Design of Economical Size of OHTs by Optimizing H/D Ratio

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Abstract – The Overhead water tanks are built for direct distribution by gravity flow without pumping and are usually of capacities ranging from 50KL – 3000KL.

Index Terms – OHTs, H/D Ratio, Optimizing.

1. INTRODUCTION

Circular Overhead tanks are widely used as the circular shape has least perimeter.

Here we are studying only the Elevated tanks, which have circular reservoir of required quantity, elevated at a required height termed as staging. The reservoir rests on a ring beam, which is supported by columns and beams. The top and bottom of reservoir are conical. So, the type of tank is Intze tank. The main advantage of Intze tank is that the inward radical trust of the conical bottom balances the outward radical trust of the spherical bottom.

For large capacity of the tank generally intze type of tank is preferred compared to any other shape. Intze tank can be termed as improved version of cylindrical tanks. In case of cylindrical tank when dome with small rise is used only compressive stresses are produced which helps in making the water retaining structure water tight.

2. OBJECTIVE

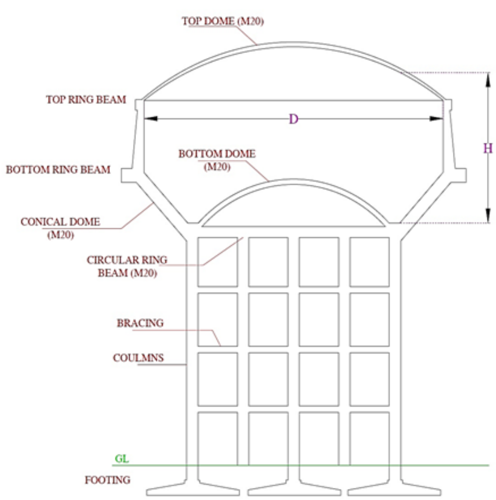


Figure 1

1. To make the study about the analysis and design of water tank.
2. To develop excel spread sheet for water tank to avoid calculations.
3. To prepare Bill of Quantities and evolve estimated cost of tank as per standard rates.
4. To know economical design of water tank by working out with different values of Height of Reservoir/ Diameter of reservoir ie. H/D ratio.
5. Analysing the results obtained by different values of H/D and plotting graph for the same.
6. Obtain economical H/D for different capacities of reservoir ranging from 50KL to 1000 KL.

3. PREVIOUS RESEARCH

M. Bhandari & Karan Deep Singh studied Economic Design of Water Tank of Different Shapes With Reference To IS: 3370 2009 and concluded that 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. The formwork required for the construction of water tank is minimum for circular shaped tank as compared to square shaped and rectangular shaped tanks.

S. A. Halkude & A. B. Jadhav studied Optimization of Circular Elevated Service Reservoir and concluded

i. 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.
ii. For higher capacities, (more than 1000 Cum) cost of water tank increases steeply with increasing D/H ratio.
iii. 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 increase in the cost at certain points with increasing D/H ratio.
iv. As the D/H ratio increases, the total cost of tank tends to form an inverted parabolic profile.

Riyaz Sameer, A. R. Mundhada , Snehal Metkar studied Comparison Of R..C..C.. And Prestressed Concrete Circular Water Tanks and concluded RCC tanks are cheaper only for smaller capacities up to 10-12 lac litres. For bigger tanks, prestressing is the superior choice resulting in a saving of up to 20%.

Keyur Y. Prajapati, H. S. Patel, A. R. Darji studied Economical Aspects of Hybrid Staging Systems for Elevated Storage Reservoir.

They concluded:

i. Graph of total cost revels that total cost of the innovative type water tank staging system of model 2 is nearly equal to frame type water tank model 1.

ii. In case the total cost, innovative type water tank staging system of model 3 is nearly value to shaft type water tank model 5.

Total cost of innovative models of water tank staging systems are nearly of shaft type staging and frame type; but the cost of innovative water tank staging systems of model 4 is considerably higher. However the some extra cost of model 4 but innovative elevated water tanks are prominently aesthetics visible from near as well as from long distances in public view. The innovative supporting structure must receive due attention from the point of aesthetics.

4. DESIGN METHODOLOGY

1. Design of top dome:-

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.

If R = radious of dome

the radius r_{top} is given by, $R = \frac{D/2^2+r^2}{2r}$

Meridional Thrust T1 = w R/(1+ cos □)

Circumferential Thrust T2 = w R x (cos □ – 1/(1+ cos □))

2. Design of 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.

Hoop Tension, F_t = T1cos □ x D/2

3. Design of top cylindrical 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.

Maximum Hoop Tension at the base of the wall, Ft = whD/2

Where, w = density of water = 10 kN/m^3

4. Design of 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.

Horizontal force on beam, H1 = V1 cotθ = 156.46 x cot 45

Horizontal Tension due to vertical loads,

Hg = H1D/2

Hoop Tension due to water pressure

Hw = whdD/2

Therefore, total horizontal Hoop

Tension= Hg + Hw.

5. Design of conical dome

Hoop Tension in the conical dome will remain maximum at the top of the slab, since diameter D is maximum at this section.

Hoop Tension, H = (p cosec □ + q cot □) D/2

6. Design of bottom spherical dome

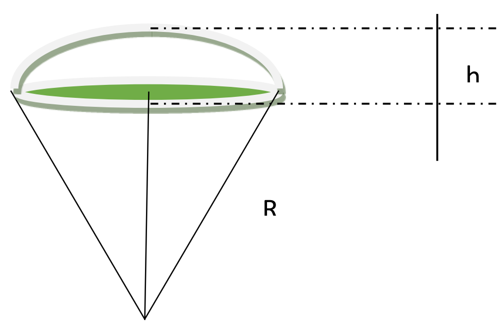


Figure 2

Volume of frustum of sphere = $\pi h^2 (3R – h)$

Surface Area = 2 π R h

If R is the radius of dome,

$(2R-r)r = (D/2)^2$

Meridional Thrust, T1 = w R/(1 + cos θ)

Circumferential Force, T2,at θ = 0 $= w\ R\left(\cos\theta - \frac{1}{1+\cos\theta}\right)$

7. Design of bottom circular girder

Net horizontal force on the ring beam = T1cosα – T2cosβ

Vertical load on the ring beam = T1sinα + T2sinβ

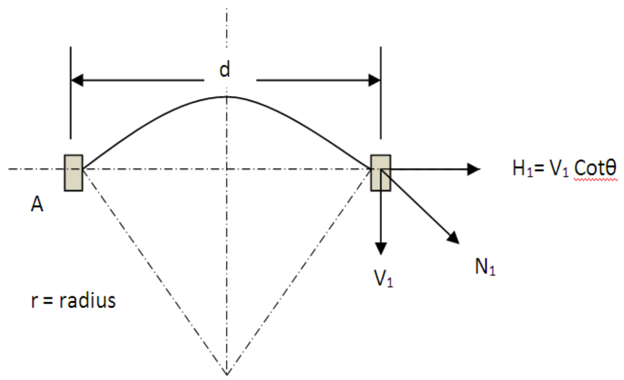


Figure 3

F_1 = Weight of the contents above dome including weight of dome.

Shear force $V_1 = F_1 / (\pi\ d)$

(force per unit length of perimeter)

Circumferential tension in Beam at A = H_1x d /2

8. Design of column supporting tower

i) Basic wind speed V_b = 39 m/s

ii) Design wind speed $V_z = V_b\ k_1\ k_2\ k_3$

For the coefficient , k_1 = 1.06, k_3 = 1.0

iii) Design wind pressure,

= 0.6 V_z^2

iv) Reduction coefficient for circular shape = 0.7

v) Wind pressure on :

1. Top Dome + Cylindrical Wall

9. Design of horizontal bracings

i) Reinforcement for Bending Moment:

Bending moments in horizontal braces due to horizontal loads shall be calculated when horizontal forces (wind) act at a critical direction.

The moment in the braces shall be same of moments in the upper and lower columns at the joint resolved in the direction of Horizontal bracing.

So, moment in the braces = 2 x column moment

(Assuming wind was blowing along the bracing direction).

10. General design considerations:

Intensity of wind	1.50	kN/m^2
Concrete	M 20	
s_{cc}	5	N/mm^2
unit weight	24	kN/m^3
s_{cb}	7	N/mm^2
m	13	
Steel HYSD fy	415	
Resistance to cracking s_{ct}	1.2	N/mm^2
s_{cb}	1.7	N/mm^2
Nominal Cover	25	mm
Effective Cover	40	mm

Finishes load	0.1	kN/m^2
wt of water	10	kN/m^3
Bearing capacity of earth	250	kN/m^2
Tensile stress (Tank)	150	N/mm^2

5. APPROACH AND METHODOLOGY

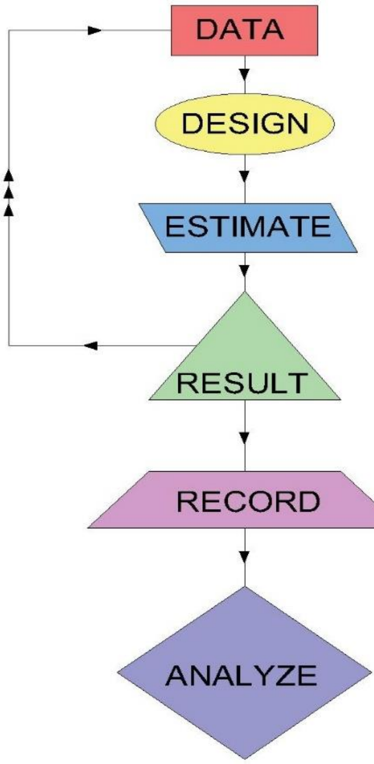
For a very high value of H/D, cost of OHT is higher as width of vertical increases due to hoops stress. Similarly, for very low value of H/D, cost of OHT is higher as diameter of tank increases, more No. of columns and footings are to be provided. So, economical cost can be achieved by optimizing the value of H/D.

So, approach to this thesis would be:

Design Overhead Tank for different values of H/D.

1. Prepare Bill of Quantities (BOQs) and estimates for the same.

2. Record and analyze the cost of OHTs of same capacity & different H/D ratio. Repeat same analysis



6. ANALYSIS

1. Design of Intze tank for capacity of 50KL

Intze tank of capacity 50 Kilo Litres is designed for Height/ Diameter ratio and following results are obtained. The cost obtained at different values of H/D is tabulated below:

S.No.	H/D Ratio	Estimated Cost (Rs. Lacs)	Variation (%)	Steel (Kg)	Concrete (Cum)
1	0.40	9.14	6.16	4604.37	35.77
2	0.50	8.87	3.02	4479.71	31.39
3	0.60	9.00	4.53	4917.27	28.11
4	0.70	9.07	5.35	5104.18	26.09
5	0.80	9.14	6.16	5010.73	25.88
6	0.90	8.78	1.98	4065.81	26.68
7	1.00	8.61	0	3387.93	27.77
9	1.10	8.75	1.63	3230.17	29.25
10	1.2	8.67	0.7	2663.20	30.91
11	1.3	8.81	2.33	2617.62	31.53
12	1.4	9.05	5.12	2664.22	32.99

Table 1

Graph for the results obtained in above table are plotted.

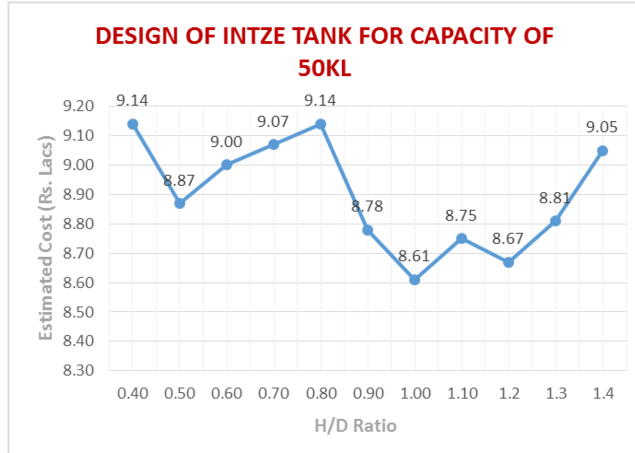


Figure 5

So, Minimum Cost for 50KL OHT is Rs.8.61Lacs at 1.00 H/D Ratio. The cost of the tank increases at 0.8 H/D, as in increase in quantity of steel. The maximum variation between 0.4-1.4 H/D is 6.16% at both 0.4 and 0.8 H/D.

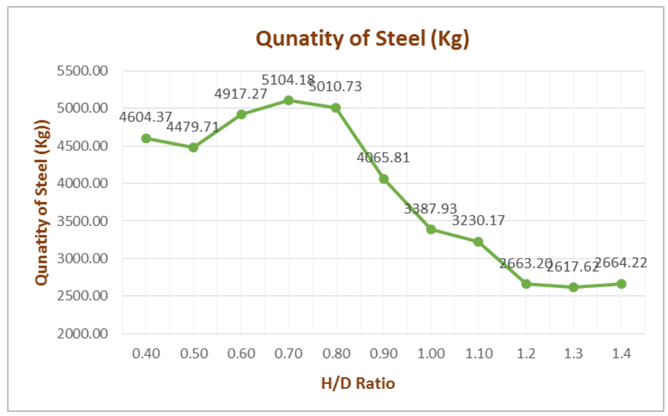


Figure 6

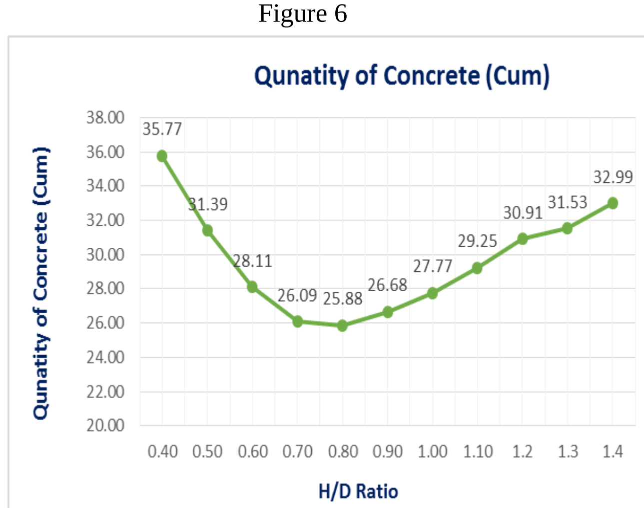


Figure 7

Maximum quantity of steel is 5104.18KG obtained at 0.7H/D ratio and minimum quantity of steel is 2617.62KG obtained at 1.3H/D ratio. Whereas maximum quantity of concrete is 35.78cum obtained at 0.4H/D ratio and minimum quantity of concrete is 25.89cum obtained at 0.8H/D ratio.

2. Design of Intze tank for capacity of 100KL

Intze tank of capacity 100 Kilo Liters is designed for Height/ Diameter ratio and following results are obtained. The detailed design and cost estimation of tank is attached in annexure form Annexure B1 to Annexure B10. The cost obtained at different values of H/D is tabulated below:

S.No.	H/D Ratio	Estimated Cost (Rs. Lacs)	Variation (%)	Steel (Kg)	Concrete (Cum)
1	0.40	12.24	6.35	5280.99	62.42
2	0.50	11.76	2.18	5149.19	53.87
3	0.60	11.65	1.22	5226.39	48.78
4	0.70	11.56	0.44	5091.80	46.13
5	0.80	11.51	0	4862.57	44.67
6	0.90	11.59	0.7	4440.52	47.07
7	1.00	11.55	0.35	3889.34	48.70
8	1.10	11.93	3.65	3907.41	51.99
9	1.20	12.07	4.87	3683.76	53.53
10	1.30	12.37	7.48	3601.64	56.19

Table 2

Graph for the results obtained in above table are plotted.

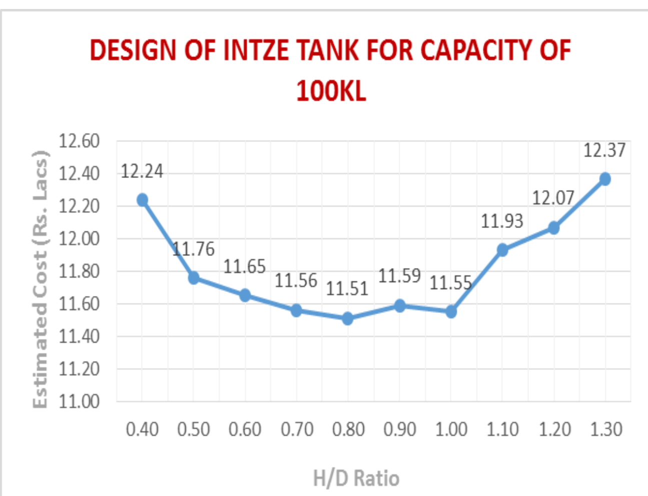


Figure 8

So, Minimum Cost for 100KL OHT is Rs.11.51Lacs at 0.8 H/D Ratio. The maximum variation between 0.4-1.3 H/D is 7.48% at 1.3 H/D.

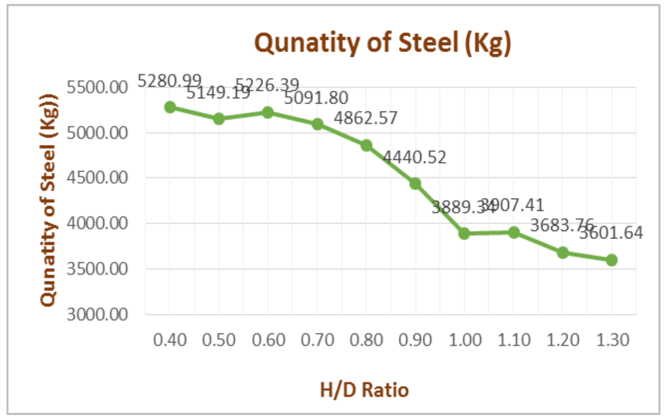


Figure 9

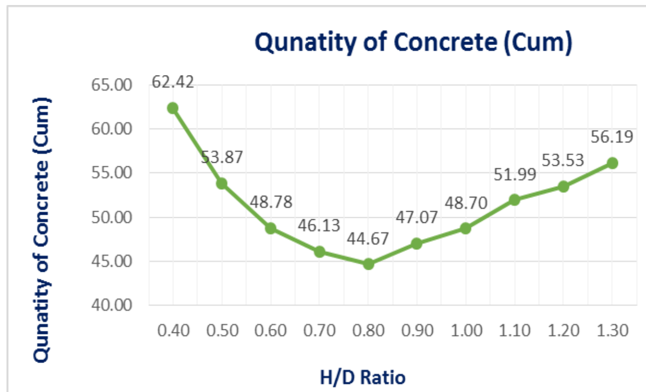


Figure 10

Maximum quantity of steel is 5280.99KG obtained at 0.4H/D ratio and minimum quantity of steel is 3601.64KG obtained at 1.3H/D ratio. Whereas maximum quantity of concrete is 62.43cum obtained at 0.4H/D ratio and minimum quantity of concrete is 44.67cum obtained at 0.8H/D ratio.

3. Design of Intze tank for capacity of 250KL

Intze tank of capacity 250 Kilo Liters is designed for Height/ Diameter ratio and following results are obtained. The cost obtained at different values of H/D is tabulated below:

S.No.	H/D Ratio	Estimated Cost (Rs. Lacs)	Variation (%)	Steel (Kg)	Concrete (Cum)
1	0.40	20.80	12.56	9011.40	138.66
2	0.50	19.64	6.28	8233.89	122.16
3	0.60	18.87	2.12	7820.85	108.90
4	0.70	18.48	0	7448.71	101.16
5	0.80	18.62	0.76	7208.10	101.36
6	0.90	19.01	2.87	7122.34	104.49
7	1.00	19.65	6.34	7136.02	111.48
8	1.10	20.09	8.72	6936.97	116.17
9	1.20	20.47	10.77	6642.71	121.17

10	1.30	21.19	14.67	6868.90	126.66

Table 3

Graph for the results obtained in above table are plotted.

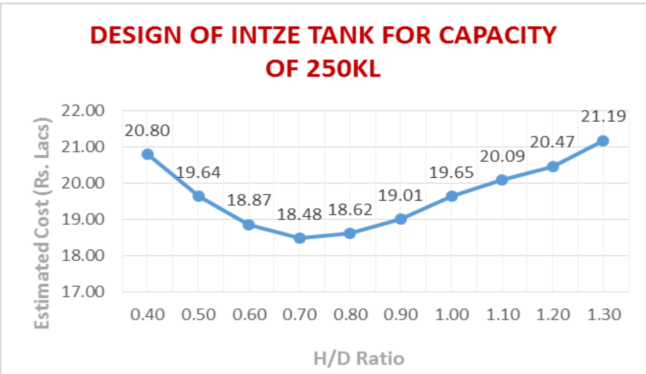


Figure 11

So, Minimum Cost for 250KL OHT is Rs.18.48Lacs at 0.7H/D Ratio. The maximum variation between 0.4-1.3 H/D is 14.67% at 1.3 H/D.

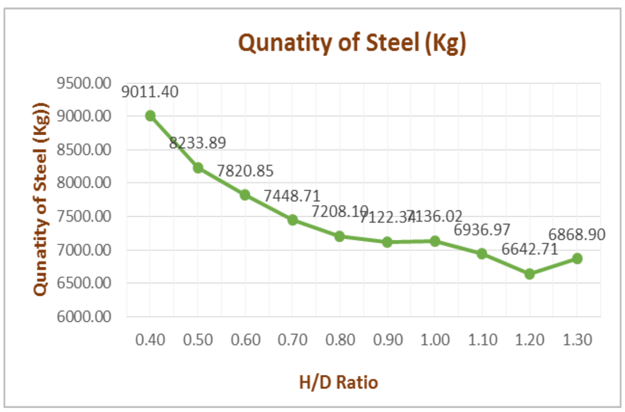


Figure 12

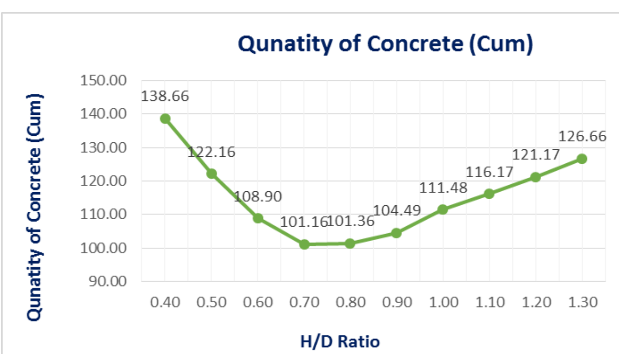


Figure 13

Maximum quantity of steel is 9011.4KG obtained at 0.4H/D ratio and minimum quantity of steel is 6642.72KG obtained at 1.2H/D ratio. Whereas maximum quantity of concrete is 138.66cum obtained at 0.4H/D ratio and minimum quantity of concrete is 101.17cum obtained at 0.7H/D ratio.

4. Design of Intze tank for capacity of 500KL

Intze tank of capacity 500 Kilo Liters is designed for Height/ Diameter ratio and following results are obtained. The cost obtained at different values of H/D is tabulated below:

S.No.	H/D Ratio	Estimated Cost (Rs. Lacs)	Variation (%)	Steel (Kg)	Concrete (Cum)
1	0.40	33.79	13.17	15976.37	259.67
2	0.50	31.52	5.56	14614.80	226.51
3	0.60	29.95	0.31	13485.14	202.85
4	0.70	29.86	0	13589.03	193.59
5	0.80	29.92	0.21	13112.03	192.50
6	0.90	30.46	2.01	12597.60	201.24
7	1.00	31.61	5.87	12721.70	214.57
8	1.10	32.77	9.75	13328.69	223.69
9	1.20	34.19	14.51	14173.65	234.65

Table 4

Graph for the results obtained in above table are plotted.

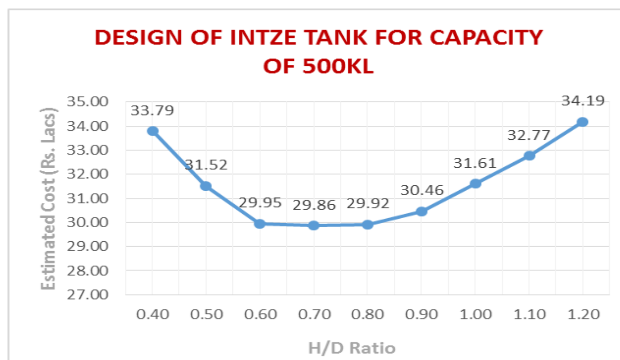


Figure 14

So, Minimum Cost for 500KL OHT is Rs.29.86Lacs at 0.7 H/D Ratio. The maximum variation between 0.4-1.3 H/D is 14.51% at 1.3 H/D.

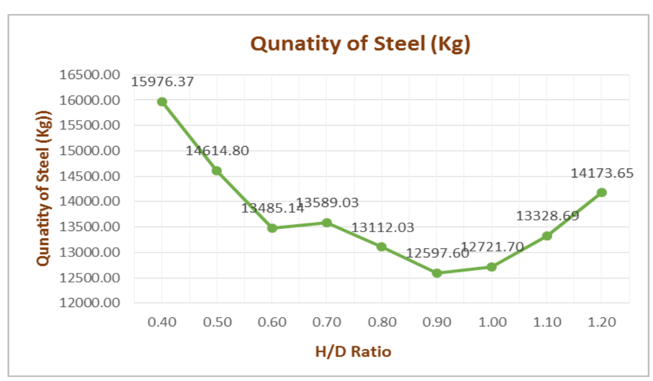


Figure 15

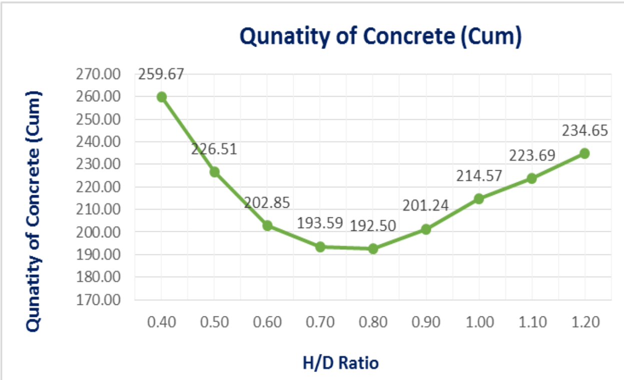


Figure 16

Maximum quantity of steel is 15976.38KG obtained at 0.4H/D ratio and minimum quantity of steel is 12597.61KG obtained at 0.9H/D ratio. Whereas maximum quantity of concrete is 259.68cum obtained at 0.4H/D ratio and minimum quantity of concrete is 192.5cum obtained at 0.8H/D ratio.

5. Design of Intze tank for capacity of 1000KL

Intze tank of capacity 1000 Kilo Liters is designed for Height/ Diameter ratio and following results are obtained. The cost obtained at different values of H/D is tabulated below:

S.No.	H/D Ratio	Estimated Cost (Rs. Lacs)	Variation (%)	Steel (Kg)	Concrete (Cum)
1	0.40	62.70	12.96	39040.41	498.98
2	0.50	58.75	5.84	36713.62	439.35
3	0.60	56.58	1.93	35099.96	405.03
4	0.70	55.51	0	34311.37	383.80
5	0.80	55.59	0.15	33798.80	380.95
6	0.90	57.96	4.42	35183.06	402.89
7	1.00	60.33	8.69	36319.32	427.66
9	1.10	63.72	14.8	39716.61	447.30

Table 5

Graph for the results obtained in above table are plotted.

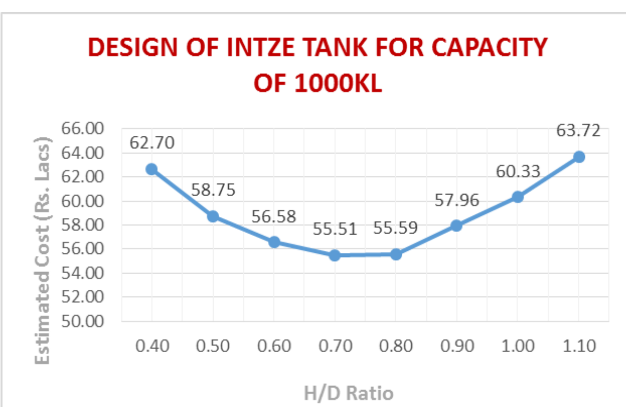


Figure 17

So, Minimum Cost for 1000KL OHT is Rs.55.51Lacs at 0.7 H/D Ratio. The maximum variation between 0.4-1.3 H/D is 14.80% at 1.3 H/D.

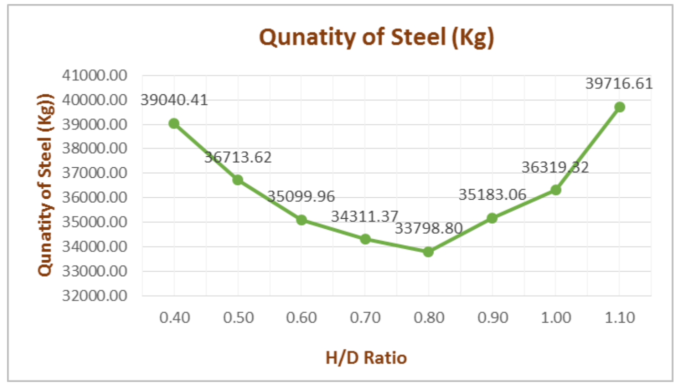


Figure 18

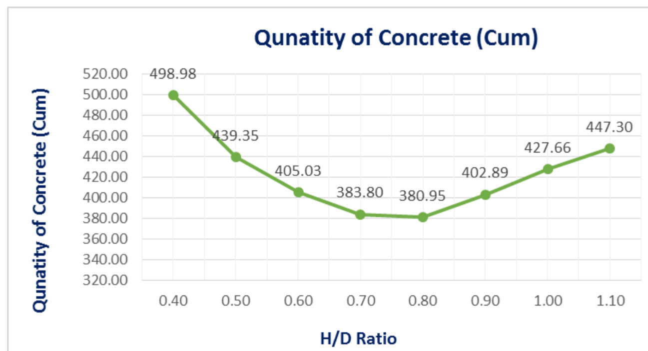


Figure 19

Maximum quantity of steel is 39716.62KG obtained at 1.1H/D ratio and minimum quantity of steel is 33798.8KG obtained at 0.8H/D ratio. Whereas maximum quantity of concrete is 498.99cum obtained at 0.4H/D ratio and minimum quantity of concrete is 380.95cum obtained at 0.8H/D ratio.

7. RESULT

1. Optimum H/D ratio for all capacities

Capacity (KL)	Optimum H/D Ratio	Min. Cost (Lacs)
50	1.00	8.61
100	0.80	11.51
250	0.70	18.48
500	0.70	29.86
1000	0.70	55.51

Table 6

Graph for the results obtained in above table are plotted.

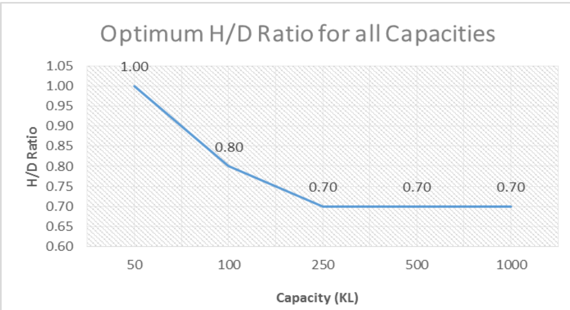


Figure 20

2. Min. & max cost of OHTs

Capacity (KL)	Min. Cost (Lacs)	Max. Cost (Lacs)	Variation (%)
50	8.61	9.14	6.16
100	11.51	12.37	7.48
250	18.48	21.19	14.67
500	29.86	34.19	14.51
1000	55.51	63.72	14.8

Table 7

Graph for the results obtained in above table are plotted.

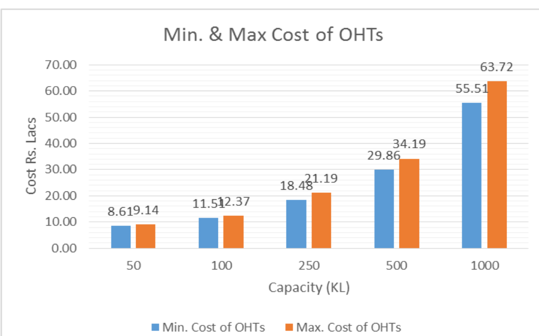


Figure 21

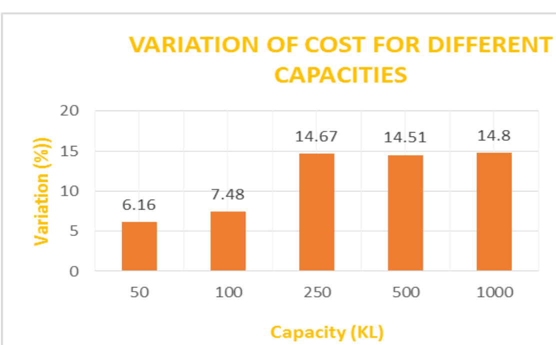


Figure 22

3. Cost per kilolitre

Capacity (KL)	Min. Cost (Lacs)	Cost per KL (Lacs)
50	8.61	0.173
100	11.51	0.116
250	18.48	0.074
500	29.86	0.06
1000	55.51	0.056

Table 8

Graph for the results obtained in above table are plotted.

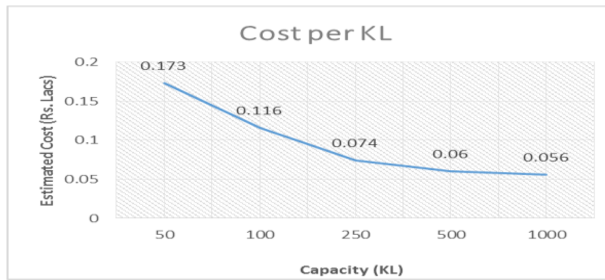


Figure 23

4. Optimum H/D ratio for min. Quantity of steel and concrete

Capacity (KL)	Minimum Quantity of Steel (Kg)	Optimum H/D Ratio for min. quantity of steel	Minimum Quantity of Concrete (Cum)	Optimum H/D Ratio for min. quantity of concrete
50	2617.62	1.3	25.88	0.8
100	3601.64	1.3	44.67	0.8
250	6642.71	1.2	101.16	0.7
500	12597.60	0.9	192.50	0.8
1000	33798.80	0.8	380.95	0.8

Table 9

Graph for the results obtained in above table are plotted.

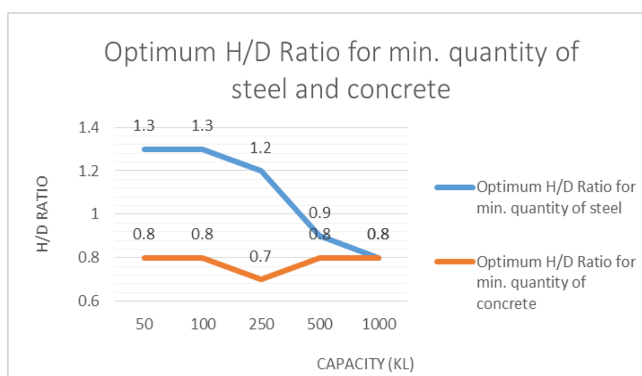


Figure 24

8. CONCLUSION & SCOPE OF FUTURE WORK

8.1. During study of topic "Design of economical size of OHTs by optimizing H/D ratio" following points are observed:

1. Over Head Tank (OHT) is designed for different values of H/D varying from 0.4-1.2. It is observed that lowest cost can be achieved for H/D value ranging from 0.60 to 1.00.
2. For OHTs of lower capacity (50KL- 100KL) optimum H/D is higher i.e. greater than 0.70.
3. For OHTs of higher capacity (250KL and higher) optimum H/D is about 0.70.
4. With increase in capacity optimum value of H/D increases. It increased upto a value of 0.70 and then maintained uniform.
5. Minimum quantity of steel is obtained at 1.3 H/D ratio for lower capacities of OHT while for higher capacities it reduces to 0.8. But, minimum quantity of concrete can be obtained between 0.7- 0.8 H/D ratio for all capacities of OHT.
6. However, for value of H/D ranging from 0.40 to 1.2, a variation upto 15% is observed in total cost of the OHT.
7. For OHTs of lower capacity (less than 100KL) variation of cost is less i.e. 6.5-7.5%. But for OHTs of higher capacity (250KL and higher) variation of cost is more i.e. 14-15%.
8. So, upto 15% of total project cost can be saved by following suggestions described below:

8.1. For OHTs of capacity 100KL and below, adopt H/D ratio between 0.80 to 1.00.

8.2. For OHTs of capacity 100KL – 250 KL , adopt H/D ratio between 0.70 to 0.80.

8.3. For OHTs of capacity 250 KL – 1000KL, adopt H/D ratio between 0.65 to 0.75.

9. It is also observed that cost per liter of OHT decreases with increase in capacity of tank. So, it is more economical to propose single OHT of higher capacity than to propose two OHTs of lower capacity having same volume.

(Eg: 4X 250KL > 2X 500KL > 1X 1000KL)

8.2. Scope of Future work:

1. This thesis is limited to OHTs of capacity 1000KL as these capacities are frequently adopted. So, it also necessary to perform same analysis for OHTs of capacity more than 1000KL.
2. As total height of these tanks are ranging from 10-15m, earthquake forces are not considered in the design. So, same analysis can be performed on OHTs including seismic forces of different zones.
3. For more economical design of Intze type OHTs, analysis for optimum value of d/D (dia. Of bottom circular girder/ Dia. Of reservoir) can be performed, as it can be observed that, with increase in d/D ratio, area for supporting towers increases with increase in no. of columns and decrease in area of footing, and vice- versa can be observed while decreasing d/D ratio.

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