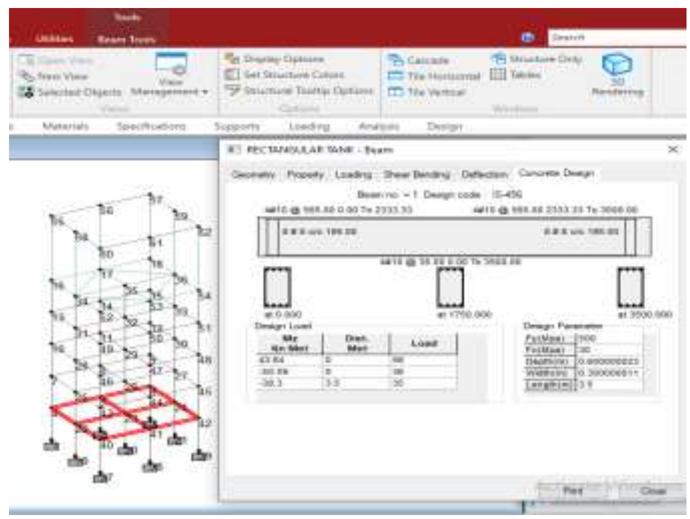

Fig.14. Staging Beam design in Rectangular water tank

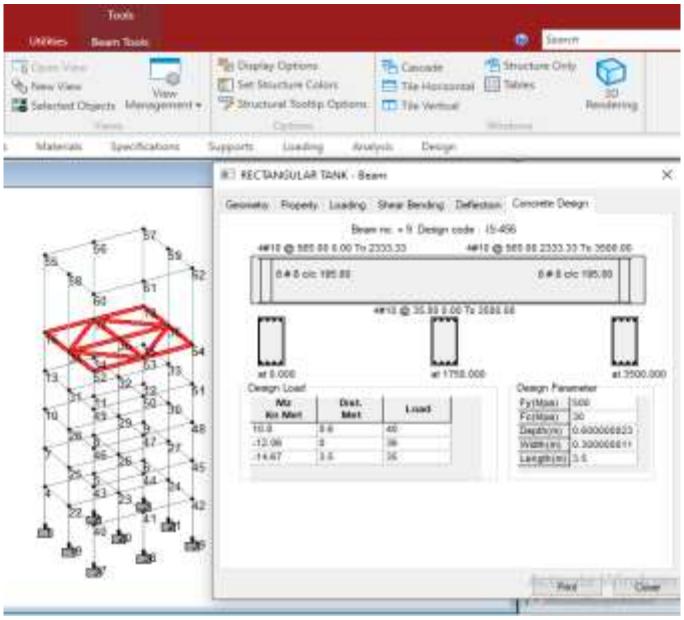

Fig.15. Base Beam Design in Reactanglar water tank

DETAILS OF CIRCULAR TANK

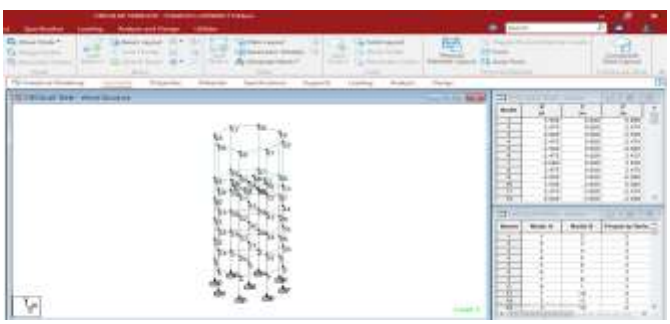

Fig.16. Circular tank.

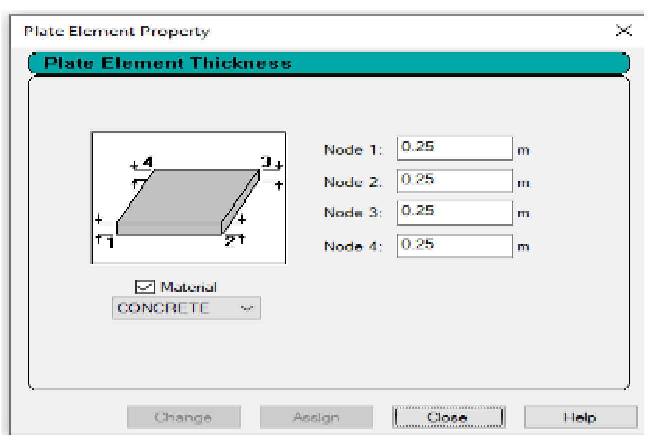

Fig.17. Circular tank Plate Property.

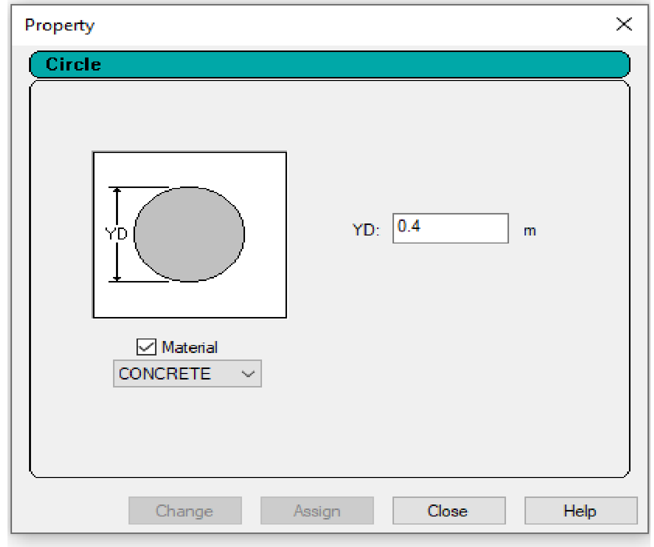

Fig.18.Circular tank circle Property.

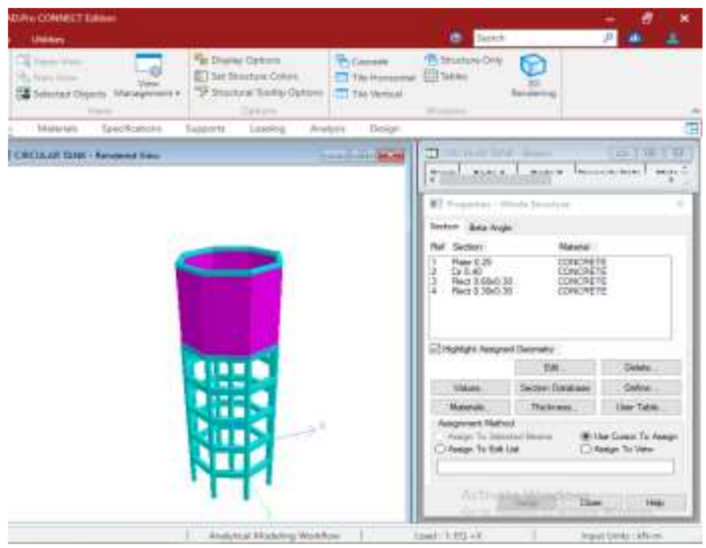

Fig.19. 3D view.

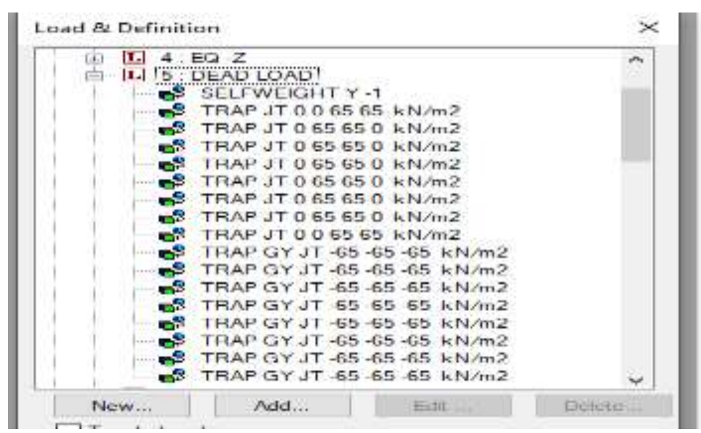

Fig.20. Load Properties.

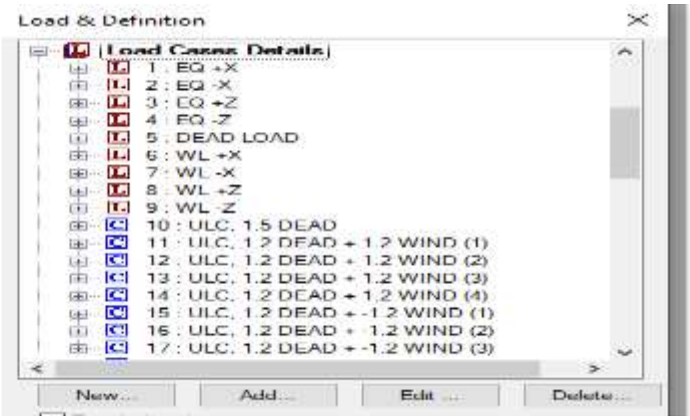

Fig.21. Load Case Details

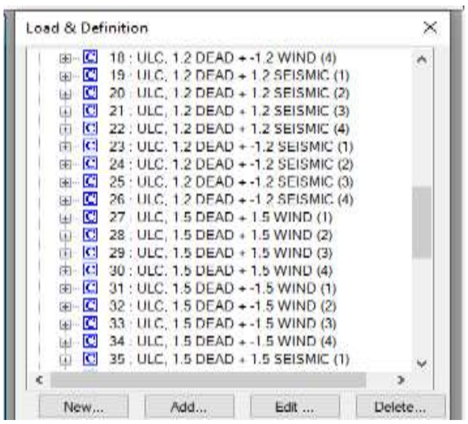

Fig.22. Load Combinations

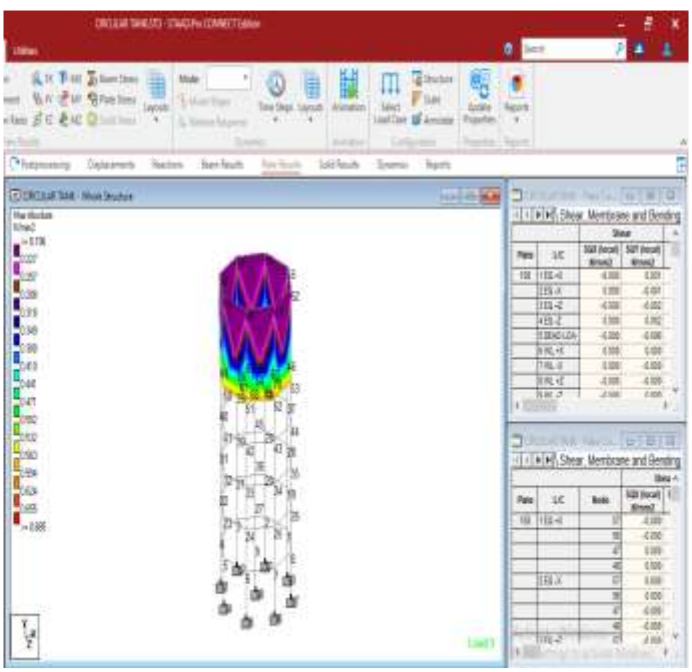

Fig.23. Load impact on Circular water tank.

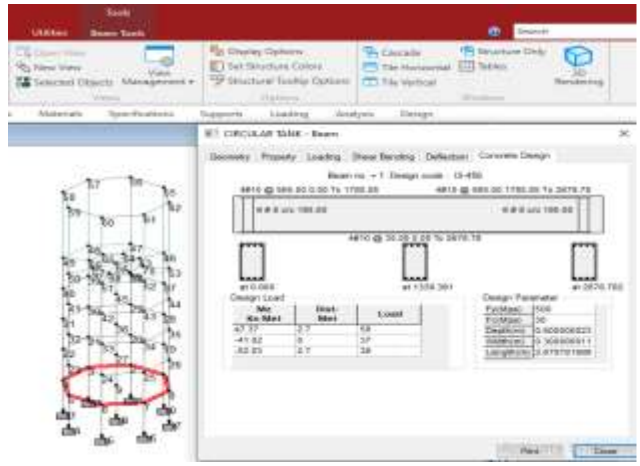

Fig.24. Staging Beam design in Circular water tank

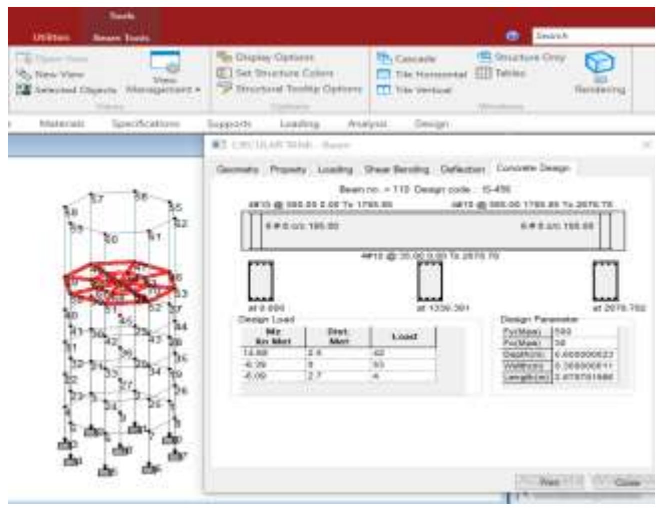

Fig.25.Beam Design Properties in Circular water tank

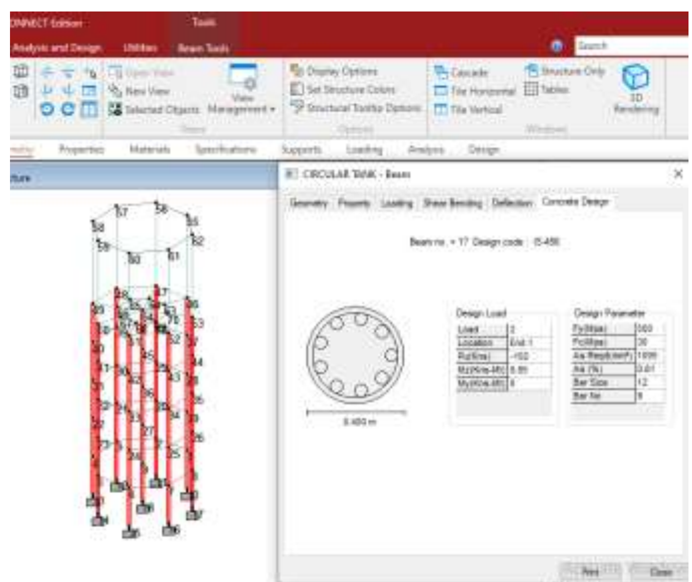

Fig.26. Column design Properties in Circular water tank

Results Comparison between Rectangular and Circular water tank-

Table 5:- Rectangular Tank Results.

	RECTANGULAR Tank Results	R1	R2	R3
S No.	Types of Data	Zone III	Zone IV	Zone V
1	CONCRETE QUANTITY (CUM)	70.15	92.21	129.78
2	STEEL QUANTITY (KN)	41.98	58.77	77.67
3	MAX AXIAL FORCES (KN)	916.62	1145.78	1558.25
4	MAX MOMENT (KN-M)	39.34	49.18	66.88

Table 6:- Circular Tank Results.

	CIRCULAR Tank Results	C1	C2	C3
S No.	Types of Data	Zone III	Zone IV	Zone V
1	CONCRETE QUANTITY (CUM)	62.25	87.15	115.16
2	STEEL QUANTITY (KN)	33.85	47.39	62.63
3	MAX AXIAL FORCES (KN)	847.18	1058.98	1440.25
4	MAX MOMENT (KN-M)	35.2	44.45	58.84

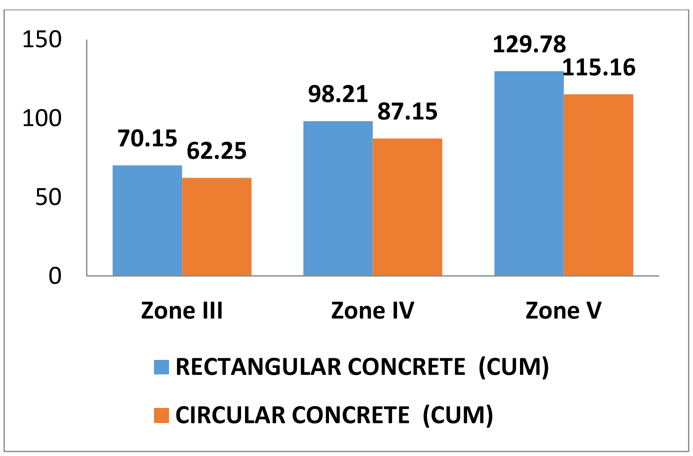

Fig.27. Concrete Quantity (CUM)

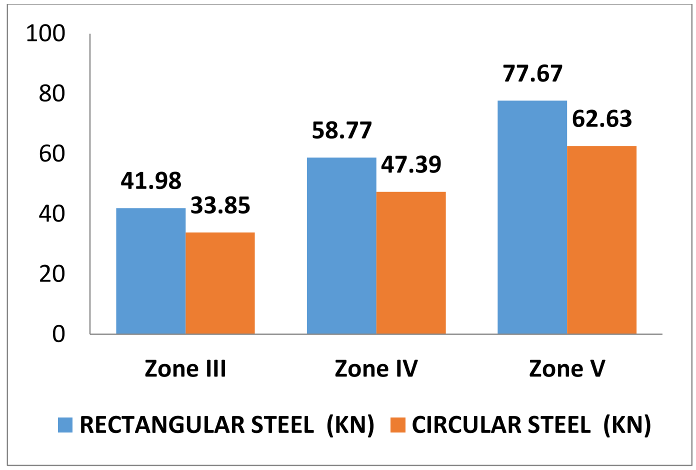

Fig.28. Steel Quantity (KN)

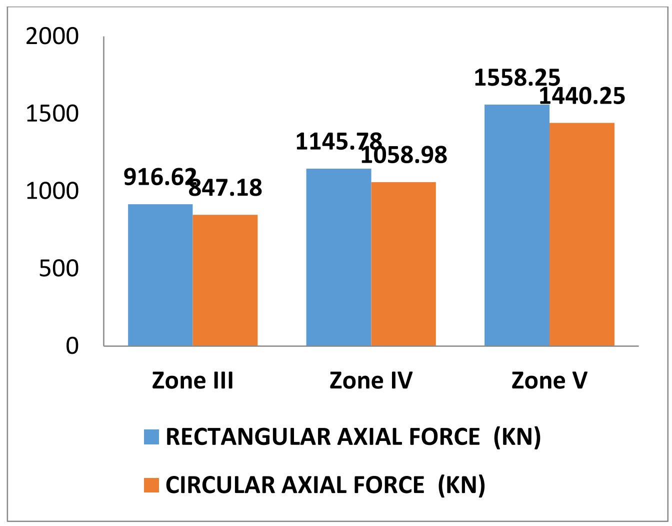

Fig.29. Maximum axial force (KN)

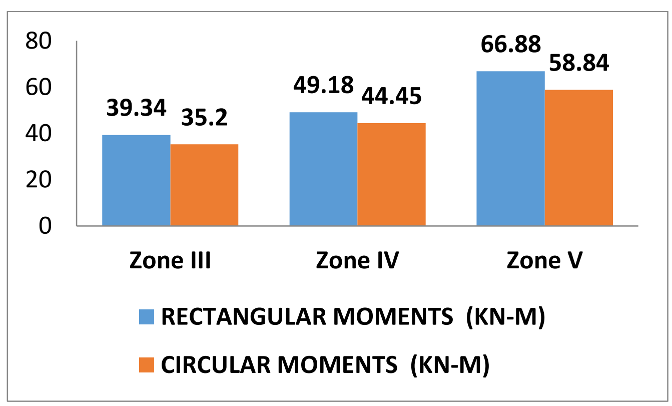

Fig.30. Maximum Moments (KN-M)

XI. CONCLUSION

Rectangular and Circular water tanks differ in design, structural efficiency, and cost. Circular tanks are preferred for larger capacities due to their ability to evenly Concrete quantity (cum), Steel quantity (kn) and Max axial forces (kn), resulting in lower material usage and better durability.

They are also more resistant to seismic and wind forces. Rectangular tanks, on the other hand, are simpler to construct and are often used for smaller capacities or where space constraints dictate the shape. However, they experience uneven pressure distribution, requiring more reinforcement, which can increase costs for larger sizes. Ultimately, the choice depends on capacity, site conditions, and budget considerations.

The quantities of materials needed for the rectangular water tank were constantly more than those needed for the circular water tank, at each varied seismic zone.

It can be clearly seen from the results that the formwork required for the construction of water tank is minimum for circular shaped tank as compared to rectangular shaped tanks.

REFERENCE

[1] Abdellatif, H. E., Belaadi, A., Alshahrani, H., Khan, M. K., &Bourchak, M. (2023). Modeling three-dimensional flow in a thermal energy tank: Numerical analysis of the impact of tank shape on the melting and solidification of phase change material. Journal of Energy Storage, 72, 108286.

[2] Assegie, M. A., Siram, O., Kalita, P., &Sahoo, N. (2024). Novel small-scale spring actuated scissor-jack assembled isobaric compressed air energy storage tank: Design analysis and simulation. Journal of Energy Storage, 89, 111627.

[3] Das, A., &Konar, T. (2023). Design and optimization of roof-top fire water tanks as compliant deep tank dampers-inerter for seismic protection of multi-storeyed buildings. Journal of Building Engineering, 80, 107957.

[4] Das, A., Konar, T., & Banerjee, A. (2023, December). Wind-induced vibration control of tall buildings by designing the overhead fire water tanks as compliant deep tank dampers-inerter. In Structures (Vol. 58, p. 105522). Elsevier.

[5] Huang, P. (2023). A comprehensive investigation on liquid sloshing of rectangular water tank with vertical baffles. Ocean Engineering, 288, 116126.

[6] Jin, J. W., &Ahn, D. (2024). Development of a lightweight carbon fiber reinforced plastic water tank for fire trucks. Journal of Science: Advanced Materials and Devices, 9(2), 100697.

[7] Liu, D., Gu, D., Zhang, W., Ren, Y., & Sun, T. (2024). Performance and economic analysis of a novel water storage tank coupled with geothermal heating System: A field test. Applied Thermal Engineering, 124012.

[8] Ma, Y., Xi, J., Cai, J., &Gu, Z. (2024). The optimization and energy efficiency analysis of a multi-tank solar-assisted air source heat pump water heating system. Thermal Science and Engineering Progress, 48, 102387.

[9] Rabbani, S. A., &Tholkapiyan, M. (2023). Analysis of shear stress bending moment and deflection design of side wall for circular water tank resting on ground with varying outer wall cross section and its comparison using manual and STAAD Pro. Materials Today: Proceedings, 79, 1-5.

[10] Raikar, R. G., Kangda, M. Z., Sathe, S., Khan, M. A., Asiri, A. N. M., Islam, S., ...&Majdi, A. (2024). Enhancement of the structural behavior of elevated water tanks using X-plate dampers. Journal of Constructional Steel Research, 221, 108886.

[11] Reddy, R. B., Kalpana, V. J., Srinivas, V., & Prasad, V. V. S. (2023). Design formulation and analysis of overhead water tank: Material used for automatic cleaning mechanism. Materials Today: Proceedings.

[12] Romero-Méndez, R., Pérez-Gutiérrez, F. G., & Sen, M. (2024). Thermodynamics of freezing water inside a self-pressurizing elastic tank and its departure from isochoric condition. International Journal of Refrigeration.

[13] Wang, Q., Zhang, J., Liu, Z., Chen, N., & Yu, X. (2024). Minimum water level in surge tank and control methodology under the combination condition of load acceptance after rejection. Sustainable Energy Technologies and Assessments, 67, 103846.

[14] Workeluel, N., Saha, P., Matiyas, S., &Mohanty, T. (2023). A comparative study on analysis and design of RC C elevated water tank using different country codes. Materials Today: Proceedings.

[15] Zhang, Z., Zhang, J., Yuan, H., Zheng, X., & Mei, N. (2023). Design and experimental analysis of energy-saving and heat storage of a hot water tank based on the source-sink matching principle. Case Studies in Thermal Engineering, 41, 102672.