

Economic Design of Water Tank of Different Shapes With Reference To IS: 3370 2009

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ABSTRACT: The conventional method of designing water tanks which is working stress method outlined in the previous version of IS: 3370 1965 is irrational and leads to relatively thicker sections with a substantial amount of reinforcement. Limit state method which is widely used has been recently adopted in the new version of IS 3370-2009 concrete structures for storage of liquids – code of practice. For quick cost prediction of tanks, this study therefore examines the cost effectiveness in terms of amount of materials and formwork used for Circular, Square and Rectangular overhead water tanks each of three capacities of 100kl, 150kl, 200kl and draw reasonable inferences on tank's shape design effectiveness. Each water tank was designed by Limit State method and then the crack width was checked by limit state of serviceability IS 3370 (2009). The results have been presented in the form of graphs and tables and it has been observed that Circular-shaped tank consumed lesser of each material as compared to Square and Rectangular ones. The amount of formwork required for circular tank is also less than that for square and rectangular tanks thereby giving Circular-shaped tanks a more favorable selection over the rectangular and square shaped tanks.

Keywords: Working stress method, limit state method, Crack width, effective cost.

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: 3370 1965. This method leads to thicker and heavily reinforced sections. The use of limit state method of design has been adopted in the revised code IS 3370: 2009 and provision for checking the crack width is also included in this code. 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. Problem Formulation

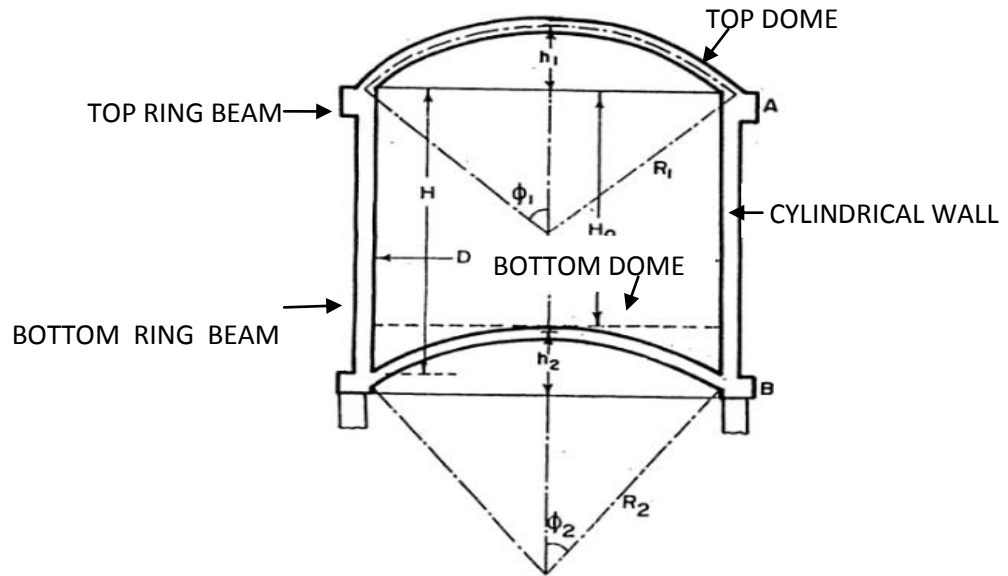
In order to carry out the cost analysis, overhead water tanks of circular, rectangular and square shapes, which are commonly adopted by designers, were considered for the recent study. Water tank of each shape was designed for capacities of 100 kl, 150 kl, and 200 kl. Only the tank portion was considered in this study. The design of all water tanks was done by limit state method as per the the provisions of the IS: 3370 2009. Each element of water tank was also checked for crack width to ensure the proper strength and serviceability.

III. Analysis and Design

3.1 Circular Tank

The Overhead circular water tanks are built for direct distribution by gravity flow and are usually of smaller capacities. As the circular shape has least perimeter, circular tanks are widely used.

The main structural elements of overhead circular tank are shown in Fig. 3.1 and their design methodology is explained in the following sections.:



3.1.1 Top Dome: Top dome is designed for self weight and a service live load as per provisions of the relative Indian Standard Codes. . The top dome is supported on the cylindrical wall. Two types of forces that is the Meridional thrust (T) acting along the direction of meridian and the Hoop stress (H) – along the latitudes develop in the dome due to the applied loads. These are illustrated in Fig. 3.2 and 3.3 respectively.

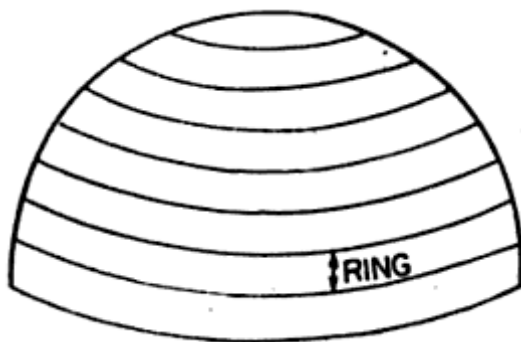


Fig. 3.2 Frustum of spherical dome

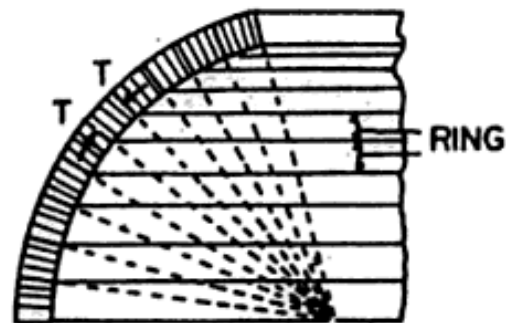


Fig. 3.3 Vertical section of dome

Top dome is designed and checked for these two forces. As the stresses developed are very small in magnitude, minimum reinforcement as specified in code is normally provided in the form of a mesh.

3.1.2 Top Ring Beam

Normally the domes are segmental and the meridional thrust developing at the base of the dome is at some inclination with the horizontal . The horizontal component of the meridional thrust produces hoop tension which is resisted by providing a ring beam at the base along the periphery of the dome. The ring beam is supported on the cylindrical wall of the tank and is designed for direct tension.

3.1.3. Cylindrical Vertical Wall

The tank wall is supported on the bottom ring beam the walls of tank are assumed to be free at top as well as bottom. . Due to this, the tank wall will be designed for hoop tension caused by the horizontal water pressure, without any bending moment. The maximum hoop tension will occur at the base. The tank walls are adequately reinforced with horizontal rings provided at both faces. In addition to this, vertical reinforcement is provided on the both faces in the form of distribution steel. The spacing of the vertical steel is halved at the bottom portion of the wall to cater for any bending moment.

3.1.4 Bottom Spherical Dome

The bottom dome is subjected to vertical loads consisting of self-weight and weight of water. The weight of water over the surface of dome is calculated as

$$\text{Weight of water} = \left[\frac{\pi}{4} D^2 \times H - \frac{\pi}{3} h_2^2 (3 \times R_2 - h_2) \right] \times \gamma_w$$

Where D = Inner diameter of tank

H = Height of cylindrical wall

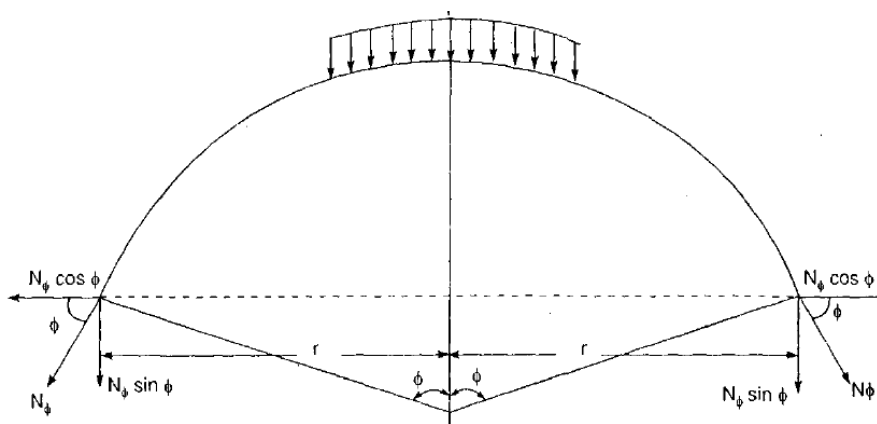
h_2 = rise of bottom spherical dome

R_2 = Radius of bottom spherical dome

γ_w = unit weight of water

3.1.5. Bottom Ring Beam

Bottom Circular beam is supported usually on columns and is designed to support the tank and its contents. The girder should be designed for the bending moments, shear force and torsion. In addition to these forces, it is also subjected to hoop tension due to meridional thrust of bottom spherical dome.



3.2 Over Head Square / Rectangular Water Tank

The main structural elements of a rectangular or square tank are the top slab, the side walls and the bottom slab.

1. Top slab/ Beam
2. Side walls
3. Bottom slab/ Beam

3.2.1. Top Slab: The top slab is designed as one way continuous slab supported on beams. It is designed only for self-weight and service live load.

3.2.2. Cylindrical Side Walls: The walls of a rectangular and square water tanks are subjected to bending moments both in the horizontal as well as in vertical direction. The analysis of the moment in the walls is difficult, since water pressure results in a triangular load on them. The magnitude of the moment will depend upon the several factors such as length, breadth and height of the tank and the conditions of support of the wall at top and bottom edges. If the length of the wall is more in comparison to its height the moments will be in the vertical direction i.e. Panel will bend as a cantilever. If, however, height is large in comparison to length, the moments will be in horizontal direction and panel will bend as thin slab supported on the edges. For the intermediate conditions bending will take place both in horizontal as well as in vertical direction. In addition to the moments, the walls are also subjected to direct pull exerted by water pressure on some portion of side walls. The wall of the tank will thus be subjected to both bending moment as well as direct tension. The design of the walls is done on the premise that no cracks are developed in it. Though, reinforcement is provided both for moments as well as direct tension.

There are two method of analysis that is the approximate method and the exact analysis. In this study exact analysis , which is based on the elastic theory, has been used. The resulting differential equations are very difficult to be solved directly. IS 3370 1965 (Part IV) gives the table for moments and shear forces in walls for certain edge conditions. Moment coefficients for individual panels considered fixed along vertical edges, but having different edge conditions at top and bottom are given in table in IS 3370 (Part IV). The coefficients for individual panels with fixed side edges apply without modification to continuous walls provided there is no rotation about the vertical edges.

3.2.3. Floor Slab: The floor slab should be designed as two way slab supported on floor beams. Generally the thickness of base slab is kept equal to vertical walls.

Check for crack width: as per given in IS 3370 2009 part 2

To be effective in distributing cracking, the amount of reinforcement provided needs to be atleast as great as given below:

$$\rho_{crit} \geq \frac{f_{ct}}{f_y}$$

where, ρ_{crit} = critical steel ratio, the minimum steel ratio, of steel area to the gross of the whole concrete section, required to distribute the cracking .

f_{ct} = Direct tensile strength of the immature concrete which is given in IS 3370 2009 part 2

f_y = characteristic strength of the reinforcement.

$$\text{Maximum spacing of crack } S_{max} = \frac{f_{ct}}{f_y} \times \frac{\phi}{2 \rho}$$

$\frac{f_{ct}}{f_y}$ = ratio of the tensile strength of the concrete to the average bond strength between concrete and steel which can be taken as 2/3 for immature concrete.

ϕ = size of each reinforcing bar

W_{max} = Width of fully developed crack,

$$W_{max} = S_{max} \times \alpha \times \frac{T-1}{2}$$

α = (Coefficient of thermal expansion of concrete) , = 1×10^{-5} for concrete, $T = 30^{\circ} C$

IV. Results and Discussions

The circular, rectangular and square water tanks of different capacities were designed following the provisions of IS 3370: 2009. The quantities of materials were calculated and have been tabulated and shown graphically in the following section.

Table1: Amount of Concrete in cubic meters.

Tank Capacity(kl)	Circular O.H.T	Square O.H.T	Rectangular O.H.T
100	22.834	23.04	24.375
150	28.274	36.86	39.765
200	35.689	52.83	55.275

Fig 1: Comparison of Concrete quantity for 100kl Capacity water tank with respect to shape of tank.

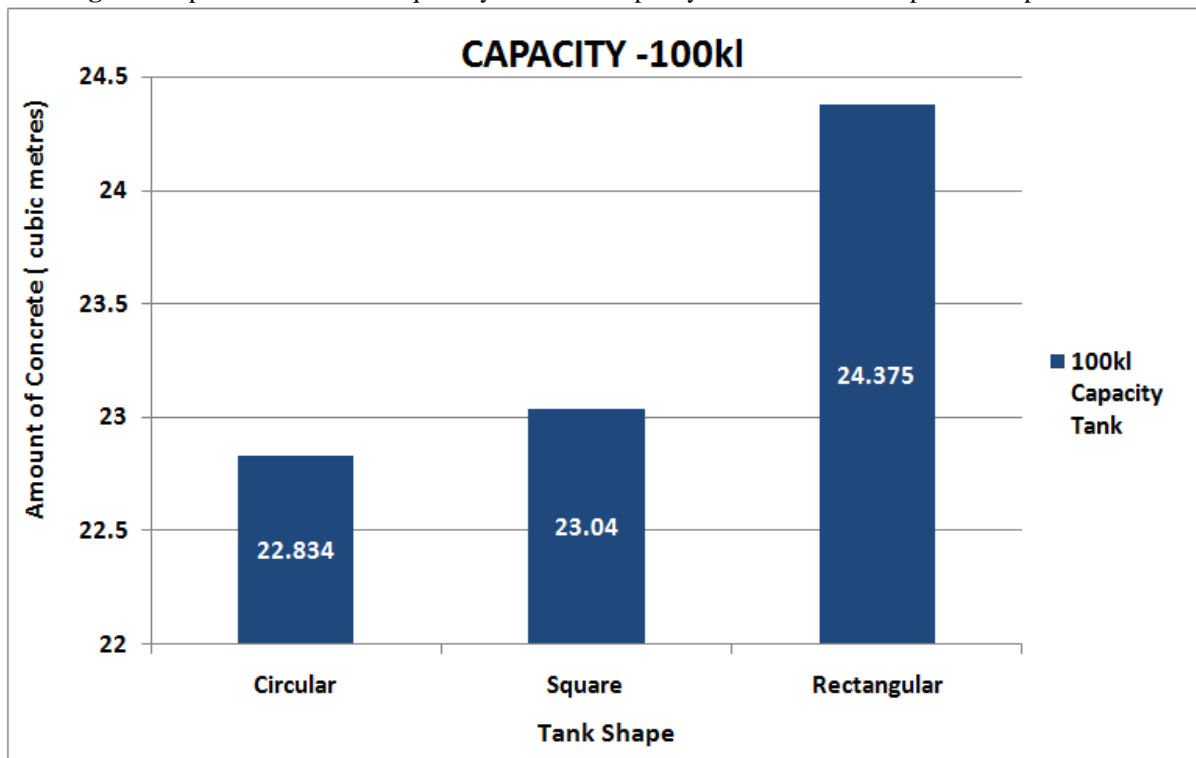


Fig 2: Comparison of Concrete quantity for 150kl Capacity water tank with respect to shape of tank.

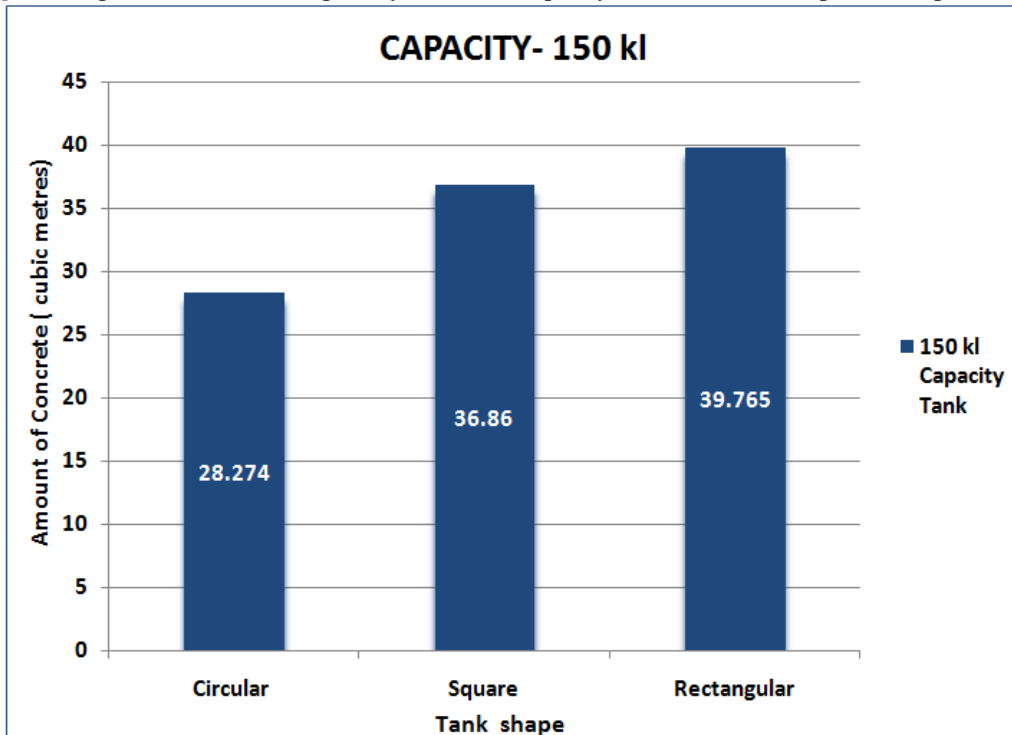


Fig 3: Comparison of concrete quantity for 200kl Capacity water tank with respect to shape of tank

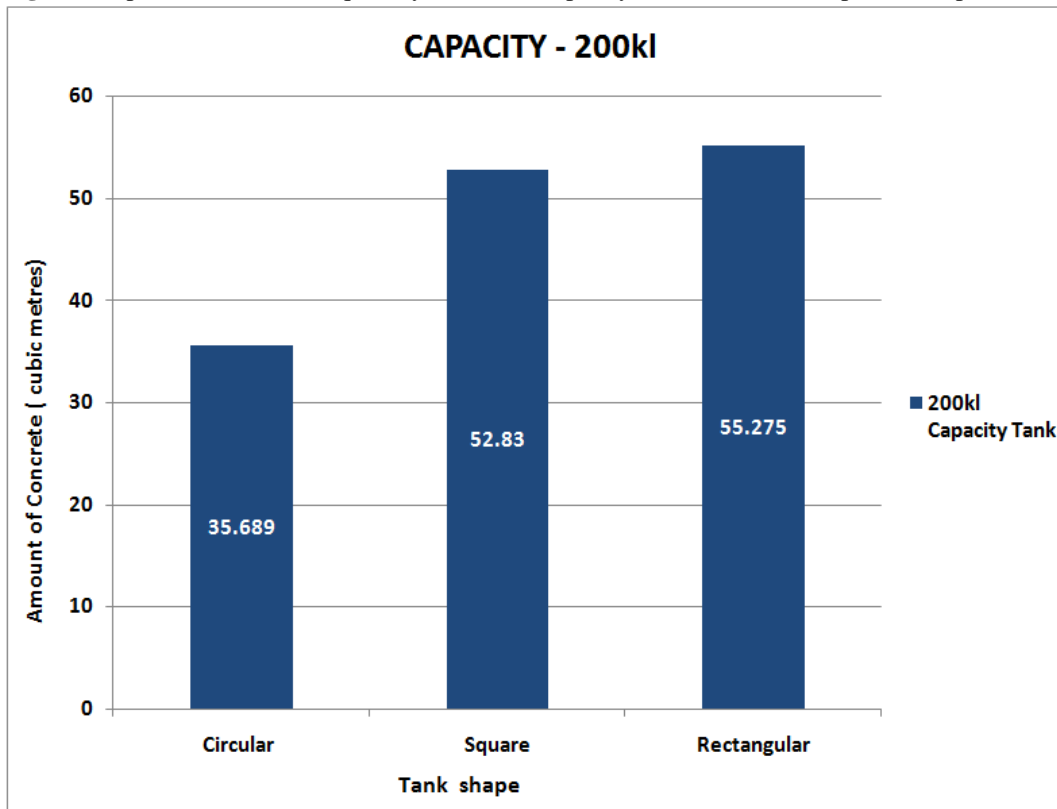


Fig 4: Amount of Concrete against Tank Capacity

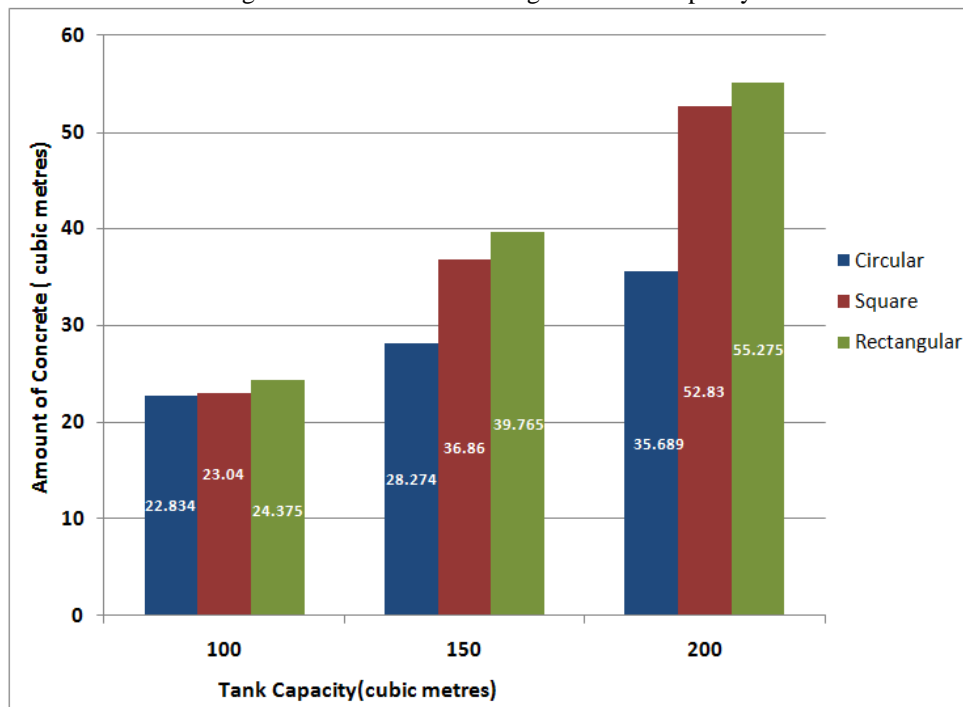


Table 2: Amount of Reinforcement in kilograms

Tank Capacity(kl)	Circular O.H.T	Square O.H.T	Rectangular O.H.T
100	1234.669	3566.7	4129.74
150	1816.71	5772.955	6038.77
200	2422	7696.549	8201.123

Fig 5. Comparison of Reinforcement quantity for 100kl Capacity water tank with respect to shape of tank

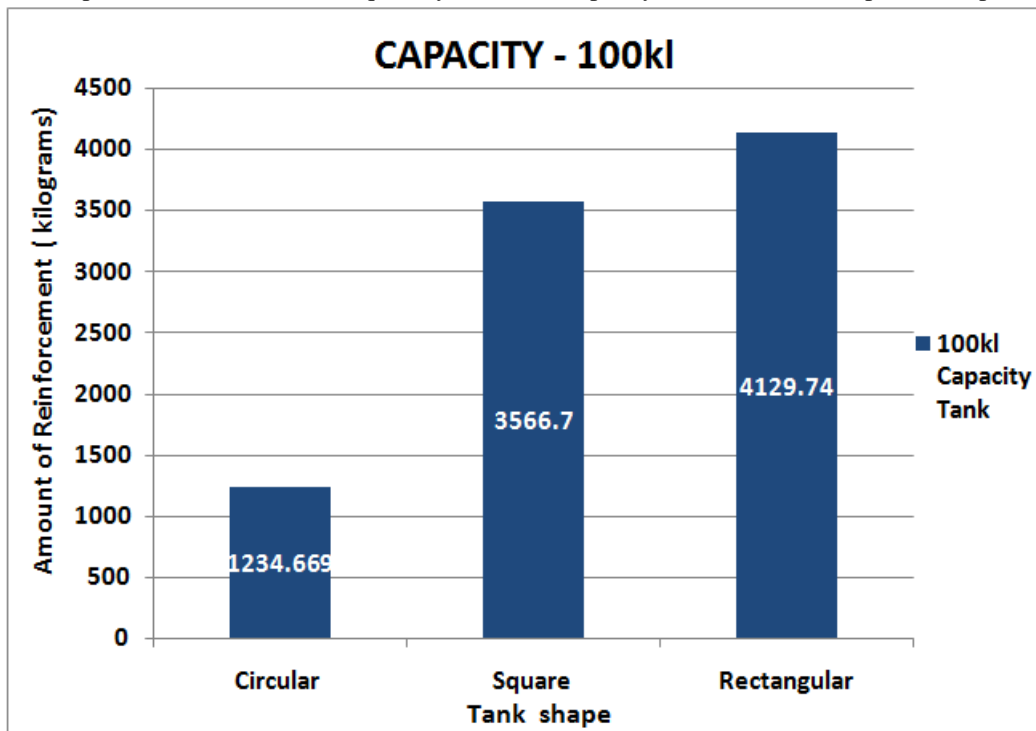


Fig 6. Comparison of Reinforcement quantity for 150kl Capacity water tank with respect to shape of tank

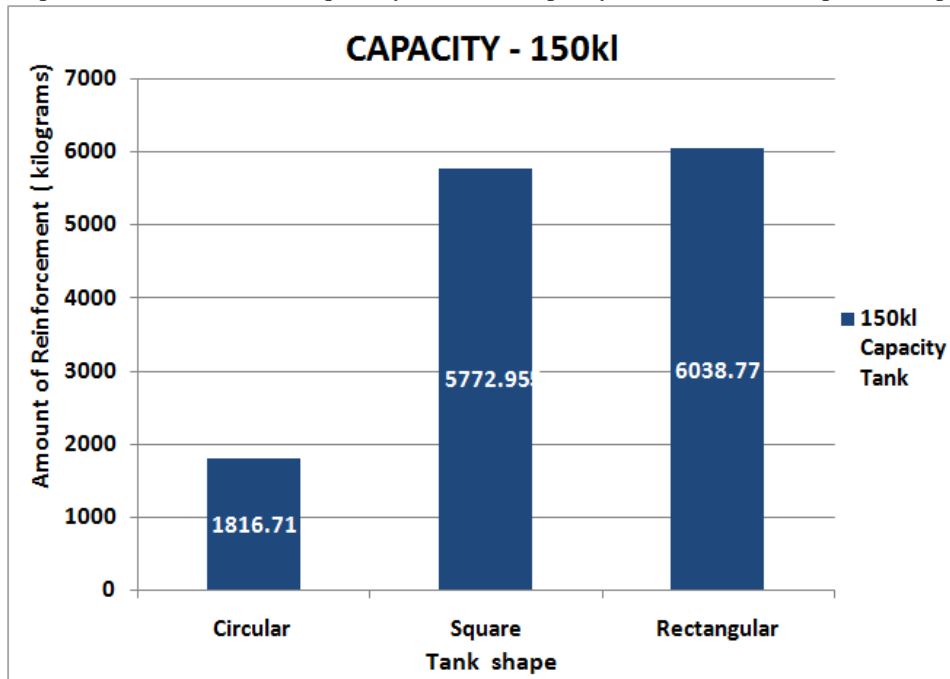


Fig 7. Comparison of Reinforcement quantity for 200kl Capacity water tank with respect to shape of tank

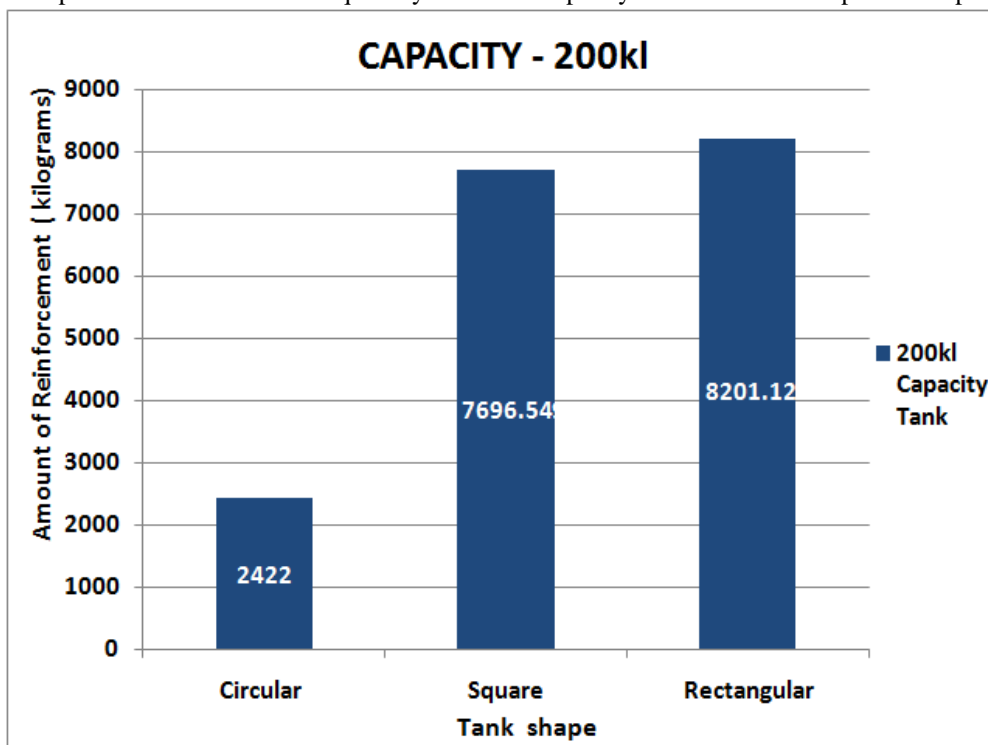


Fig 8:..Amount of Reinforcement against Tank Capacity

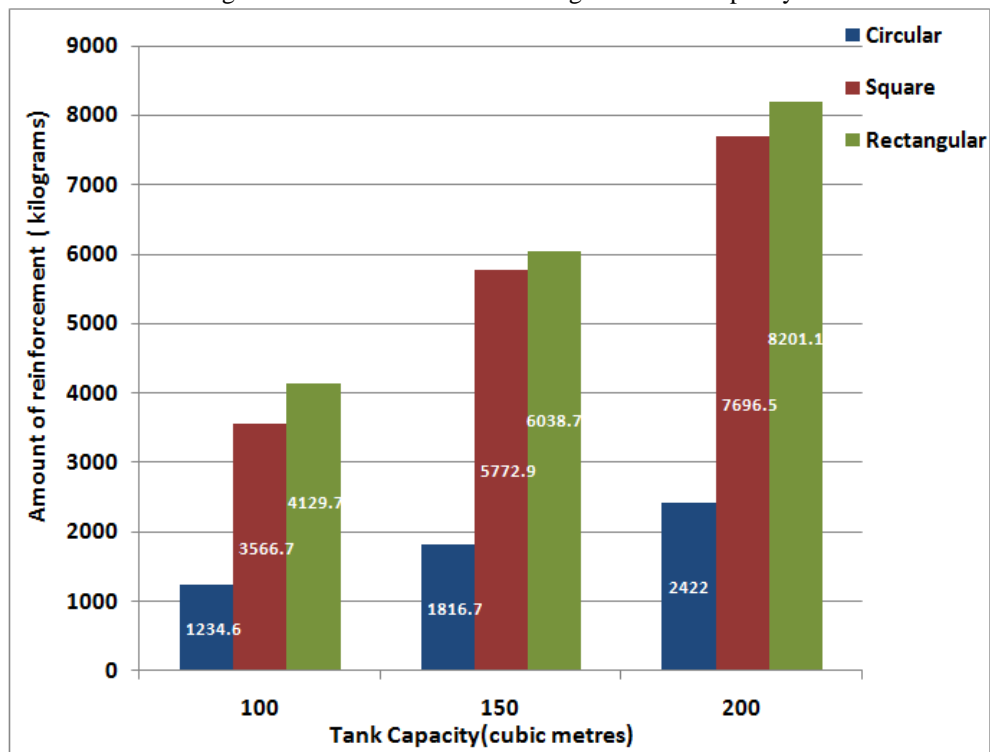
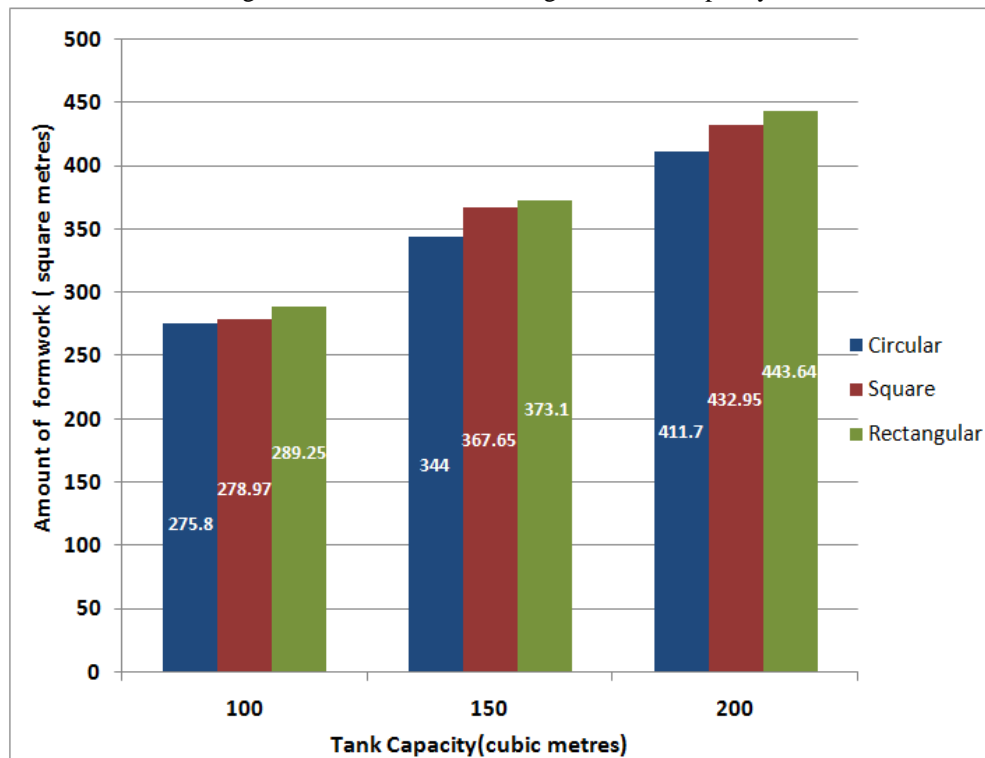


Table 3: Amount of Formwork in square meters

Tank Capacity(kl)	Circular O.H.T	Square O.H.T	Rectangular O.H.T
100	275.8	278.97	289.25
150	344	367.65	373.14
200	411.7	432.95	443.64

Fig 9: Amount of Formwork against Tank Capacity



Assessing the relative reductions in the amounts of materials for the circular tanks when compared with those of square and rectangular tanks, it could be deduced that if the relative ease of putting up the shuttering; that is the formwork, would be significantly more challenged in the construction of the circular tanks, their presumed material-quantity advantage could be given up for a selection of rectangular tanks (though with potential increase in material-requirements).

V. Conclusions

- As the capacities increase, the amounts of materials for the structure also increases. But, a rather non-perfect proportionality resulted; that is, a proportional increase in the capacity would not, necessarily lead to a proportional increase in any of the materials required.
- The quantities of materials needed for the rectangular water tank were constantly more than those needed for square tank which is more than the quantity required for the circular water tank, at each varied capacity.
- 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 square shaped and rectangular shaped tanks.
- Generally, the construction material-outputs for all water tank capacities would be based on the choice of the design considerations and from the results obtained here points out that the circular shaped tank is the most economical among other two shapes considered for study as per IS3370 – 2009 adopting limit state method of design.

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