



iJRASET

International Journal For Research in
Applied Science and Engineering Technology



INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 11 Issue: VI Month of publication: June 2023

DOI: <https://doi.org/10.22214/ijraset.2023.53662>

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Design of Circular Overhead Water Tank, Modelling and Analysis Using Staad-Pro

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Abstract: Water tanks are frequently used for storing potable water. Due to inadequacy of water around the world, significance is given more on the water storage project. So water storage is very essential as it plays a vital role in everyday life. water tanks and Storage reservoirs are used to store water, petroleum products, liquid petroleum, and similar liquids. All tanks are analysed and designed as crack free structures to get rid off any leakage. This project provides a brief explanation of the theory underlying the manual analysis and design of an overhead circular water tank using the Working Stress Method (WSM) and software modeling and analysis using Stat-Pro.

Keywords: Overhead Circular water tank, Staad-Pro, Population Forecasting Method, Limit State Method, Working State Method, IS Code

I. INTRODUCTION

Water is an essential necessity for human survival, and the distribution of enough water in a given region depends on the water tank's design. An elevated water tank is a type of water storage container used to maintain a water supply at a height high enough to pressurize a water distribution system. They were swept away by the wind. Damage of the important lifeline facility like elevated water tanks often results in significant hardships even after the occurrence of the disaster, claiming human casualties and economic loss to build environment. Investigating the effects of wind has been recognized as a necessary step to understand the natural hazards and its risk to the society in the long run. Because water towers rely on the elevation of water caused by gravity and hydrostatic pressure to force the water into home and industrial water distribution systems, they can provide water even when there is no electricity.

A. Objective

- 1) To make a study about design of water tank.
- 2) Design of Circular Overhead Water Tank by WSM and other staging members by LSM Method.
- 3) To make a study about the Analysis of Water Tank using Staad-Pro.
- 4) To make a study about the guidelines for the Design of Liquid retaining Structures according to IS Code.

II. METHODOLOGY

In this project we have designed a Water Tank Manually and same analyzed on Staad-Pro software.

A. Data Collection

Details of data collection

1.	Capacity of tank	140000 L.
2.	Soil bearing capacity	125 KN/sq.m at minimum depth 3.00m
3.	Height of tank from ground	12m
4.	Grade of steel	fe500
5.	Grade of concrete	M30

	Ground water table	Maximum height of water table is assumed to be well below the foundation strata level hence no uplift pressure has been considered in the design footing.
6.	External force on tank	Basic wind speed 39m/s
7.	Free board	0.2m
8.	Width of gallery	1m
9.	Earthquake zone	III
10.	Use of water	Domestic purpose only
11.	Current population in year 2011	2480
12.	Population forecasting 2041	3500

B. Population Forecasting

We have forecasted the population by using Arithmetic Mean Method. We have collected the data from our proposed site and received data from 1979. Has been forecasted till 2041 by Arithmetic Progression. Population Forecasted is 3500 no of people.

III. DESIGN CRITERIA

A. Loads

- 1) **Dead Load:** The weight of all permanent construction including domes, ring beams, walls, stair case, slabs and foundation are considered. The unit weights of materials are in accordance with IS: 875-1987. The unit weight of Concrete (RCC), Soil, Structural steel is taken as 25 kN/m³, 18 kN/m³, 78.5 kN/m³.
- 2) **Live Load:** The Live load on roof slab, walk way slab and staircase be 1.5 kN/m², 1.5 kN/m² and 2.0 kN/m² respectively.
- 3) **Water Load:** Weight of water due to gross volume is calculated and applied on bottom of container unit wt. of water is 10 kN/m³
- 4) **Wind Load:** As per figure -1 IS: 875(PART-3)-1978) design wind pressure = $0.6Vz^2 = 2117.01 \text{ N/m}^2$
- 5) **Earthquake load (EQ)**

It is in zone-III as per IS 1893 part1 2002

Seismic coefficient $a_h = \beta I F_o (S_a/g)$

β , coefficient of depending upon soil foundation = 1

I, factor depending upon importance of factor = 1.5

So, seismic zone factor for average acceleration spectra = 0.16

S_a/g is considered as per CI 6.3.5, (IS 1893, part-1).

B. Structural design of RCC OHSR

Calculations

1) Dimension of Tank

- Diameter Of Tank D = 7.2m
- Radius = 3.6m
- Height = 4m
- Thickness Of Tank Wall = 170mm

2) Wind load calculations

By using IS 875 Part3 1987 Appendix A.

Basic Wind Speed - 39 m/s.Table 1

$P_z = 0.6 v z^2$ - Design wind speed.

$P_z = 0.527 \text{ kN/m}^2$

3) Seismic Load Calculations

Using IS 1893 Part-1-2016 as the site exist in zone 3
all the parameters taken according to that.

Total Seismic weight on structure,
=4102.04+4102.04+4071.50
=12275.58KN

4) Circular Slab (Top roof)

Diameter D =7.2m
Thickness=170mm
L.L =1.5 Kn/m²
M30 And Fe 500

- Total Load =5.75 Kn/m²
- Max BM = -9.315 Kn.m

$$d_{req} = \sqrt{(M/0.133f_c k b)}$$

$$= \sqrt{(9.315 \times 10^6 / 0.133 \times 30 \times 1000)}$$

$$d_{req} = 48.31 \text{ mm}$$

Provide D =150mm

Using 10mm bar and clear cover 15mm

$$d = 150 - 15 - 10/2 = 130 \text{ mm for bottom layer}$$

$$\text{And } d = 130 - 10 = 120 \text{ mm for top layer}$$

- steel reinforcement at centre (provide in mutually parallel direction)

$$A_{st} = 0.5 f_c k / f_y [1 - \sqrt{1 - (4.6 M u) / (f_c k b d^2)}] b d$$

$$A_{st} = 206.77 \text{ mm}^2$$

$$A_{st \text{ min}} = 0.12 / 100 \times 1000 \times 170$$

$$= 204 \text{ mm}^2$$

Provide min. reinforcement Using 10mm bar

$$\text{Spacing} = 1000 a_{st} / A_{st}$$

$$= 380 \text{ mm}$$

Max. Spacing = $3d = 3 \times 120 = 360 \text{ mm}$ or 450mm }less

Provide mesh reinforcement consisting of 10mm ϕ 360 c/c in mutually both direct at as bottom reinforcement.

At edge = no reinforcement (M_{ϕ})e= 0

5) Design of Top Ring Beam

- Load Of Slab = 4.25 Kn/m²
- For hoop force
- $T = w \times R \times (\cos \phi - 1 / H \cos \phi)$
= 10.35kn/m
- Hoop stress = $10.35 \times 10^3 / 1000 \times 170$
- = 0.06 < 8N/mm² (8 N/mm² = permissible stress in concrete) Table 2, IS 3370 (part 2): 2009
- It is designed for hoop tension -

$$W = T \cos \phi = 10.35 \times \cos 0 = 10.35 \text{ KN/m}$$

Total hoop tension in beam

$$W \times D/2 = \frac{10.35 \times 7.2}{2} = 37.26 \text{ kN}$$

AST for hoop tension

$$T / \sigma_{st} = 37.26 \times 10^3 / 130 = 286.61 \text{ mm}^2 \quad [\sigma_{st} = 130 \text{ N/mm}^2 \text{ Table 4, IS 3370}$$

(part 2):2009]

σ_{st} = permissible stress in steel reinforcement use 12 mm \emptyset bar

To find out dimension of ring beam

$$\sigma_{ct} = T / Ag + (m-1) Ast < 1.5$$

$$Ag = b \times D.$$

Assume $b=230$ mm

$$m = 280 / \sigma_{cbc} = 280 / 3 \times 10 = 9.33$$

σ_{cbc} = permissible stress in concrete [Table2 ,page3 ,IS 3370(Part 2): 2009]

$$\sigma_{ct} = 37.26 \times 10^3 / 230 \times D + (9.33-1) \times 286.61 < 1.5$$

$$= 37.26 \times 10^3 < 345D + 3581.19$$

$$= 33678.808 / 345 < D$$

$$= 97.61 < D$$

Consider $D=350$ mm

Provide minimum shear reinforcement

6) Design of Tank Wall

Max. hoop tension at base,

$$T = (\gamma_w \times H \times D) \div 2$$

$$= (10 \times H \times 7.2) \div 2$$

$$= 72H \div 2$$

$$T = 36H \text{ KN/m}$$

$$Ast = T \div \sigma_{st}$$

$$= (36 \div 130) \times 10^3 = 276.92H \text{ mm}^2$$

To find thickness of wall:-

$$\sigma_{ct} = T \div [Ag + (m-1)Ast]$$

$$T = 36 \times 4 = 144 \text{ KN}$$

$$\sigma_{ct} = 1.5$$

$$Ag = 1000 \times t$$

$$(m-1) = 9.83 - 1 = 8.3 \text{ m/s calculated at ring beam } \sigma_{ct} = (144 \times 10^3) \div [1000 \times t + (8.33 \times 2 \times 565.45)] < 1.5$$

$$= (144 \times 10^3) \div (1000t + 9420.397) < 1.5$$

$$144 \times 10^3 < 1500t + 14130.595$$

$$86.57 < t$$

Provide $t=200$ mm at base and 150mm at top

Average thickness of wall = 175mm

Distribution Steel:-

$$H \div 3 = 4 \div 3 = 1.33 \text{ m}$$

Cantilever moment (m):-

$$M = [\gamma_w \times H \times (H/3)^2] \div 6$$

$$= [10 \times 4 \times (1.33)^2] \div 6$$

$$M = 11.84 \text{ KN-m}$$

Ast for moment = $M \div (\sigma_{st} \times j \times d)$

$J = 1 - (K \div 3)$ from the base slab

$$d = 175 - 50 = 125 \text{ mm}$$

$$\text{Ast for moment} = (11.84 \times 10^6) \div (130 \times 0.85 \times 125) = 857.19 \text{mm}^2$$

7) Design of Base Slab

$$H = 4\text{m} \quad D = 7.2 \quad R = 3.6\text{m}$$

Assume thickness = 250mm

1) load (/m²area)

$$\text{a) weight of water} = 10 \times V$$

$$= 10 \times 1 \times 4$$

$$= 6.25 \text{KN}$$

$$\text{Total} = 40 + 6.25 = 46.25 \text{KN}$$

According IS 3370, part 4 table 20 pg 47

Moment = coefficient X PR² (Kgm/m)

At R = 0, at centre

$$M_r = M_t = +0.075 \times 46.25 \times 3.6^2$$

$$= +4495 \text{KN.m}$$

At support, where R=R

$$M_r = -0.125 \times 46.25 \times 3.6^2$$

$$= -74.92 \text{KN.m}$$

$$M_t = -0.025 \times 46.25 \times 3.6^2$$

$$= -14.98 \text{KNm}$$

Check for d (to check if d_{pro} > d_{req})

$$d_{req} = \sqrt{M_{max} / R \times b}$$

$$= 74.92 \times 10^6 / 1.618 \times 1000$$

(R is design constant)

$$d_{req} = 99.27 \text{mm}$$

d_{pro} = depth of base

Slab 250 mm clear cover = 25 diameter = 20

$$d_{prv} = 250 - 25 - 20 / 2$$

$$= 215 \text{mm} > d_{req}$$

1] Ast for - M_r at support

$$\text{Ast} = M / \text{Sigma St} \times j \times d_{prov}$$

$$= 74.92 \times 10^6 / 115 \times 0.85 \times 215$$

$$= 3564.8 \text{mm}$$

Assume dia. = 20 mm

$$n = \text{Ast} / \text{ast} = 3564.8 / \pi / 4 \times 20^2$$

$$n = 6.80 = 7$$

$$\text{Spacing} = 1000 / n = 1000 / 7 = 142.85 = 150 \text{mm c/c.}$$

Check for shear

$$V = P \times 2R / 2 = 46.25 \times (2 \times 3.6) / 2 \dots\dots R = \text{Radius}$$

$$V = 166.5 \text{KN}$$

$$\text{Tau}_v = V / b d_{prov} = 166.5 \times 1000 / 1000 \times 215$$

$$100 \text{Ast} / b d_{prov} = 100 \times [1000 \times (\pi / 4) \times 20^2] / 1000 \times 215$$

$$= 1.46$$

$$\tau_c = 0.4436 \text{N/mm}^2$$

$\tau_v > \tau_c \dots\dots \text{Not safe}$

Provide a haunch of 20 mm size at the junction.

8) *Design of Brace Beam*

Assuming Beam Size

Square beam = 300x300 mm

Length between bracing= 3.8m

Total load = 2.5 + 2.25 + 5.375= 10.125Kn/m

Effective depth= 300- 50 = 250mm

Load calculation= Design load = 10.125 x 1.5

= 15.187KN/m

Moment calculation= $M_u = w \times L^2 / 8$

= 15.187 x (3.8)²/8

= 27.41KNm

$M_{ub} = 0.138 \times f_{ck} \times b d^2$

= 111.78 x 10⁶ KNm.

$M_{ub} > M_u$hence singly reinforced beam

9) *Design of Bottom Ring Beam*

- Total vertical load = $v_1 = 31.875$ KN/m.
- Horizontal force = $H = v_1 \cos \phi = 31.875$ KN
- Hoop tension due to vertical loads-
- $H_g = H \times D / 2 = 26.775 \times 7.2 / 2$
= 96.39 KN.
- Hoop tension due to water pressure
- $H_w = w \times h \times \text{depth of beam} \times \text{dia} / 2$
= 10 x 4 x 0.350 x 7.2 / 2. = 50.4 KN
- Total hoop tension = $H_g + H_w = 96.39 + 50.4 = 146.79$ kN
- $A_{st} = 146.79 \times 10^3 / 150 = 978.6$ mm²

10) *Design of Column*

6 Columns equally spaced on 7.2m diameter circle

Height of Column=12m

Distance between Columns=3.8m

Diameter of Column=300mm

$P_u = 1095.845$ KN

Condition:-

Column is effectively held in position. and restrained against rotation in both ends.

Leffective =6m

Slenderness ratio =20mm>12mm

Minimum Eccentricity:

$e_{min} = 34$ mm>20mm

Area of Reinforcement(A_{sc}):-

$A_g = (\pi \div 4) \times (300)^2 = 70685.83$ mm²

$A_c = 70685.83 - A_{sc}$

$P_{uz} = 0.4 f_{ck} \cdot A_c + 0.67 f_y \cdot A_{sc}$

$$1095.845 \times 10^3 = [0.4 \times 30 \times (70685.83 - Asc)] + (0.67 \times 500 \times Asc)$$

$$Asc = 766.61 \text{ mm}^2$$

Assume 5% of steel,

Adopt 12mm \varnothing bar

Helical Reinforcement:-

Assume cover 40mm

Core Diameter(d_c)=220mm

Area of Cover(A_c)=38013.27mm²

P=Pitch of Spiral ties

V_c =Volume of core =38013.27×P

Using 10mm & spirals (helical reinforcement)

Provide pitch of 30mm

11) Design of Footing

Area of Footing:-

As per IS code guidelines self wot of footing to taken 10% of column load

As load carried by column is 1095.85KN

Note: Design of square footing is done exactly in the same manner as PL was for square column

Side of square column:-

$$b = 0.717D = 0.717 \times 300 = 215.1 \approx 220 \text{ mm}$$

Note- As per IS recommendation for the purpose of design of footing for circular column the size of column is taken as 0.7170 times dia.

$$\text{Area of Footing} = \text{Load} \times \text{SBC} = 1205.4295 \times 125.12$$

SBC is taken as per test results on site

$$1205.4295 \div 125.12 = 9.63 \text{ m}^2$$

Side of square footing

$$B = \sqrt{9.63} = 3.10 = 3.2 \text{ m}$$

Therefore size of square footing for circular column

$$B \times B = 3.2 \times 3.2 \text{ m}$$

Net upward pressure (P_o) =117.71KN

Step-Depth of Footing on the basis of BM

$$M = P_o(B \div 8)(B - b)^2$$

Now, Ultimate moment (M_u):-

$$M_u = 1.5 \times M$$

$$= 1.5 \times 395.97$$

$$M_u = 593.955 \text{ KN-m}$$

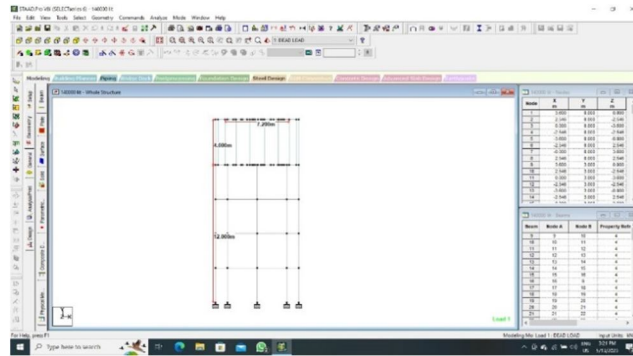
D_{req}

$$d = 215.68 \text{ mm} \approx 220 \text{ mm}$$

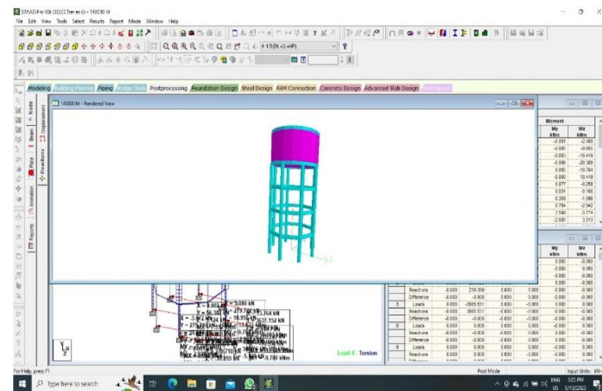
$$A_{st} = 3582.34 \text{ mm}^2$$

Footing has been checked for one way and two way shear, it has been safe.

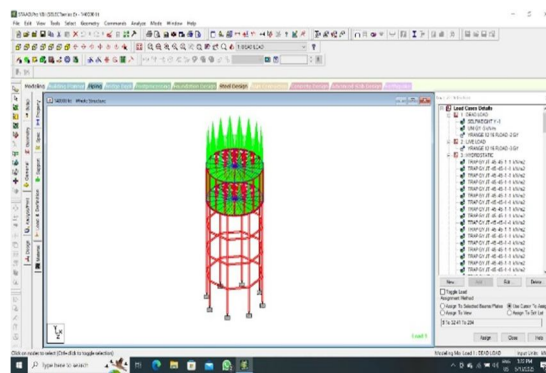
C. Modelling on Staad-Pro



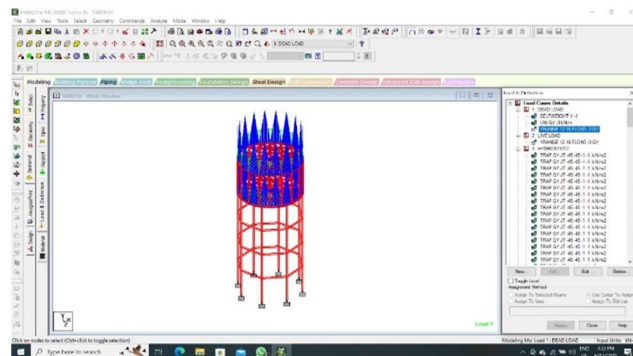
Column-450 mm, Ring Beam- 230 x 380, Slab- 170mm



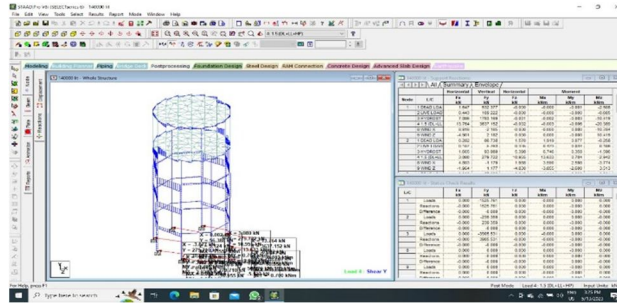
Created model by using material properties



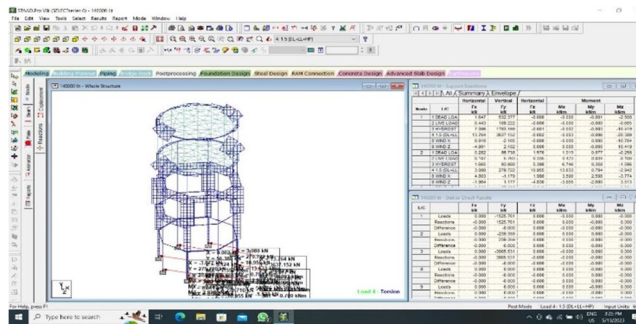
Dead Load Application



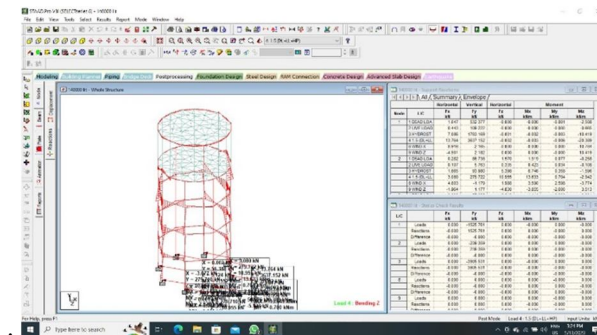
Hydrostatic Load Application



Shear Forces



Bending Moments



Torsional Moments

IV. CONCLUSION

- 1) The tank has been analyzed in STAAD Pro software.
- 2) In terms of the loads used, tank design is safe from software design.
- 3) We use circular water tanks for larger capacity while rectangular water tanks are used for smaller capacities. Since our proposed tank is of 1.40 lakh capacity we had prepared and analyzed the circular over head tank in STAAD Pro software.
- 4) Design of water tank is also done by manually by WSM and LSM method.
- 5) Design of water tank by manually and by using software are within limit and safe.

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IS code

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