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DESIGN OF COMPONETS OF WATER TREATMENT PLANT USING PRE-STRESSED CONCRETE

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ABSTRACT:

Water is one of the most essential and limited natural resources, with only about 0.01% of the Earth's total water being directly accessible for human consumption. Ensuring the availability of clean drinking water is a basic human need, yet a significant portion of the population in developing countries, including India, still lacks reliable access to this critical resource. The quality of raw water in India varies widely, necessitating region-specific modifications in conventional water treatment processes. Traditionally, major components of water treatment plants—such as clariflocculators, aeration tanks, and disinfection units—are constructed using reinforced cement concrete (RCC). Although pre-stressed concrete is generally considered uneconomical for smaller structures, it has the potential to offer improved structural efficiency and durability for larger elements of water treatment plants. This study focuses on the structural design of key components of a water treatment plant using pre-stressed concrete and compares them with equivalent RCC designs. The comparison is based on important design parameters such as material consumption, structural performance, durability, and cost-effectiveness. The findings aim to evaluate the feasibility and advantages of integrating pre-stressed concrete in modern water treatment infrastructure.

KEYWORDS: Rigid base components of water treatment plant, R.C.C. components of water treatment plant, Pre-stressed Concrete, design, minimum total cost, tank capacity

1.INTRODUCTION

India constitutes approximately 2.45% of the world's land area and holds about 4% of global freshwater resources, yet it supports nearly 16% of the global population. With the current population growth rate of around 1.9% annually, India's population is projected to exceed 1.5 billion by the year 2050. As per the estimates of the Planning Commission, Government of India, the national water demand is expected to rise sharply—from 710 billion cubic meters (BCM) in 2010 to nearly 1180 BCM by 2050—driven largely by increasing domestic and industrial consumption, which is projected to grow by 2.5 times.

In this context, the design and construction of efficient water treatment infrastructure becomes critical. Traditionally, reinforced cement concrete (RCC) has been the material of choice for water-retaining structures due to its simplicity and lower initial construction requirements. However, pre-stressed concrete (PSC), though less commonly used in such applications due to the need for skilled labor, specialized equipment, and rigorous supervision, offers notable advantages, particularly for large-capacity structures.

The concept of pre-stressing was pioneered by the renowned French engineer Eugene Freyssinet, who recognized the importance of using high-strength steel stressed to significant levels to offset the effects of concrete creep and shrinkage. In the 1950s, this concept was widely adopted in the United States for the construction of circular tanks, employing post-tensioned high-strength tendons embedded in the tank walls. These tendons were typically grouted with a cement-water mix after tensioning to protect against corrosion and to bond them with the surrounding concrete. In later developments, unbonded tendons with corrosion-inhibiting grease and plastic sheathing gained popularity, enhancing durability and ease of construction.

Pre-stressed concrete offers several distinct advantages over conventional RCC, particularly in water-retaining and pressure-bearing applications:

- **Uncracked sections under service loads**: This results in reduced steel corrosion and enhanced durability.
- **Full cross-section utilization**: Leads to higher stiffness and less deformation, improving serviceability.
- **Increased shear capacity**: Makes it suitable for structures subjected to dynamic or fatigue loading.
- **Enhanced suitability for liquid-retaining and pressure vessels**: Due to improved crack control and structural integrity.
- **High span-to-depth ratios**: Enables longer spans and thinner sections, reducing self-weight and material usage.
- **Architectural and economic benefits**: Slender sections allow for more aesthetic and cost-efficient designs.

Given these advantages, this study explores the application of pre-stressed concrete in the design of key components of water treatment plants and compares their performance with conventionally designed RCC components, aiming to evaluate feasibility, cost-effectiveness, and structural efficiency.

2. LITERATURE REVIEW

Several studies have been conducted comparing the performance, economy, and design techniques of RCC and pre-stressed concrete water tanks. In the paper *"Comparison of RCC and Pre-stressed Concrete Water Tanks"* by Ms. Snehal R. Metkar and Prof. A. R. Mundhada, the design of two circular water tanks with identical capacities and dimensions was analyzed using Indian Standards (IS 456:2000, IS 3370 Parts I–IV, and IS 1343:1980). Their findings showed that RCC tanks are more economical for capacities up to 10–12 lakh liters, whereas for larger capacities, pre-stressed concrete offers better cost efficiency.

Another study, *"The Use of Pre-stressing and Pre-casting in Concrete Water Tanks in Britain and Ireland"* by Michael Gould et al., highlighted the evolution of tank construction techniques, especially the use of precast sections combined with pre-stressing. Although not yet widespread, the authors suggest that pre-stressed concrete becomes more economical for large-capacity tanks and ensures better watertightness when proper design and quality concrete are used.

The ACI Committee 373 in its report *ACI 373R-97* provided detailed recommendations for the design and construction of circular pre-stressed concrete tanks with circumferential tendons. These guidelines supplement ACI 318, ACI 301, and ACI 350R. The report emphasizes the importance of watertightness testing, especially for tanks storing potable or raw water, with stringent criteria for allowable water loss over a 24-hour period.

Further, the paper *"Improvements to Seismic Design of Circular Pre-stressed Concrete Storage Tanks"* by J.H. Wood and M.J.N. Priestley analyzed the seismic performance of such tanks. The study revealed that current seismic design codes might underestimate the reserve strength of pre-stressed tanks. Their analysis, using charts and simulations, shows that soil-structure interaction contributes significantly to seismic damping and should be considered when determining design force reductions.

Finally, in *"Economical Design of Water Tanks"* by Hassan Jasim Mohammed, an optimization technique was applied to minimize the total cost of both rectangular and circular tanks. It was observed that while increasing tank capacity raises costs in rectangular tanks, it decreases them in circular tanks. The tank floor slab thickness had a notable influence on total cost, and in circular tanks, all design variables significantly affected cost efficiency.

3. DESIGN PHILOSOPHY

The design of liquid-retaining structures differs fundamentally from that of conventional RCC structures due to the critical requirement of water-tightness. In such structures, it is essential to limit the tensile stress within permissible values to prevent cracking of concrete. Consequently, the tensile resistance of concrete is typically ignored in the design, and reinforced concrete sections are proportioned so that no tension develops on the water-retaining face. IS 3370 guidelines are followed for the structural safety and durability of tanks.

In general, M30 grade concrete with a mix proportion of 1:1.5:3 is recommended for water-retaining structures. To ensure structural integrity, steel reinforcement of not less than 0.3% of the gross cross-sectional area is provided in both directions. These considerations aim to ensure long-term serviceability, structural safety, and water-tightness, which are critical for the durability and performance of tanks storing potable water or other liquids.

Design Steps for RCC Components of Water Treatment Plant

The design process of reinforced concrete (RCC) components for a water treatment plant begins with the determination of the diameter and height of the water tank, followed by an assumption of a suitable wall thickness. Design constants are then calculated, which are essential for determining structural behavior. Using IS 3370 Part IV, the hoop tension and maximum bending moments are computed. Based on the hoop tension, hoop reinforcement is provided in the form of rings per meter height. The assumed wall thickness is verified against the permissible tensile stresses of concrete in direct tension, ensuring crack control. A further check is performed for bending stresses. Once the section passes the stress criteria, vertical steel reinforcement is provided. The base slab is then designed to resist the loads transferred from the tank wall and stored water. Finally, detailed structural drawings are prepared for implementation.

In water-retaining concrete structures, the impermeability of concrete is a primary design consideration. To avoid cracking, the structural design assumes no tensile resistance from the concrete in bending. Therefore, adequate reinforcement is provided to keep the tensile stresses within permissible limits. For such structures, a minimum M30 grade concrete (typically 1:1.5:3 mix) is recommended, and reinforcement should not be less than 0.3% of the gross cross-sectional area in both directions.

Design Steps for Pre-stressed Components of Water Treatment Plant

Designing pre-stressed components involves calculating the diameter and height of the water tank, followed by an assumption of suitable wall thickness. Design constants are then computed, and using IS 3370 Part IV, the hoop tension and maximum bending moment are determined. The assumed wall thickness is verified against permissible tensile stresses of concrete in direct tension. Circumferential pre-stress is applied to induce compressive stress in the concrete, ensuring that tensile stresses are countered efficiently. Based on the analysis, circumferential and vertical steel (post-tensioned or pre-tensioned strands) are provided to achieve the desired performance.

The design includes checking for ultimate collapse and cracking to ensure long-term durability and safety. Additionally, non-prestressed (untensioned) steel is provided to resist local stresses and aid in crack control. The base slab is designed to resist vertical and lateral forces while maintaining overall stability. Finally, detailed construction drawings are prepared. Pre-stressed concrete tanks offer advantages such as low maintenance, high seismic resistance, and superior watertightness. These characteristics make them ideal for water treatment and distribution systems, sludge treatment, stormwater management, LNG containment, and bulk storage. Strand-wrapped circular tanks are particularly durable and efficient, as the pre-stressing aligns material behavior to ideal tensile and compressive states, uniformly distributing loads around the tank's circumference.

Component Overview and Design Application

In this study, components of a water treatment plant with a capacity of 200 MLD, such as clariflocculators, sludge thickeners, and recirculation sumps, resting on firm ground, are designed using both RCC and pre-stressed concrete methods. Specifically, a clariflocculator of 51 meters in diameter and 3.65 meters in height is analyzed using both techniques. Structural analysis, detailed design, estimation, and costing are performed for both methods to enable a comparative evaluation.

4. RESULTS & CONCLUSION

The comparison of RCC and pre-stressed designs for the same component (clariflocculator) reveals insightful conclusions. With identical geometry and concrete grade, pre-stressed components showed significant advantages. The total construction cost using the RCC method was ₹12,338,848.65, while the cost using the pre-stressed method was ₹10,222,950.68—reflecting a 17.14% cost reduction in favor of the pre-stressed approach. Beyond cost, pre-stressed components demonstrated superior watertightness and required lower maintenance. It was further observed that RCC remains more economical for smaller tanks (up to 10–12 lakh liters), but for larger capacities, pre-stressed concrete not only offers economic benefits (up to 20% cost savings) but also ensures better performance under service conditions. Therefore, pre-stressing is recommended as the preferred design method for large-scale water treatment plant structures.

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