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Design of Water Tank for the Town Population 40000 Souls

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Abstract:

The design of the RCC Elevated Service Reservoir (ESR) for a town with a population of 40,000 has been meticulously undertaken, considering essential design parameters as per IS codes, CPHEEO norms, and site-specific requirements. The design capacity of 2700 m³ has been derived based on 50% of the daily water demand, ensuring an uninterrupted water supply during peak demand and emergency situations. A circular tank shape has been selected for its structural efficiency, aesthetic appeal, and economical construction. The tank features a working water depth of 4.0 m and a freeboard of 0.5 m, culminating in a total depth of 4.5 m. The design incorporates a dome-shaped roof for effective load distribution, a thick bottom slab for uniform load transfer, and a staging system of columns and braces for stability. A comprehensive structural analysis has been performed using STAAD Pro software, enabling precise modeling of the tank, including seismic (Zone III) and wind load considerations as per IS 1893:2016. The reinforcement detailing is carefully developed to prevent cracking, control deflection, and ensure long-term durability under varying load conditions, such as hydrostatic pressures, wind, seismic forces, and dead loads. The foundation design adopts a raft system based on a safe bearing capacity of 200 kN/m², ensuring the safe transfer of loads to the soil without excessive settlement. The design meets the essential requirements of safety, serviceability, and durability, ensuring a robust and sustainable water storage solution for the community. This project highlights the integration of structural design principles, IS code compliance, and advanced modeling techniques using STAAD Pro, demonstrating a comprehensive understanding of both theoretical knowledge and practical engineering judgment.

Keywords: Water Tank Design, Population Demand, Hydraulic Analysis, Structural Stability, RCC Water Tank, Steel Water Tank, IS Codes, Sustainable Water Storage

I. INTRODUCTION

Water is an essential component of life and plays a pivotal role in sustaining human civilization, agriculture, industry, and the environment. With the continuous growth in population and urbanization, the demand for potable water has increased manifold, making it imperative to design and develop reliable and sustainable water supply systems for urban and rural areas alike. The provision of adequate and safe drinking water is a fundamental requirement for any community, and the storage of this water is an integral part of the overall water supply infrastructure. A water tank is a critical element in the distribution network of a water supply system. It acts as a buffer to store water and regulate supply according to demand fluctuations, ensuring uninterrupted supply even during peak consumption periods or in case of disruptions in the pumping system. Water tanks serve to balance the daily variation in water demand, store emergency reserves for fire-fighting purposes, and help maintain the required pressure in the distribution system. For towns and cities, water tanks are often elevated structures that rely on gravity flow to distribute water to various zones of the network efficiently.

The town under consideration, with a population of 40,000 souls, is experiencing increasing water demand due to population growth, urban development, and improvements in the standard of living.

Ensuring a reliable water supply system for such a population necessitates the design of a suitable water tank that can store an adequate quantity of water, meet the peak demands, and provide a consistent supply across the entire distribution network. The design of the water tank must consider various factors such as the population served, per capita water demand, fire-fighting requirements, topography of the area, hydraulic considerations, material selection, structural integrity, and economic feasibility. Furthermore, the design and analysis of such structures require precise engineering calculations, adherence to relevant codes and standards (such as IS 3370, IS 456, and IS 1893), and the use of advanced design software tools for accurate modelling and analysis. The adoption of structural analysis software like STAAD Pro enhances the accuracy, efficiency, and reliability of the design process, allowing engineers to visualize, analyze, and optimize the tank structure under various loading conditions, including dead load, live load, wind load, seismic forces, and water pressure. This study aims to design a water tank for the town population of 40,000 souls, ensuring an efficient, safe, and cost-effective solution that addresses the present and future water demands. The design will focus on achieving structural stability, durability, and compliance with the latest design codes, thereby contributing to the development of robust urban infrastructure and enhancing the quality of life of the residents.

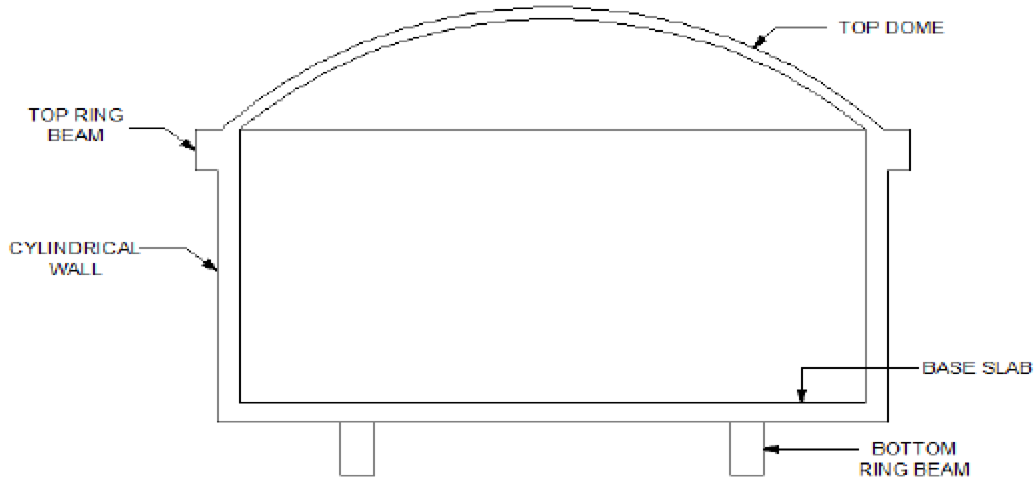


Fig.1.1: General Diagram of Circular Water Tank

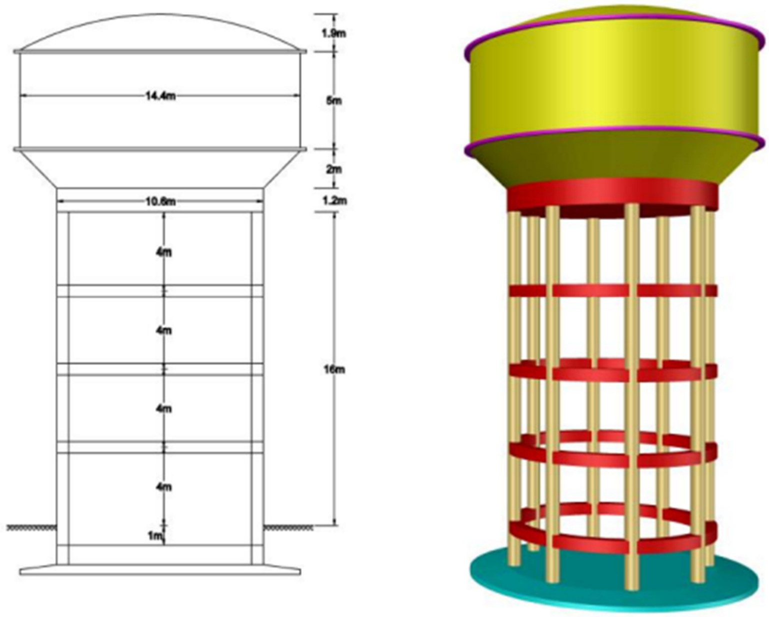
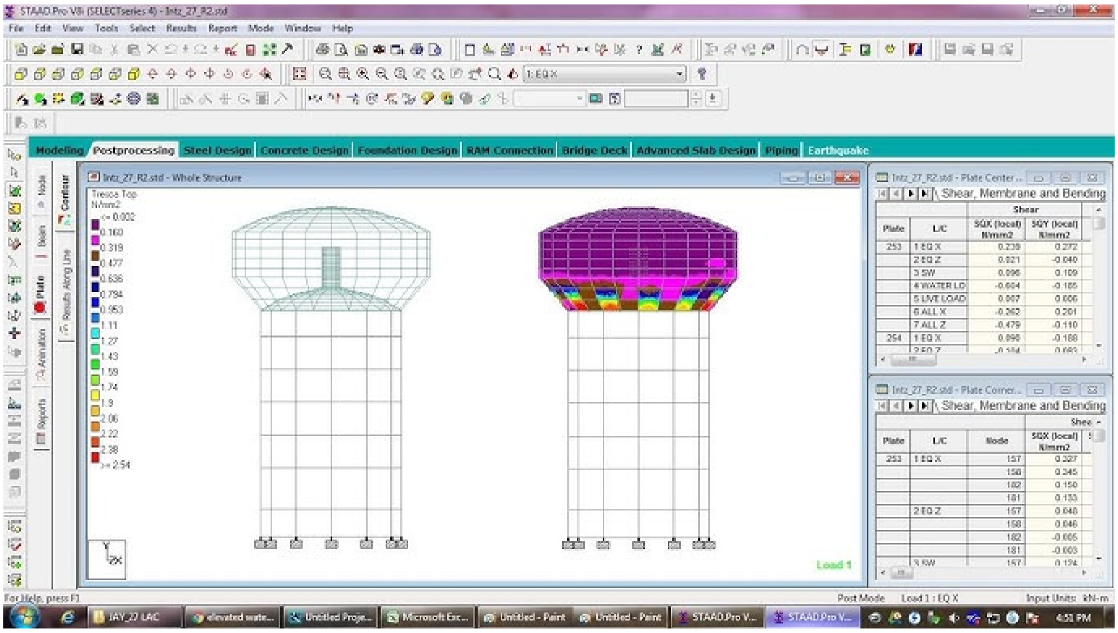


Fig.1.2: Intze Tank

Fig.1.3: RCC Over Head Water Tank



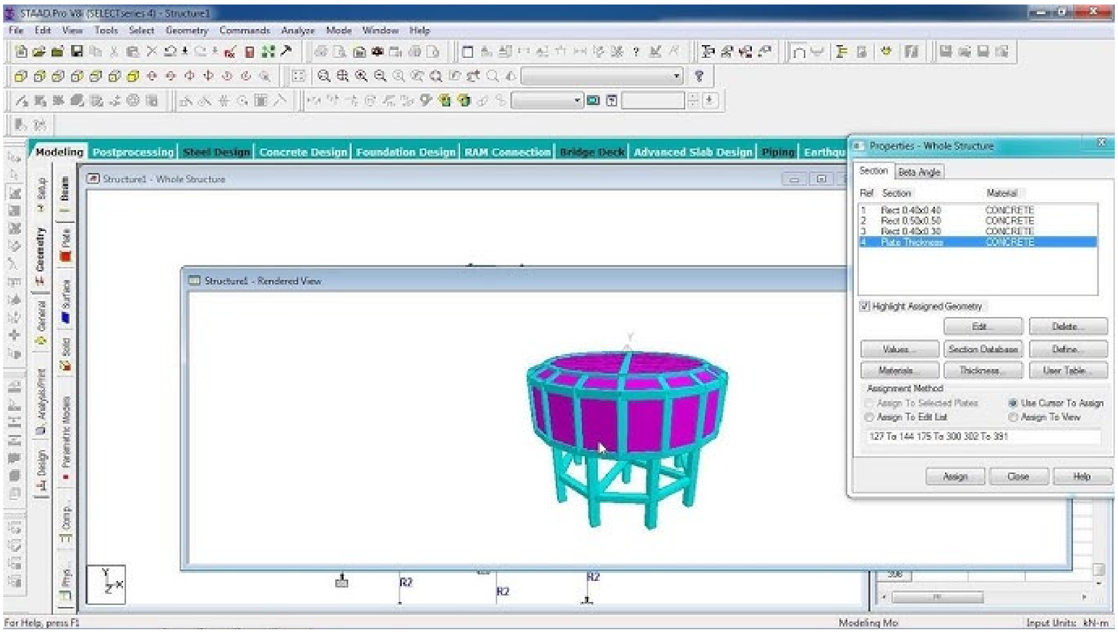


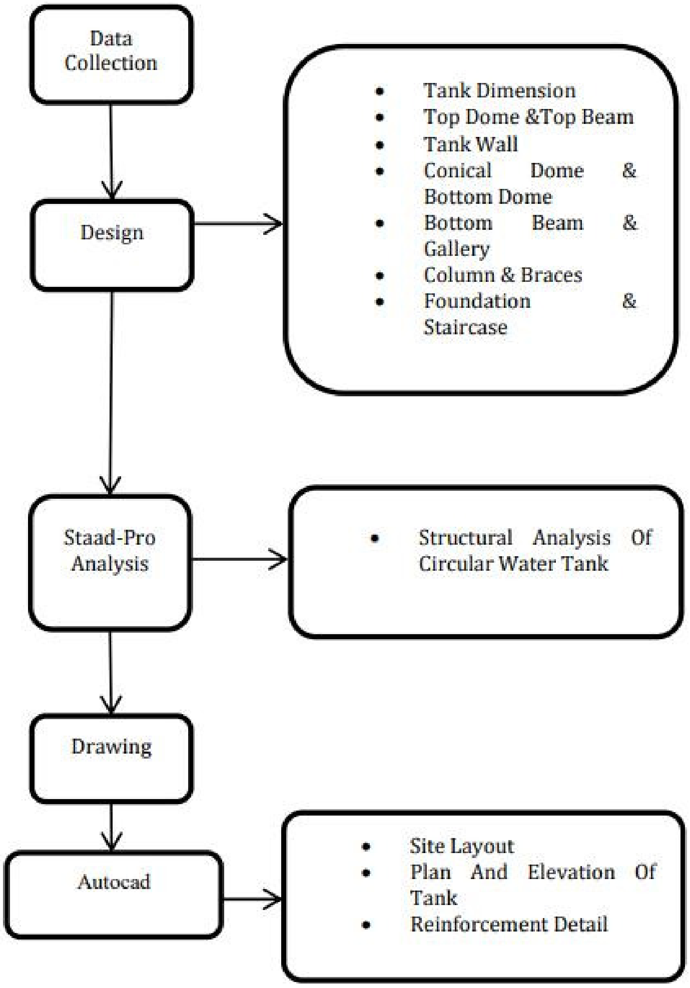
Fig.1.4: Working Interface of Circular Water Tank by using STAAD Pro

The main objectives of this study are as follows:

1. To estimate the water demand for a population of 40,000 souls, considering various factors such as per capita demand, peak demand, and fire-fighting requirements.
2. To determine the required capacity of the water tank based on the calculated demand and storage requirements.
3. To select a suitable type of elevated water tank structure (cylindrical, rectangular, or Intze tank) based on functional efficiency, cost-effectiveness, and site constraints.
4. To perform detailed structural analysis and design of the RCC Circular water tank and its supporting staging system using STAAD Pro software.
5. To ensure the designed structure satisfies the safety and serviceability requirements under various loading conditions, including dead load, live load, wind load, seismic load, and hydrostatic pressure.
6. To comply with relevant Indian Standard codes such as IS 456, IS 3370, IS 875, and IS 1893 in the design process.
7. To contribute to the development of reliable and sustainable water infrastructure for the town, ensuring continuous water supply and improved quality of life for residents.

II. PROPOSED METHODOLOGY

2.1 METHODOLOGY



2.2 WATER DEMAND

Water Demand Calculation for Town Population 40,000

1. Per Capita Demand (PCD)

As per CPHEEO Manual and IS 1172:1993, for urban areas,
PCD=135 lpcd (litres per capita per day)

2. Total Daily Water Demand (Without Peak Factor)

Daily Water Demand=Population × PCD =40,000×135=5,400,000 litres/day=5400 m^3/day

3. Add Fire-Fighting Demand

For a population > 50,000, 10,000 litres per minute for 4 hours is recommended.
For population < 50,000, per CPHEEO, add 1% to 5% of the total demand.
Let's conservatively consider 1% of total demand:
Fire-Fighting Demand=0.01×5400=54 m^3

4. Total Demand Including Fire-Fighting

Total Daily Demand=5400+54=5454 m^3

5. Peak Factor (As per CPHEEO: 1.8 for populations up to 50,000)
Peak Daily Demand=1.8×Average Demand
=1.8×5454=9817.2 m^3/day

6. Design Capacity of ESR
Typically, the capacity of ESR is designed for 50% of the peak daily demand to cover balancing storage:
ESR Capacity=0.5×9817.2=4908.6 m^3

7. Adopted ESR Capacity
For design purposes, we adopt the nearest practical standard size:
ESR Capacity = 5400 m^3

Table 2.1: Summary of Water Demand

Description	Value
Population	40,000
Per Capita Demand (PCD)	135 LPCD
Average Daily Demand	5400 m^3
Fire-Fighting Allowance	1% = 54 m^3
Total Daily Demand	5454 m^3
Peak Factor	1.8
Peak Daily Demand	9817.2 m^3
ESR Capacity (50% of Peak)	~5400 m^3

3.3 STAAD PRO MODELING

The entire structural analysis and design of the RCC ESR has been performed using STAAD Pro software. The 3D model includes the tank wall, dome roof, bottom slab, columns, braces, and raft foundation. The following key steps were taken:
- The geometry of the tank, including the circular tank wall and dome roof, has been accurately modeled.
- Staging columns are modeled as vertical members with appropriate support conditions.
- Bracings are provided at regular intervals to ensure lateral stability.
- The tank and staging system are modeled as a space frame system.
- Material properties are defined as per M30 concrete and Fe500 steel.
- Load cases considered: Dead Load, Live Load (water load), Wind Load (as per IS 875 Part 3), and Seismic Load (as per IS 1893 Part 1, Zone III).
- Response Spectrum Analysis has been performed for seismic forces.
- The design has been checked for strength, serviceability, and stability as per IS 456:2000 and IS 3370:2009.
- Reinforcement detailing has been extracted from STAAD output and verified manually.

The analysis confirms that the structure is safe and serviceable under the applied loads. The output includes member forces, deflections, support reactions, and reinforcement requirements.

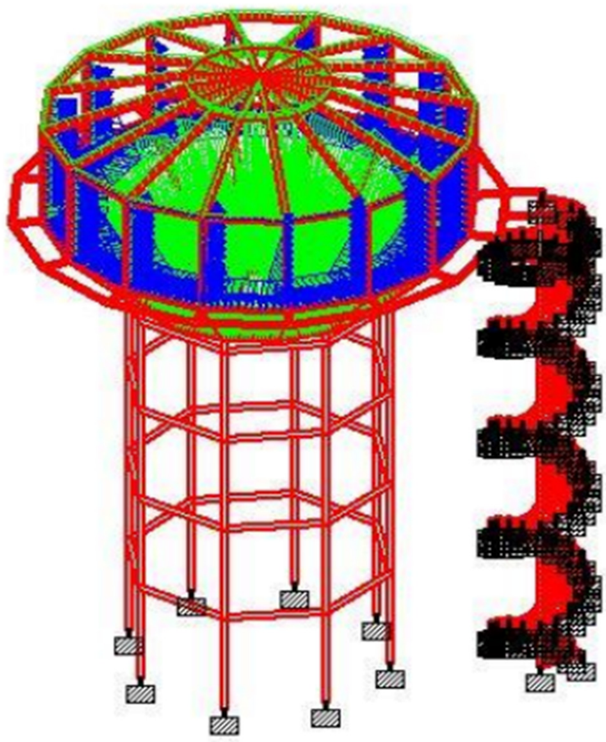


Fig.2.1: Loading Diagram

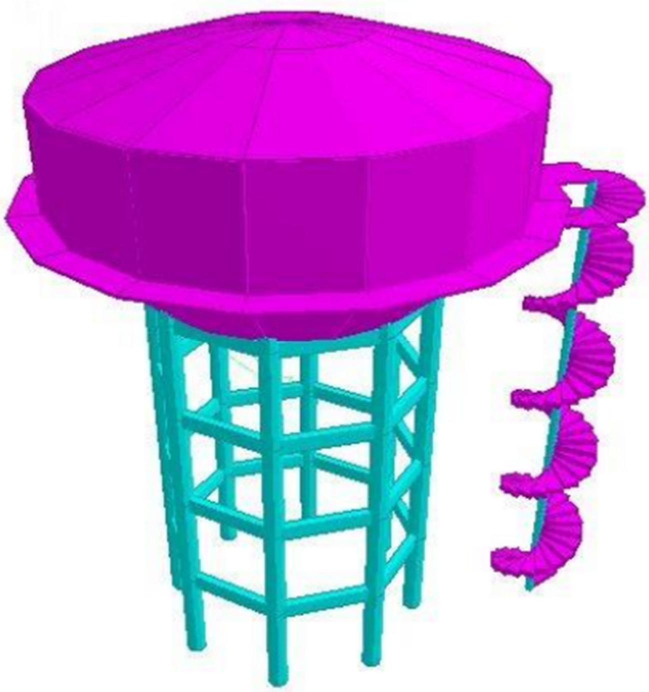


Fig.2.2: 3D Rendered View

III. RESULTS AND DISCUSSION

3.1 DESIGN OF RCC ESR (2700 M³) FOR 40,000 POPULATION

3.1.1 Design Parameters Recap

Table 3.1: Design Parameters

Parameter	Value
Population (P)	40,000 Souls
Water Supply Rate (q)	135 lpcd (CPHEEO)
Daily Demand (Q)	5400 m^3/day
ESR Capacity	50% of daily demand = 2700 m^3
Shape	Circular
Staging Height (h)	12 m
Water Depth (H)	4.0 m (working) + 0.5 m freeboard
Design Period	15 Years
Concrete Grade	M30
Steel Grade	Fe500
Seismic Zone	Zone III (assumed)
SBC	200 kN/m² (assumed)

3.1.2 Capacity and Dimensions of Tank

Tank Capacity (V)
$V=2700m^3$

Dimensions (Circular Tank):
Let's adopt 4.0 m water depth.

$$\pi D^2/4 \times H = 2700$$

$$D^2 = \frac{2700 \times 4}{\pi \times 4} = \frac{2700}{\pi} \approx 859.4 \Rightarrow D \approx 29.3m$$

Adopt D = 30 m for ease of construction.

3.1.3 Design of Tank Components

A. Tank Wall (Circular)

1. Thickness of Wall
Using IS 3370-2:2009 for water retaining structures:
- Minimum thickness for water depth 4.0 m = 250 mm
- Adopt 250 mm.

2. Hoop Tension Calculation
At base, max water pressure:

$$p = \gamma_w \times H = 9.81 \times 4.0 = 39.24kN/m^2$$

Hoop tension:

$$T = \frac{p \times D}{2} = \frac{39.24 \times 30}{2} = 588.6kN/m$$

3. Reinforcement in Tank Wall
Assuming:
- Effective cover = 40 mm

- Effective depth = 250 - 40 = 210 mm

Using:

$$T = 0.87 \times f_y \times A_s$$

Solving for A_s:

$$A_s = \frac{T \times 1000}{0.87 \times 500} = \frac{588.6 \times 1000}{435} \approx 1353.1 mm^2/m$$

Provide 12 mm @ 150 mm c/c (Area = 753 mm²/m), double layer → Total = 1506 mm²/m > 1353 mm²/m (OK).

B. Dome Roof

Assuming spherical dome:

- Rise = 1/5 span = 6.0 m
- Thickness = 150–200 mm

Meridional Force:

$$N_m = \frac{w \times R}{2} \quad \text{(w = DL+LL, R = dome radius)}$$

Design based on membrane theory. Provide 8 mm @ 150 mm c/c in both directions.

C. Bottom Slab

For 30 m diameter, flat slab:

- Thickness = 300 mm.
  Provide reinforcement 12 mm @ 150 mm c/c both ways.

D. Staging System

Columns:

- Provide 12 columns of 600 mm diameter.
- Spacing: Approx. 8–10 m.

Bracings:

- Provide horizontal bracings at 3.0 m c/c.
- Bracing: 300 x 450 mm beams.

E. Foundation

Assume SBC = 200 kN/m².
Total load estimation:

- Tank + water + roof + self-weight + wind + seismic.

Approx. weight of tank + water = 2700 m³ x 10 = 27,000 kN.
With columns, staging, and wind/seismic, factor of safety = 1.5.
Design Raft Foundation:

- Thickness = 600 mm.
- Provide 12 mm @ 150 mm c/c both ways.

3.1.4 Seismic and Wind Load Check

- Seismic Zone: III
- Response Reduction Factor (R) = 3.0 (Ordinary RCC frame)
- Importance Factor (I) = 1.5 (Water tank)
- Damping = 5%

Perform dynamic analysis (response spectrum method) as per IS 1893 (Part 2):2014.

Table 3.2: Summary of Reinforcements

Component	Reinforcement	Thickness
Tank Wall	12 mm @ 150 mm c/c (hoop)	250 mm

Dome Roof	8 mm @ 150 mm c/c both ways	200 mm
Bottom Slab	12 mm @ 150 mm c/c both ways	300 mm
Columns	600 mm dia. with 8 bars of 20 mm	-
Bracing	12 mm @ 150 mm c/c	300x450 mm
Raft Foundation	12 mm @ 150 mm c/c both ways	600 mm

Design in compliance with:

1. IS 3370 (Part 2):2009 for liquid retaining structures
2. IS 456:2000 for RCC
3. IS 875 (Part 3):2015 for wind loads
4. IS 1893 (Part 2):2014 for seismic design

IV. CONCLUSION

The design of the RCC Elevated Service Reservoir (ESR) for a town of 40,000 population has been meticulously carried out considering all relevant parameters as per IS codes, CPHEEO norms, and site-specific conditions. The design capacity of 2700 m^3 has been derived based on 50% of the daily water demand, ensuring an adequate supply to meet peak requirements and emergency conditions. A circular tank shape has been adopted for its structural efficiency and aesthetic appeal, with a working water depth of 4.0 m and a freeboard of 0.5 m, resulting in a total water depth of 4.5 m. The design includes a dome-shaped roof for effective load transfer and minimal material usage, a thick bottom slab to distribute the load uniformly, and a staging system of columns and braces to safely transfer loads to the foundation. Comprehensive structural analysis, including seismic and wind load considerations, has been incorporated to ensure stability and resilience of the tank, especially in seismic Zone III as per IS 1893:2016. The reinforcement detailing has been done to avoid cracking, control deflection, and provide long-term durability under varying loading conditions, including hydrostatic pressures, wind, seismic, and dead loads. The foundation has been designed as a raft type, considering the safe bearing capacity of 200 kN/m^2, ensuring safe transfer of loads to the soil without settlement issues. The entire design adheres to safety, serviceability, and durability requirements, ensuring a robust and sustainable structure that can serve the community's water needs efficiently for years to come. This project demonstrates a comprehensive understanding of structural design principles, the application of relevant IS codes, and the ability to address practical challenges through sound engineering judgment.

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