International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 3 Issue 9, September- 2014

Optimization of Circular Elevated Service Reservoir

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Abstract :- **This research is an application of optimization technique to the structural design of elevated circular water tank with flat top and flat bottom slab, for varying tank capacities and varying the D/H ratio, with fixed supporting structure height, basic wind speed & soil bearing capacity conditions. The objective of the research is to arrive at an optimum geometry of a given capacity of water tank, using continuity analysis method. The elevated circular water tank is found to be insignificant for D/H ratio consideration with small capacities of tank, while the D/H ratio is more significant for higher capacities of E.S.R.**

Keywords–Optimization, Tank capacity, D/H ratio, Continuity analysis.

1. INTRODUCTION

Elevated circular water tank is an important element of water supply scheme. The main purpose of E.S.R. is to store the water and distribute it to the various zones as per the required hydraulic pressure to varioussections of community.

For a tank form structure to be economical, it must be efficient not only in enclosing space, but also in resisting the stored water loads. Each component of the tank should be designed such that it transfers all loads including wind load safely to the ground.

In general, the choice of structural form is based on approximated thumb rules. Elevated circular water tanksare visuallyprominent structure as they areaesthetically good-lookingand economicalstructures. Circular water tank with flat roof & base slab is used for all types of capacities due to its simplicity in geometry which gives economical result & better stability in seismic prone zones. In this paper cost comparison is carried out for different capacities of water tanks with various combination of D/H ratio.

2. TYPES OF E.S.R.

The E.S.R. is classified according to its shape as follows:-

1. Rectangular tank
2. Intze tank
3. Circular tank

Circular water tank with flat roof & base slab is used for all types of capacities due to its simplicity in geometry which is economical and provides better stability in seismic prone zones.

3. DIMENSIONAL PARAMETER

The term “dimensional parameter” refers to the relative ratios between dimensions of a given form that fix its shape. The parameters and shapes of tanks vary according to their shapes and capacity. As far as the framed supporting structures are concerned, the vertical distance between two levels of horizontal braces is 3m.

4. THEORETICAL FORMULATION

In this study, water tank is analysed using continuity analysis method because it is assumed that joints are monolithic therefore one need to construct the various components of water tank simultaneously for ensuring monolithicness. W.P.S. Dias and M.T.P. Hettiarachchi[(16)] analysed four different elevated water tanks, for cost comparison and found that the cylindrical tank form is the cheapest form for lower capacities, while the Intzetank form isthemost economical for higher capacities. The present work employs continuity analysis for studyingvarious combinations of depth & accordingly diameter of circular water tank, for finding an optimum geometry for elevated circular water tank with flat top and bottom for known capacity.

4.1 Design Approach

All the components of the ESR are analysed considering Dead load, Live load, Wind load and Earthquake forces and their various combinations. Also, the ESR is analysed for the tank full and tank empty conditions. The permissible stresses in material are increased by 33% for wind force. Whenever the effect of wind and seismic forces together are taken into account, the safe bearing capacity of soil is increased by 25%. The design is done in accordance with the procedure laid down in *I.S: 3370-1967 Part I-IV (1).*

4.2 Continuity Analysis

In this analysis the stresses are obtained by applying the principle of consistent deformation. The vertical displacement is always same at each joint. Now,as eachwall is free to deform in horizontal direction hence

consistency needs to be satisfied for horizontal forces & angular displacement between the walls meeting at a joint.
In the circular water tank for continuity analysis, wall is restrained at any end;therefore the expansion and angular movement of the wall atthat point will be restraineddue to a bending moment and a radial force as shown in Figure 1.

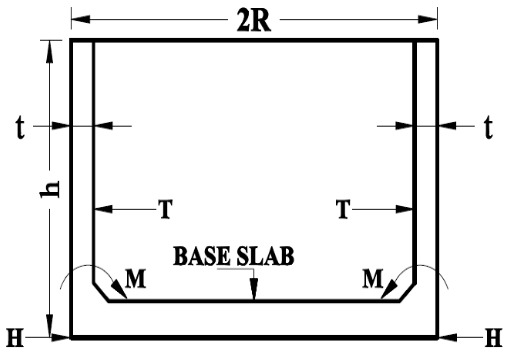

Figure 1 Bending moment and radial force in circular tank walls

The bottom edge of a tank wall is subjected to a clockwise moment and an outward radial force. The following equations give the moment and hoop tension in the wall atany levelof tank height.

$$T = Ete^{\wedge}(-\mu x)\ [Mo\mu\ [\cos \mu x - \sin \mu x] + \quad Ho\cos \mu x]/\ 2R\mu^{\wedge}3\ Z \quad (1)$$

$$M = e^{\wedge}(-\mu x)\ [Mo\mu\ [\ \cos \mu x + \sin \mu x] + \quad Ho\sin \mu x]/\ \mu \quad (2)$$

The joint reaction, clockwise moment and outward radial force at bottom of a tank depend upon its condition of fixity and pressure distribution.

Where$Mo = \lfloor 1 - 1/\mu h \rfloor\ wh/2\mu^2$

$Ho = -\lfloor 2\mu - 1/h \rfloor\ wh/2\mu^2$

$$\mu^4 = \frac{3}{R^2\, t^2}$$

$$Z = E\ \frac{t^3}{12}$$

The above equations areusedfor calculating bending moment and hoop tension in the wall at any level above the base.

5. DESIGN PARAMETER

The identified parameters of significance for study are as follows:

1. Tank capacity
2. Container shape & size

The elevated tanks are designed for the following volume capacities.

- Circular tanks – $25m^3$,$50m^3$,$75m^3$,$100m^3$,$150m^3$,$200m^3$,$250m^3$, $300m^3$ to $1000m^3$, $1250m^3$, $1500m^3$, $1750m^3$, $2000m^3$.

The tank capacity rangeis chosen on the basis of existing practices observed in literature review. The elevated tank capacities are designed for the supporting staging height of 9m, which is assumed to be a base line for constructing tanks in India.
The above combinations (of the capacity & supporting structure height of elevated tanks) are designed for Zone IV. Therefore, the basic wind speed considered is 39.0 m/sand soil bearing capacity is $200kN/m^2$.

6. PARAMETRIC STUDY

In the present parametric work, continuity analysis method is used toanalyse the tank andcost comparison is done to optimize with various combination of D/H ratio of the tank.
The range of variable parametersis as mentioned below:

1. Tank Capacity 25 Cum to 2000 Cum
2. Height of container tank varies from 2.8m to 6.8m depending upon the capacity.

The variation in cost of tank for different D/H ratio is shown with the help of graphs.

6.1. Variation incost for capacities with respect to D/H ratio from 25cum to 500 cum

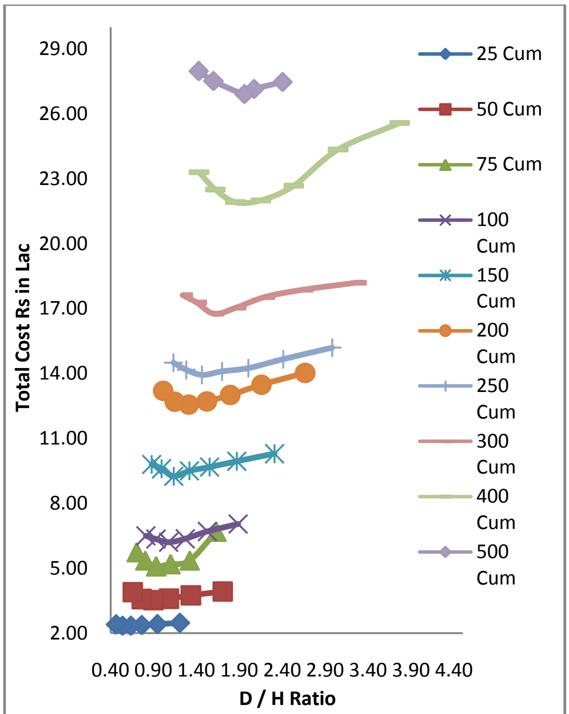

Figure.2 Variation in cost for capacities between 25-500 Cum

Figure 2: Shows Total cost Vs D/H ratio.The above graph indicates the following conclusion:

1. For capacity ranging from 25 Cum to 500 Cum thereisnosignificant change in optimum cost of tank because it is nearly same as that of highest cost of tank. Therefore, for small capacity of tanks, variation of D/H ratio is not significant.
2. Initially for all capacities, the total cost of tank decreases as the D/H ratioincreasesup to a pick point and from that point there is an increase in cost of tank.
3. As the D/H ratio increases, total cost of tank tends to form an inverted parabolic profile.

6.2. Variation in cost for capacities with respect to D/H ratio from 600cum to1000 cum

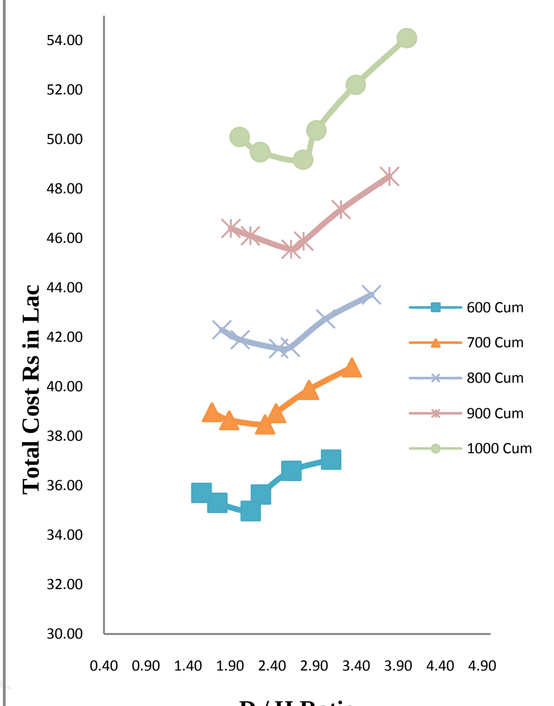

Figure.3 Variation in cost for capacities between 600-1000 Cum

Figure 3: Shows Total cost Vs D/H ratio. The above graph indicates thefollowing conclusion:

1. The capacities ranging from 600 Cum to 1000 Cum are more economical compared to capacity ranging from 25 Cum to 500 Cum.
2. As the D/H ratio increases the total cost of tank tends to form as a 'V' shape profile.
3. Initially, for all capacities, the total cost of tank decreases as the D/H ratio increases up to a pick point and from that point there is an increase in cost of tank with increasing D/H ratio.

6.3. Variation in cost for capacities with respect to D/H ratio from 1250cum to2000 cum

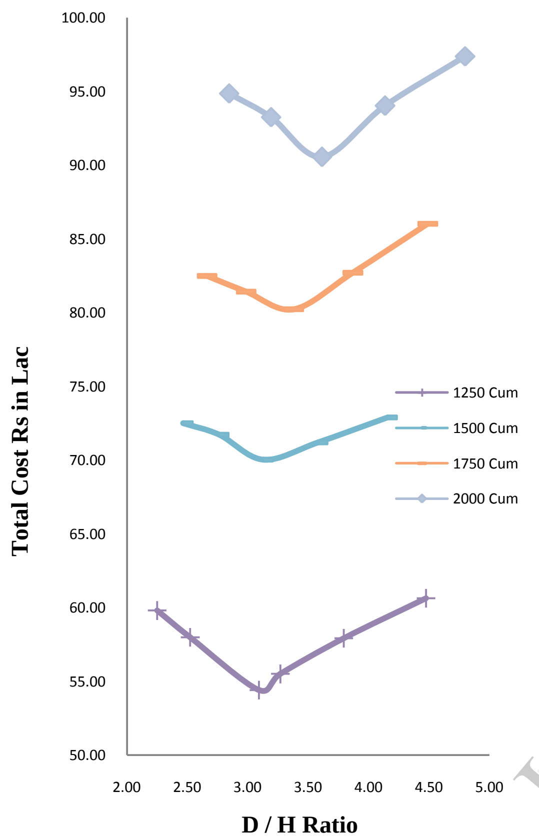

Figure.4 Variation in cost for capacities between 1250-2000 Cum

Figure 4: Shows Total cost Vs D/H ratio. The above graph indicatesthefollowing conclusion.

1. Cost of tank reduces significantly for capacities ranging from 1250 Cum to 2000 Cum.
2. Tanks are more economical for capacity greater than 1000 Cum.
3. As the D/H ratio increases the total cost of tank tends to form as a'V' shapes profile.
4. Initially for all capacities, the total cost of tank decreases as the D/H ratio increases up to a pick point and from that point there is an increase in cost of tank with increasing D/H ratio.

6.4. Variation ofOptimum cost for optimum D/H ratio

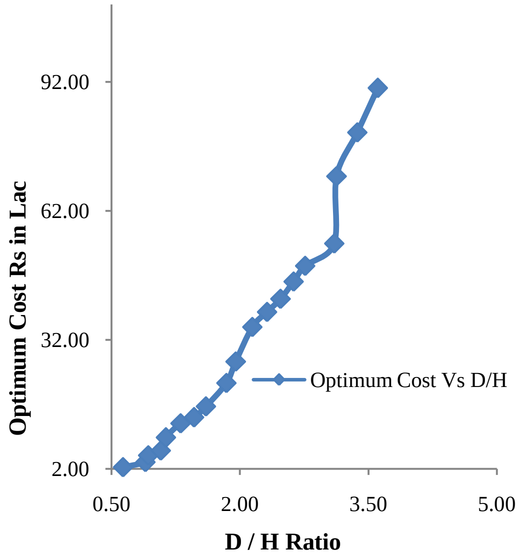

Figure.5 Optimum cost Variation for optimum D/H ratio

Figure 5: Shows the variation in optimum cost Vs corresponding D/H ratio. It is observed that the optimum cost of tank increases mildly with increasing D/H ratio for lower capacities. For higher capacities,optimum cost of water tank increases steeply with increasingcorresponding D/Hratio.

6.5. Variation ofOptimum cost for capacity of tank.

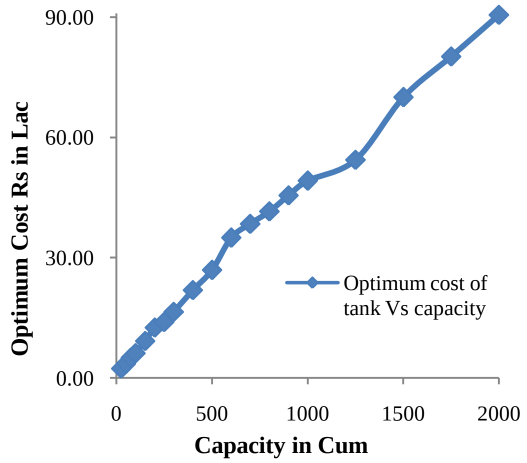

Figure.6 Optimum cost variation for tank capacities

Figure 6: Shows the variation in optimum cost Vs capacity. It is observed that the optimum cost tends to form nearly linear variation with respect to increasing capacities of E.S.R.Becomes more economical with increasing capacity of ESR.

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6.6. Variation ofOptimum cost for optimum D/H ratio.

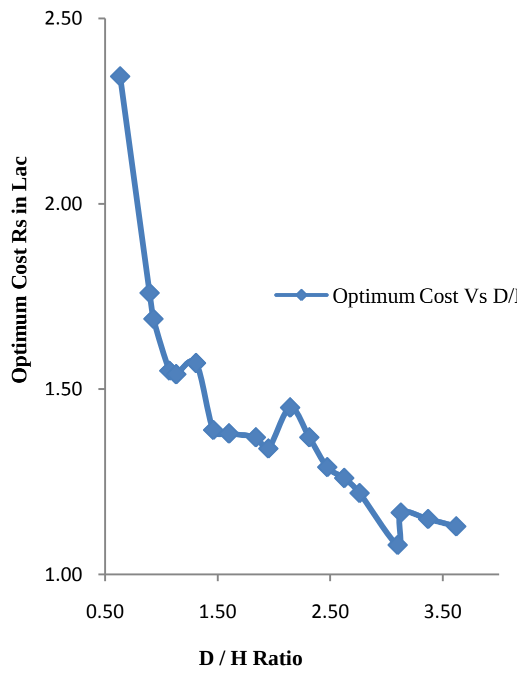

Figure.7 Optimum cost variation per 25 cum of its capacity

Figure 7: Shows optimum cost Vs D/H ratiofor various water tank capacities. The above graph indicates the following:

The cost of water tank per 25 Cum of its capacity decreases with increasing capacity of water tank, however, it is observed that there is a minor increasein the cost at certain points with increasing D/H ratio.

7. COMPARISON WITH PARAMETRIC STUDY

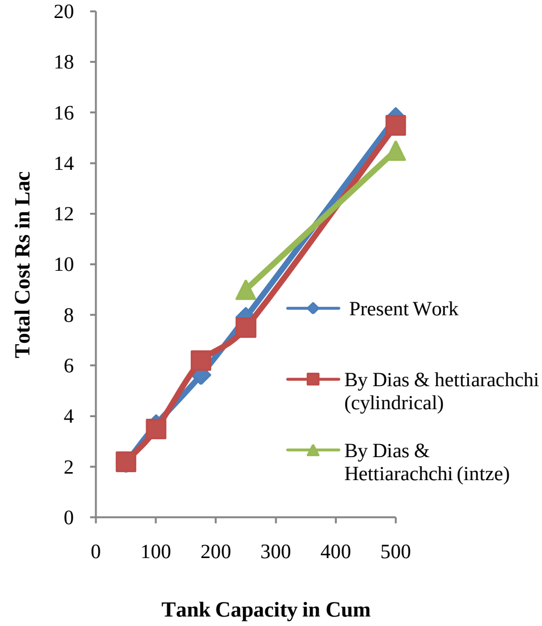

Figure.8 Cost comparision between cylindrical & intze tank

Figure 8: Shows the comparison of the total cost of cylindrical water tank with thosereported by Dias and Hettiarachchi (1992). The above graph indicates thatthe results of the present study are in close agreement with those reported by Dias and Hettiarachchi(cylindrical). It is also found that theintze water tank is more economical in comparison with cylindrical water tank of capacity 500 Cumand for lower capacity (400 Cum) cylindrical water tank is economical.

8. CONCLUSION

1. The optimumcost of circular water tank varies with increasing D/H ratio with respect to capacity of E.S.R. asmentioned below:

   a) For tank having capacity up to 500Cum, the optimization that can be achieved is up to 10% of the total cost of tank.

   b) For tank having capacity between 600-1000 Cum, the optimization that can be achieved is up to 18% of the total cost of tank.

   c) For tank having capacity between1250-2000 Cum, the optimization that can be achieved is up to 28% of the total cost of tank.

2. Initially for all capacities, the total cost of tank decreases as the D/H ratio increases up to a pick point and from that point there is an increase in cost of tank with increasing D/H ratio.

3. For higher capacities, (more than 1000 Cum) cost of water tank increases steeply with increasing D/H ratio.

4. The cost of water tank per 25 Cum of its capacity decreases with increasing capacity of water tank, however, it is observed that there is a minor increasein the cost at certain points with increasing D/H ratio.
5. As the D/H ratio increases, the total cost of tank tends to forman inverted parabolic profile.

6. Theoverall optimization improves with increasing capacity of water tank.

9. NOTATION

E Modulus of elasticity
tThickness of wall
R Radius of the tank.
wWater density
hHeight of tank at any level
xDistance above the base
Mo Clockwise moment at bottom of tank
HoOutward radial force at bottom of tank
M Moment in the wall at any level of tank height
T Hoop tension in the wall at any level of tank Height

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