Analysis and Design of Intze Water Tank by Using STAAD Pro

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Abstract. Water tank is a water storage structured built for long term use. These tanks were utilized for various uses like distribution of water, firefighting, agriculture, food industry, paper mills etc. It comes in handy when there is an intermittent supply of water or scarcity of water. Materials like concrete, pvc Galvanized Iron, fibre is used to manufacture tanks. Water is pumped through pipe by using pumps from a source. For distribution purpose water can be distributed either gravity or pump to reach individual with desired pressure and velocity. Volume is calculated based upon population and their usage and demand. Water demand varies hour to hour. For a continues supply water tanks are best suited. To meet water demand by public water tanks are to be constructed. Design and analysis are similar for any liquid present in water tank but is should be crack free to avoid leakage

1 Introduction

Overhead tanks and reservoirs are liquid storage containers. These containers are generally used for storing water for irrigation works, human consumption, fire, manufacturing units, rainwater harvesting, and for many purposes. The main purpose of design of tanks are economical, strength, service life, to provide safe portable drinking water after storing for a long time and it also resist special conditions like wind and earthquakes. Water tanks are generally constructed with reinforced concrete or steel and design is based on IS code. Design of tanks depends on the position of tank i.e, above or below, at the ground level. The overhead tanks are generally constructed at certain height from the ground level using columns and braces, for direct distribution of water by gravity. In any case, the underground tanks are rest underneath the ground level.

2 Effect of Wind

The wind pressure acting on a Design structure are processed by method suggested as per the IS code.

Design wind speed (V_z) at any elevation can be determined as follows:

$$V_z = V_b \times k_1 \times k_2 \times k_3$$

Where, V_z = Design wind velocity for elevation 'z' in m/sec

V_b = Basic wind speed based on locations.

k_1 = Risk coefficient or Probability factor

k_2 = elevation & construction, Terrain size factor and

k_3 = Topography factor

k_1 , k_2 and k_3 are determined through IS 875 (Part-3) 2015. The design wind pressure for elevation above mean ground level will be acquired by the accompanying connection between wind pressing factor & wind speed

$$P_z = (0.6 V_z^2)$$

Where, P_z is Design Wind pressure (N/m²) at elevation z,

V_z is Design wind speed (m/s) elevation z

3 Intze tank

A German hydraulic engineer is given the name tank as Intze. The water tower built in accordance with the Intze precept has a brick shaft on which the water tank sits. the bottom of the tank is fixed with a hoop anchor (Ring Anker) manufactured from iron or metal, so that

handiest vertical, no longer horizontal, forces are transmitted to the tower. In this project Intze tank is designed with working stress method and elements of Intze tank is designed with limit state method.

Components of Intze tank:

Top dome: In general, we provide 100 mm to 150 mm thick dome at top with reinforcement along the latitudes and longitudes. Usually, the rise of the dome is 1/5th of the length.

Top ring beam: The top ring beam is subjected to meridional thrust. The beam is design for hoop tension which caused due to water load.

Cylindrical walls: The wall is mainly subjected to hoop tension which is caused by the water pressure. So, the wall is designed for hoop tension.

Bottom ring beam: This ring beam provided between the cylindrical wall and conical slab. The ring beam is provided to resist the horizontal component of the reaction of the conical wall on the cylindrical wall. The bottom ring beam is designed for the induced hoop tension.

Conical slab: The slab is subjected to both meridional thrust and hoop tension. The hoop tension is due to fluid pressure and meridional is due to vertical pressure. So, the slab should be designed safely.

Bottom dome: The bottom slab may be circular or domed. This slab is supported on the circular girder

Circular girder: The girder should be designed for the loads which are coming from the conical slab (inclined thrust) and from the bottom dome (outward thrust). It will be placed on the columns and should be designed for resulting bending moment and torsion.

Columns: The columns are designed for the total transmitted from the tank. Columns are also designed for wind and earthquake loads. In columns, bracings are provided at intervals to resist the wind and earthquake effects.

Foundations: In general, to support the all columns combined footing is adopted. To support a circular girder and circular slab are design.

METHODOLOGY

Manual design

Capacity of Intze water tank = 0.3 ML

SBC of soil 200 kN/m²

Wind pressure as IS 875- 1200 N/m²

Assuming M_{30} concrete,

For which

$$\sigma_{cbc} = 10 \text{ N/mm}^2, \sigma_{cc} = 8 \text{ N/mm}^2$$

$$\text{Tension in bending} = 2.0 \text{ N/mm}^2$$

$$\text{Modular ratio} = \frac{280}{3\sigma_{cbc}} = 9.33$$

For Rebar stress,

$$\text{Indirect tension (Tensile stress)} = 115 \text{ N/mm}^2$$

$$\text{Tensile stress (bending) for liquid face} = 115 \text{ N/mm}^2 \text{ for } t \text{ less than } 225 \text{ mm}$$

$$\text{Volume} = 0.585 D^3 \text{ for (as per) figure}$$

$$D = 8.0 \text{ m}$$

Design of Top Dome:

Assuming the rise = 1.5 m

Therefore radius is given by

$$1.5 (2R - 1.50) = \left(\frac{8}{4}\right)^2$$

$$R = 6.08 \text{ m}$$

Fig 2. TOP DOME

$$\sin \phi = \frac{4}{6.08} = 0.6579$$

$$\cos \phi = 0.7531 \text{ and}$$

$$\phi = 41.14^\circ < 51.8^\circ \text{ (Therefore no tension).}$$

$$\text{Self-weight} = 2.4 \text{ kN/mm}^2$$

$$\text{Live load} = 1.5 \text{ kN/mm}^2$$

$$\text{Finishes} = 0.10 \text{ kN/mm}^2$$

$$\text{Total load} = 5.2 \text{ kN/mm}^2$$

$$f = \frac{WR}{t} \left(\cos \phi - \frac{1}{1 - \cos \phi} \right)$$

$$= 5200 * \frac{6.08}{10} \left(0.75 - \frac{1}{1.75} \right)$$

$$f = 0.0564 \text{ N/mm}^2$$

$$\text{hoop stress at crown, } \phi = 0^\circ$$

$$f = 4950 * \frac{6.08}{0.1} \left(1 - \frac{1}{2} \right)$$

$$f = 0.15 \text{ N/mm}^2$$

$$T = \frac{WR}{1 + \cos \phi} = 4950 * \frac{6.08}{1 + 0.75} = 17197.71 \text{ N/mm}^2$$

$$\text{Compressive stress} = \frac{17197.71}{100 \times 1000} = 0.172 \text{ N/mm}^2$$

Top Ring Beam :

Horizontal component of T = $\cos \phi$

$$= 17197.71 \times 0.7531$$

$$= 12951.59 \text{ N/m}$$

Hoop stress in the ring beam = $12951.59 \times 8/2$

$$= 51806.38 \text{ N}$$

Area of steel required = $51806.38/115 = 450.49 \text{ mm}^2$

Provide 4 bars of 12mm diameter

$$A_{st} \text{ provided} = 452.39 \text{ mm}^2$$

Dimensions of the ring beam:

Let cross sectional area = $A \text{ mm}^2$

$$\text{Equivalent concrete area} = A_c + (9.33 - 1)A_{st}$$

$$= A_c + 8.33 \times 452.39$$

Concrete Cross sectional area, $51806.38/2 = 43171.98 \text{ mm}^2$

Use a ring beam of size 230mm x 200mm

$$\text{Area provided} = 46000 \text{ mm}^2 > 43565.63 \text{ mm}^2$$

Use 6 mm nominal stirrups at 100 mm c/c

$$\text{Shear stress along edge} = T \sin \phi = 17197.71 \times 0.6579 = 11314.37 \text{ N}$$

$$\text{Shear stress} = 11314.37/100 \times 1000 = 0.113 \text{ N/mm}^2$$

Design of cylindrical wall

Pressure intensity = $5 \times 9810 = 49050 \text{ N/mm}^2$ (at the bottom of cylindrical wall)

$$\text{Hoop tension} = 49050 \times 8/2 = 196200 \text{ N}$$

$$A_{st} = \frac{196200}{230 \times 0.9} = 947.83 \text{ mm}^2$$

Provide 10 nos of 12 mm dia bars

$$\text{Area provided} = 1130.97 \text{ mm}^2$$

$$\text{Spacing of 12mm dia bar} = 1000 \times \pi \frac{12^2}{4 \times 1130.97} = 200 \text{ mm}$$

Hence provide 12mm at 200 mm c/c spacing at both directions

Assume thickness of wall = 230 mm

$$\text{Distribution steel} = \frac{0.24}{100} (230 \times 1000) = 552 \text{ mm}^2$$

Provide 10mm dia rebars of spacing 100mm b/w the

compressive stress check (at the bottom of the cylindrical wall)

$$\text{Vertical component of } T_1 = V_1 = T_1 \sin \phi = 17197.71 \times \sin 41.14$$

$$= 11314.37 \text{ N/mm}^2$$

$$\text{Weight of the wall} = 0.23 \times 5 \times 25000 = 28750 \text{ N/m}$$

$$\text{Ring beam self-weight} = 0.23 \times 0.2 \times 25000 = 1150 \text{ N/m}$$

$$\text{Total load } V_2 = 41214.37 \frac{\text{N}}{\text{m}}$$

$$\text{Compressive stress} = \frac{41214.37}{230 \times 1000} = 0.18 \text{ N/mm}^2$$

Nominal vertical stress is equal to 0.24% gross area

$$= \frac{0.24}{100} \times 230 \times 1000 = 552 \text{ mm}^2$$

Provide 12 bars of 8 mm diameter of spacing 100 mm c/c

Bottom Ring Beam

Let T_2 = Thrust / meter exerted by the conical wall at the junction bottom at B

$$T_2 \sin \alpha = V_2$$

$$\tan \alpha = 1$$

$$\alpha = 45^\circ$$

$$T_2 = \frac{V_2}{\sin \alpha} = \frac{41214.37}{\sin 45} = 58285.92 \text{ N/mm}^2$$

Resolving horizontally at B

$$H_2 = T_2 \cos \alpha = 58285.92 \times \cos 45^\circ$$

$$= 41214.37 \text{ N/m}$$

The lateral load (H_2) will create hoop tension in the ring - beam B

$$\text{Hoop tension through } H_2 = H_2 \times \frac{d}{2}$$

$$= 41214.37 \times \frac{8}{2}$$

$$= 164857.48 \text{ N}$$

Assume the depth of ring beam be 500 mm deep

$$\text{Pressure due to water at ring beam} = 9810 \times 5 \times \frac{500}{1000}$$

$$= 24525 \text{ N/m}$$

$$\text{Hoop tension due to water} = 24525 \times \frac{8}{2} = 98100 \text{ N}$$

$$\text{Total hoop tension} = 98100 + 164857.48 = 262957.48 \text{ N}$$

$$\text{Steel for hoop tension} = \frac{262957.48}{230 \times 0.9} = 1270.32 \text{ mm}^2$$

Provide 6 bars of 18 mm $\emptyset$

$$A_{st} = 1526.81 \text{ mm}^2$$

$$\text{Net concrete area} = A_c + (9.33 - 1)A_{st} = A_c + 8.33 * 1526.81$$

$$= A_c + 12718.33$$

Limiting tensile stress for net concrete area = 2 N/mm^2

$$\frac{262957.48}{A_c + 12718.33} = 2$$

$$A_c = 118760.41$$

Provide 250 mm $\times$ 500 mm size

Conical Slab

$$\frac{W_w + W_s}{2\pi} + \frac{W_w}{2\pi} \tan \alpha$$

Where,

W_w = weight of water resting on conical slab

W_s = weight of the conical slab

α = slop of conical slab

$$= \frac{6.5+5}{2} \times 8.625 \text{ m}^2$$

$$\bar{X} = \frac{[6.5+(2 \times 3)]}{6.5+5} \times \frac{1.5}{3} = 0.72 \text{ m}$$

Self-weight of water

$$W_w = 9810 \times 8.625 \times 2\pi (2.5 + 0.72) = 2.121 \text{ m}$$

Length of the conical slab = 2121 mm

Thickness of the slab as 200 mm

$$\text{Self-weight } W_s = 0.2 \times 2.121 \times 2500 \times 2\pi \times \frac{6.5}{2} = 216557.83 \text{ N}$$

$$\text{Hoop tension} = \frac{1711842.68 + 216557.83 + 1711842.68}{2\pi} = 579362.697 \text{ N}$$

$$\text{Hoop steel on the entire section} = \frac{579362.697}{230 \times 0.9} = 2798.85 \text{ mm}^2$$

Provide 14 bars of 16 mm diameter

$$A_{st} = 2814.86 \text{ mm}^2$$

Design for Flexure

$$\text{Load/meter width of conical slab} = \frac{W_w + W_s}{2\pi \times \text{mean radius}} = \frac{1711842.68 + 216557.83}{2\pi \times 3.25} = 94435.22 \text{ N}$$

$$\text{Maximum bending moment} = \frac{wl}{8} = \frac{94435.22 \times 1.5}{8} = 17706.604 \text{ Nm}$$

Axial compression $V_2 = T_2 \sin \alpha$

$$T_2 = \frac{41214.37}{\sin 45^\circ} = 5285.92 \text{ N}$$

Provide 16 mm rebar, at the clear cover = 25 mm

Effective depth = $200 - 25 - 8 = 167 \text{ mm}$

Distance between center of section (x) = $d - \frac{t}{2} = 167 - 100 = 67 \text{ mm}$

$$\text{Resultant bending moment} = M + T_2 x = 17706.6040 \times 10^3 + 5285.92 \times 67$$

$$= 21611760.64 \text{ N-m}$$

$$A_{st} = \frac{21611760.64}{167 \times 230 \times 0.9} = 625.177 \text{ mm}^2$$

Provide 4 no's bars, 16 mm diameter

Design of bottom dome

R is the radius of dome, rise = 1.2 m

Then, $(2.5)^2 = 1.2 (2R - 1.2)$

$$R = 3.20 \text{ m}$$

Let 2θ be the angle subtended by the dome

$$\sin \theta = \frac{2.5}{3.2} = 0.78,$$

$$\theta = 51.37^\circ < 51.8^\circ$$

$$\cos \theta = 0.624$$

Thickness of dome = 0.2 m

Loads:

$$\text{Dead load} = 25000 \times 0.2 = 5000 \text{ N/mm}^2$$

$$\text{Weight of water resting on the dome} = r_w (\pi r^2 - \frac{\pi h_c}{3} (3R - h_c))$$

$$= 9810 \left(\pi \times 2.5^2 - \frac{\pi \times 1.2}{3} (3 \times 3.2 - 1.2) \right) = 1127757.6 \text{ N}$$

$$\begin{aligned} \text{Area of dome surface} &= 2\pi R h = 2 \times \pi \times 3.2^2 \times 1.2 \\ &= 24.13 \text{ m}^2 \end{aligned}$$

$$\text{Load intensity due to weight of water} = \frac{1127757.6}{24.13} = 46736.74 \text{ N/mm}^2$$

$$\begin{aligned} \text{Meridional thrust} &= \frac{WR}{1 + \cos \theta} = 46736.74 \times \frac{3.2}{1 + 0.624} \\ &= 92092.098 \text{ N/m} \end{aligned}$$

$$\text{Meridional compressive stress} = \frac{92092.098}{200 \times 1000} = 0.46 \frac{N}{mm^2}$$

Hoop stress at the crown $\theta = 0^\circ$

$$\begin{aligned} \text{Hoop stress} &= \frac{WR}{t} \left(\cos\theta - \frac{1}{1+\cos\theta} \right) = 46736.74 \times \\ &\frac{3.2}{0.2} \left(0.624 - \frac{1}{1+0.624} \right) \\ &= 0.006 \frac{N}{mm^2} \end{aligned}$$

$$\begin{aligned} \text{Max. hoop stress} &= \frac{WR}{t} \left(\cos\theta - \frac{1}{1+\cos\theta} \right) = \\ 46736.74 \times \frac{3.2}{0.2} \left(1 - \frac{1}{2} \right) \\ &= 0.374 \text{ N/mm}^2 \end{aligned}$$

Provide nominal 0.3 % of steel

Provide 8 mm diameter bars at 100mm c/c spacing

Design circular girder:

Total water weight w_1 = conical slab water weight + dome water weight

$$= 1711842.68 + 1127757.6 = 2839600.28 \text{ N}$$

Weight of the dome + cylindrical wall + ring beam at A
 $W_2 = 41214.37 \times 2\pi \times 4$

$$= 1035830.096 \text{ N}$$

Weight of ring beam at B $W_3 = 0.25 \times 0.5 \times 25000 \times 2\pi \times 4 = 78539.82 \text{ N}$

Weight of conical wall $W_4 = 216557.83 \text{ N}$

Weight of lower dome $W_5 = 5000 \times 24.13$
 $= 120650 \text{ N}$

Weight of circular girder $= 0.4 \times 0.6 \times 25000 \times 2\pi \times 2.5$

(Assume size of girder 100 x 600) $= 94247.78 \text{ N}$

Total load (W) $= 4385425.806 \text{ N}$

Let us provide 8 columns

$$\begin{aligned} \text{Maximum bending moment at supports} &= 0.0083Wr \\ &= 0.0083 \times 4385425.806 \times 2.5 \\ &= 90997.585 \text{ Nm} \end{aligned}$$

Maximum bending moment at center $= 0.00416Wr$

$$\begin{aligned} &= 0.0006 \times 4385425.806 \times 2.5 \\ &= 6578.139 \text{ Nm} \end{aligned}$$

$$\begin{aligned} \text{Shear force at supports} &= \frac{W}{2 \times \text{numbers of columns}} = \\ \frac{4385425.806}{2 \times 8} &= \end{aligned}$$

$$= 274089.11 \text{ N}$$

$$\begin{aligned} \text{Load at each support} &= \frac{W}{8} = \frac{4385425.806}{8} \\ &= 548178.22 \text{ N} \end{aligned}$$

Design of support section:

Moment of resistance = bending moment at support

$$\begin{aligned} 0.913bd^2 &= 90997.585 \times 1000 \\ d &= 499.17 \text{ mm} \end{aligned}$$

Clear cover = 40 mm, adopt D = 550 mm, d = 510 mm.

$$\begin{aligned} \text{Equivalent shear force} &= V + \frac{1.6T}{b} \\ &= 274089.11 + \frac{1.6 \times 6578.139 \times 1000}{400} \\ V_c &= 300401.66 \text{ N} \end{aligned}$$

$$\begin{aligned} \text{Equivalent nominal shear stress } \tau_{vc} &= \frac{V_c}{bd} = \frac{300401.66}{400 \times 510} \\ &= 1.47 \frac{N}{mm^2} \end{aligned}$$

Maximum shear stress $\tau_{\max} > \tau_v$

$$\tau_{\max} = 2.2 \text{ N/mm}^2$$

$$\tau_c < \tau_v$$

Longitudinal reinforcement:

$$\begin{aligned} M_e &= M + M_t \\ M_t &= \frac{T \left(1 + \frac{D}{b} \right)}{1.7} = 6578.139 \times \frac{1000 \left(1 + \frac{550}{400} \right)}{1.7} \\ &= 9190047.132 \text{ Nmm.} \end{aligned}$$

M = moment at cross section

$$\begin{aligned} M_e &= 90997.585 \times 1000 + 9190047.132 \\ &= 100187632.1 \text{ Nm} \end{aligned}$$

$$A_{st} = \frac{M_e}{230 \times 0.9 \times d} = \frac{100187632.1}{230 \times 0.9 \times 510} = 949.02 \text{ mm}^2$$

Transverse reinforcement:

$$\begin{aligned} A_{sv} &= \frac{Ts_v}{b_1 d_1 \sigma_{sv}} + \frac{Vs_v}{2.5 d_1 \sigma_{sv}} \\ b_1 &= 400 - 80 = 320 \text{ mm}, d_1 = \\ 550 - 80 &= 470 \text{ mm} \end{aligned}$$

$$A_{sv} = s_v \left(\frac{6578139}{320 \times 470 \times 230} + \frac{274089.11}{2.5 \times 470 \times 230} \right)$$

Providing 4-legged 10 mm stirrups, $A_{sv} = 315 \text{ mm}^2$

Therefore $s_v = 261.55 \text{ mm}$, take s_v as 250mm

$$A_{sv} = (\tau_{vc} - \tau_c) s_v \cdot \frac{b}{\sigma_{sv}} = \frac{1.37 - 0.2}{400} \times 400 \times s_v$$

$$s_v = 154.81 \text{ mm}$$

Provide 150 mm spacing c/c.

$$\text{Steel due to sagging moment} = 45608.428 \times \frac{1000}{230 \times 0.9 \times 510} = 432.02 \text{ mm}^2$$

Provide 4 bars of 12mm diameter

$$A_{st} = 452.39 \text{ mm}^2$$

Hoop stress:

T_c = thrust on girder acted by conical slab

$$T_c \sin \alpha \times 2\pi r = W_w + W_s$$

+ weight of cylindrical wall and upper dome

$$T_c \sin \alpha \times 2\pi r = 17111842.68 + 216557.83 + 1035830.096$$

$$T_c = 266874.52 \text{ N}$$

$$\text{Horizontal component of } T_c = H_1 = 266874.52 \cos 45$$

$$= 188708.78 \text{ N}$$

$$\text{Horizontal component due to dome } H_2 = 92092.098 \times \cos 51.37^\circ$$

$$= 57492.06 \text{ N}$$

$$H_1 - H_2 = 131216.72 \text{ N}$$

$$\text{Hoop stress} = 131216.72 \times 2.5 = 328041.81 \text{ N}$$

$$\text{Hoop compressive stress} = \frac{328041.81}{400 \times 550} = 1.5 \text{ N/mm}^2$$

Columns:

$$\text{Actual load on each column at top} = \frac{4385425.806}{8} = 548178.22 \text{ N}$$

Let α = Angle made by column with vertical axis

$$\tan \alpha = \frac{1}{10}, \alpha = 5^\circ 42', \sin \alpha = 0.0995, \cos \alpha = \frac{10}{\sqrt{101}}$$

$$= 0.995$$

$$\text{Actual length of column} = \sqrt{10^2 + 1^2} = 10.05 \text{ m}$$

Providing 300mm x 300mm column size

$$\text{Self-weight} = 10 \times 0.3 \times 0.3 \times 25000 = 22500 \text{ N}$$

$$\text{Total load} = 548178.22 + 22500 = 570678.22 \text{ N}$$

$$\text{Axial load} = \frac{540678.22}{0.9950} = 573545.95 \text{ N}$$

$$\text{Tank full condition} = 573545.95 \text{ N}$$

$$\text{Weight of water tank} = \frac{2839600.28}{8} = 354950.035 \text{ N on each column}$$

In case of empty tank

$$\text{Load on column} = 573545.95 - 354950.035$$

$$= 218595.915 \text{ N}$$

$$\text{Corresponding axial load} = \frac{218595.915}{0.995} = 219694.387 \text{ N}$$

Let A_{sc} = steel requirement without wind effect

$$\text{Then } cA_c + tA_{sc} = 573545.95 \text{ N}$$

$$5 \times A_c + 190 \times A_{sc} = 573545.95$$

$$A_{sc} = 667.82 \text{ mm}^2$$

Min requirement of steel = 0.8% Gross area

$$\frac{0.8}{100} (300 \times 300) = 720 \text{ mm}^2$$

$$\text{Provide 6 bars of 20 mm diameter } A_{sc} = 1884.95 \text{ mm}^2$$

Analysis for wind pressure:

Take reduction factor as 0.7

$$\text{Wind thrust on top dome \& cylindrical walls} = \left(5 + \frac{1.5}{2}\right) \times 8.46 \times 1200 \times 0.7$$

$$= 40861.8 \text{ N acting at 14.37 m from the base}$$

$$\text{Wind thrust on circular wall} = \frac{8.46 + 5.40}{2} \times 1.5 \times 1200 \times 0.7$$

$$= 8731.8 \text{ N acting at 10.75 from the base}$$

$$\text{Wind thrust on the circular girder} = 0.6 \times 5.4 \times 1200 \times 0.7$$

$$= 2721.6 \text{ N acting at 10 m from the base}$$

$$\text{Wind thrust on columns \& bracings} = (5 \times 0.7 \times 10 \times 1200 \times 0.7) + \left(3 \times \frac{6+8}{2} \times 0.3 \times 1200\right)$$

$$= 20160 \text{ N acting at 5 m from the base}$$

$$\text{Total moments due to wind pressure at the base} = (40861.8 \times 14.37) + (8731.8 \times 10.75) + (2721.6 \times 10) + (20160 \times 5) = 809066.92 \text{ Nm}$$

$$\text{Vertical load on column by wind load} = \frac{Mx}{Ex^2}$$

$$Ex^2 = 2 \times 4^2 + 4 \left(\frac{4}{\sqrt{2}}\right)^2 = 64 \text{ m}^2$$

Max. wind thrust in most leeward side & the most windward side

$$= 809066.92 \times \frac{4}{64} \times \frac{4}{\sqrt{2}}$$

$$= 35756.04 \text{ N}$$

Consider windward column 1

$$\text{Dead load} + \text{wind load} = 570678.22 + 50566.682$$

$$= 621244.902 \text{ N}$$

$$\text{Corresponding axial load} = \frac{621244.902}{0.9950} = 624366.74 \text{ N}$$

$$\text{Horizontal component of the axial force due to wind action} = 2 \times 50566.682 \times 0.0995 + 4 \times 35756.04 \times 0.0995 \times \frac{1}{\sqrt{2}} = 20125.54 \text{ N}$$

$$\text{Actual horizontal force at base} = 40861.8 + 8731.8 + 2721.6 + 20160 - 20125.54$$

$$= 52349.66 \text{ N}$$

$$\text{Horizontal shear column} = \frac{52349.66}{8} = 6543.71 \text{ N}$$

$$\text{Maximum bending moment for the column} = 6543.71 \times \frac{2.5}{2} = 8179.63 \text{ Nm}$$

Column section:

$$\text{Axial load} = 624366.74 \text{ N}$$

$$\text{B.M.} = 8179.63 \text{ Nm}$$

Provide 300 x 300 mm size

Use 6 rebars, 20 mm ϕ at effective cover of 50 mm

$$A_{st} = 1884.95 \text{ mm}^2$$

$$\text{Net concrete area} = A_c + (m - 1)A_{st}$$

$$= (300 \times 300) + (8.33 \times 1885) = 105702.05 \text{ N}$$

$$\text{For net concrete section the polar moment of inertia} = \frac{a^4}{12} +$$

$$(mA_{st} \times \text{effective depth from centre})$$

$$= \frac{300^4}{12} + (8.33 \times 1885 \times (150 - 50)^2) = 832.02 \times 10^6 \text{ mm}^4$$

$$\text{Equivalent moment of inertia about full section} = 832 \times \frac{10^6}{2} = 416.01 \times 10^6 \text{ mm}^4$$

$$\text{Direct stress in concrete} = \frac{\text{direct load}}{\text{equivalent concrete area}} = \frac{624366.74}{105702.05} = 5.91 \text{ N/mm}^2$$

$$\text{Bending stress in concrete} = \frac{8179630}{416.01 \times 10^6} \times 150 = 2.95 \text{ N/mm}^2$$

$$\text{Maximum stress} = 5.91 + 2.95 = 8.86 \text{ N/mm}^2$$

Design of braces:

$$\text{Moment in braces} = 2 \times \text{moment for the column} \times \sec 45^\circ$$

$$= 2 \times 8179.63 \times \sqrt{2} = 23135.49 \text{ Nm}$$

Provide 300 x 300 mm beam

$$\text{Area of steel} = \frac{23135.490}{230 \times 0.9 \times 220} = 508.02 \text{ mm}^2$$

Use 4 rebars of 18mm diameter

$$\text{S.F. for brace} = \frac{\text{bending moment for brace}}{\frac{1}{2} \text{ span of brace}}$$

$$\text{Span of brace} = 2 \times \frac{7.5}{2} \times \sin 22^\circ 30' = 2.678 \text{ m}$$

$$\text{Shear force for brace} = \frac{23135.49}{0.5 \times 2.678} = 17278.18 \text{ N}$$

$$\text{Nominal shear stress } \tau_v = \frac{V}{bd} = \frac{17278.18}{300 \times 260} = 0.22 \frac{\text{N}}{\text{mm}^2}$$

Provide nominal stirrups, 2 legged - 10 mm diameter stirrups 200mm spacing c/c

FOUNDATION Design

$$\text{Axial load on column} = 573545.95 \times 8 = 4588367.6 \text{ N}$$

$$\text{Self-weight of footing (10% of column load)} = 458836.76 \text{ N}$$

$$\text{Total load} = 5047204.36 \text{ N}$$

$$\text{SBC} = 200 \text{ kN/mm}^2.$$

$$\text{Area} = \frac{\text{load}}{\text{safe bearing capacity}} = \frac{5047204.36}{200 \times 10^3} = 25.24 \text{ m}^2$$

Provide outer diameter of 9.0 m & inner diameter of 6.0 m

$$= \frac{\pi}{4} \times (9.0^2 - 6.0^2) = 35.34 \text{ m}^2$$

$$\text{Net intensity} = \frac{5047204.36}{35.34} = 142.82 \text{ 86 kN/mm}^2$$

$$142.82 \text{ 86 kN/mm}^2 < 200 \text{ 86 kN/mm}^2, \text{ hence ok.}$$

Design at Circular Girder

Maximum negative B.M. occurs at supports

$$= 0.00416 \times 5047204.36 \times 4 = 83985.48 \text{ N-m}$$

$$\text{Maximum positive bending} = 0.0083 \times 5047204.36 \times 4 = 83985.480 \text{ N-m}$$

$$\text{Maximum torsion} = 0.0006 \times W \times r = 12113.29 \text{ N-m}$$

$$\text{Maximum shear force at support} = \frac{5047204.36}{2 \times 8} = 315450.27 \text{ N}$$

Design at Support Section:

Moment of resistant = maximum bending moment at support assume b = 500 mm

$$0.913 bd^2 = 167567.18 \times 1000$$

$$d = 605.86 \text{ mm, adopt } 610 \text{ mm}$$

Equivalent shea stress,

$$V_v = V + 1.6 \times \frac{T}{b} = 315450.27 + \frac{1.6 \times 12113.29 \times 1000}{500}$$

$$V_v = 354212.8 \text{ N}$$

$$\tau_v = \frac{V_v}{bd} = \frac{354212.8}{500 \times 610} = 1.16 \text{ N/mm}^2 \text{ but}$$

$$\tau_c = 2.2 \text{ N/mm}^2$$

$$\text{Hence, } \tau_c < \tau_v.$$

Longitudinal reinforcement:

$$M_e = M + M_t,$$

$$M_t = \frac{T(1+\frac{D}{b})}{1.7} = \frac{12113.29 \times 10^3 (1 + \frac{660}{500})}{1.7} = 16531078.12 \text{ N-m}$$

$$M_e = (167567.18 \times 1000 + 16531078.12)$$

$$M_e = 184098.26 \times 10^3 \text{ N}$$

$$A_{st} = \frac{184098.26 \times 10^3}{230 \times 0.9 \times 610} = 1457.97 \text{ mm}^2$$

Provide 9 bars of 16 mm diameter bars

$$\text{Hence } A_{st \text{ required}} = 1810 \text{ mm}^2.$$

Transverse reinforcement

$$A_{sv} = \frac{T.S_v}{b_1 d_1 \sigma_{sv}} + \frac{V.S_v}{2.5 d_1 \sigma_{sv}}$$

$$A_{sv} = 4 \times \frac{\pi}{4} \times 10^2 = 314.16 \text{ mm}^2, b_1 = 500 - 80 = 420 \text{ mm,}$$

$$d_1 = 660 - 120 = 540 \text{ mm}$$

$$314.16 = \left(\frac{12113.29 \times 10^3}{420 \times 540 \times 230} + \frac{315450.27}{2.5 \times 540 \times 230} \right) S_v$$

$$S_v = 251.7 \text{ mm}$$

Let us provide 200 mm clear cover spacing

$$\text{Steel for hogging moment } A_{st} = 665.13 \text{ mm}^2$$

Provide 4 bars of 16 mm diameter

Fig 3. INTZE WATER TANK MODEL

STAAD Pro design

Procedure

1. Open STAAD.pro.
Click on new project > add file name>Select 'space'.
Length (in m), Force (in KN).
Select add beam option and click on finish.
2. Geometry>Run structure wizard > select surface/plate model > cylindrical surface. Close it to transfer to modelling
Length :12
Division along length: 1
Start radius: 3.5
Division along periphery: 8(column)
End radius: 2.5
3. Using Add beam selecting top node and bottom node. Repeat along periphery for required number of columns.
4. Copy all vertical members using ctrl + C and paste aside using ctrl + V.
5. Add intermediate nodes along length to add required number of beams in horizontal direction. Connect all node in a plane to form a circular beam.
6. Repeat the same process at top to get circular girder.
7. Geometry>Run structure wizard> select surface/plate model>Spherical cube
Select spherical cap (Bottom dome). Close it to transfer to modelling
Diameter of sphere:
Base Diameter:
8. Shift the obtained Spherical cap to top beam
Measure distance using 'display node to node distance' tool
Select all plates > Right click mouse>Move > add (-) sign to above distance to rest on top beam.
1. Geometry>Run structure wizard > select surface/plate model > cylindrical surface
Length: 2.12
Division along length: 1
Start radius: 35
Division along periphery: 8(column)
End radius: 2.5
2. Shift the obtained Conical dome to top beam
Measure distance using 'display node to node distance' tool
Select all plates > Right click mouse>Move > add (-) sign to above distance to rest on top beam.
3. Geometry>Run structure wizard > select surface/plate model > cylindrical surface
Length: 2.12
Division along length: 1
Start radius: 35
Division along periphery: 8(column)
End radius: 2.5
4. Shift the obtained cylindrical surface to top beam
Measure distance using 'display node to node distance' tool
Select all plates > Right click mouse>Move > add (-) sign to above distance to rest on top beam.

5. Geometry>Run structure wizard> select surface/plate model>Spherical cube
 Select spherical cap (Top dome). Close it to transfer to modelling
 Diameter of sphere:
 Base Diameter:
6. Shift the obtained Conical dome to top beam
 Measure distance using 'display node to node distance' tool
 Select all plates > Right click mouse>Move > add (-) sign to above distance to rest on top beam.
7. Finally Check dimensions of tank using 'display node to node distance' tool to verify. Any corrections to be made are rectified.

GENERAL PROPERTIES

8. Click 'property' at left of screen> Define required dimensions for respective elements. Assign the property for various elements using any of the options present according to your convenient.
 Click 'Support' > Create >Select 'fixed' >click Add> assign at bottom part of beam.
9. Click 'Load and Definition'
 To apply wind load first we have to define it in first section. Enter your values. Keep exposure as -1.
 Click 'Load case details' to add DL, LL & WL.
 Add self-weight as DL
 Add Water load as LL
 Add Wind Load
 Select material as concrete and assign for entire tank

Analysis

10. Click 'Analysis and print'> Run analysis >Check for Zero errors>Post processing
 Apply given loads to see deflected shape of structure, beam moments and forces.

Design

11. Click on 'Design' >Select parameters to include in our design.
 Define parameters with respective values
 Select the required command to instruct software to design according to IS code.
 Detailing of reinforcement and quantity of concrete is present in output file.

Design in STAAD Pro

Step 1: Geometry of Structure

Step 2: Material and Property

Step 3: Loads and Definitions

Step 4: Assign Support

Step 5: Run Analysis

Step 6: Go to Post processing

Step 7: Analysis Drawings

Step 8: Design

Reinforcement Details

Ring Beam

Columns:

RESULTS

Manual design of Intze tank as per IS: 3370

Top dome:

Thickness of the dome = 100mm
 Force = 5.2 kN/mm^2
 Hoop stress = 0.15 N/mm^2
 Meridional stress = 0.17 N/mm^2
 Area of steel = 300 mm^2

Top ring beam:

Size = 230 x 200 mm
 Meridional thrust = 12.95 kN
 Hoop tension = 51.81 kN
 Shear stress = 0.113 N/mm^2
 Area of steel = 452.39 mm^2

Cylindrical wall:

Height = 4m
 Thickness of wall = 230mm
 Hoop tension = 196.2kN
 Tensile stress = 0.18 N/mm^2
 Area of steel = 1130.97 mm^2

Ring beam at bottom:

Size = 250 x 500mm
 Hoop tension = 262.95kN
 Area of steel = 1526.81 mm^2

Conical slab:

Thickness of the slab = 200mm
 Hoop tension = 579.36kN
 Area of steel = 2814.86 mm^2

Bottom dome:

Thickness of the dome = 200mm
 Meridional thrust = 92.09kN
 Hoop tension = 230kN
 Tensile stress = 0.374 N/mm^2
 Area of steel = 600 mm^2

Circular girder:

Size = 400 x 600mm
 Load = 4385.4kN
 Hoop stress = 1.5 N/mm^2
 Hoop compression = 328kN

Area of steel = 949.02 mm^2

Design and analysis in staad pro

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Client		By	Date	Chk
File tank.std		23-May-21		
Date/Time 08-Jun-2021 17:33				

Job Information

Engineer	Checked	Approved
Name:		
Date:	23-May-21	

Structure Type	SPACE FRAME
----------------	-------------

Number of Nodes	250	Highest Node	443
Number of Elements	80	Highest Beam	533
Number of Plates	224	Highest Plate	613

Number of Basic Load Cases	3
Number of Combination Load Cases	1

Included in this printout are data for:

☒ All ☐ The Whole Structure

Included in this printout are results for load cases:

Type	L/C	Name
Primary	1	LOAD CASE 1
Primary	2	LOAD CASE 2
Primary	3	LOAD CASE 3
Combination	4	COMBINATION LOAD CASE 4

Section Properties

Prop	Section	Area (cm ²)	I _{xx} (cm ⁴)	I _{yy} (cm ⁴)	J (cm ⁴)	Material
4	Rect 0.30x0.30	900.000	67.5E+3	67.5E+3	114E+3	CONCRETE
5	Rect 0.60x0.40	2.4E+3	320E+3	720E+3	751E+3	CONCRETE
6	Rect 0.50x0.25	1.25E+3	68.1E+3	260E+3	179E+3	CONCRETE
7	Rect 0.20x0.23	460.000	20.3E+3	15.3E+3	29.3E+3	CONCRETE

Plate Thickness

Prop	Node A (cm)	Node B (cm)	Node C (cm)	Node D (cm)	Material
1	20.000	20.000	20.000	20.000	CONCRETE
2	15.000	15.000	15.000	15.000	CONCRETE
3	10.000	10.000	10.000	10.000	CONCRETE

Primary Load Cases

Number	Name	Type
1	LOAD CASE 1	Dead
3	LOAD CASE 3	Wind
2	LOAD CASE 2	Live

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Print Run 1 of 3

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Combination Load Cases

Comb.	Combination L/C Name	Primary	Primary L/C Name	Factor
4	COMBINATION LOAD CASE 4	1	LOAD CASE 1	1.50
		2	LOAD CASE 2	1.50

Beam Displacement Detail Summary

Displacements shown in *italic* indicate the presence of an offset

	Beam	L/C	d (m)	X (mm)	Y (mm)	Z (mm)	Resultant (mm)
Max X	483	4.COMBINATI	0.000	0.488	-7.621	0.000	7.637
Min X	486	4.COMBINATI	3.061	-0.409	-7.622	0.000	7.638
Max Y	468	3.LOAD CASE	0.251	0.002	0.000	0.000	0.002
Min Y	525	4.COMBINATI	1.531	0.115	-8.004	-0.048	8.005
Max Z	488	4.COMBINATI	3.061	0.000	-7.622	0.488	7.638
Min Z	484	4.COMBINATI	3.061	0.000	-7.622	-0.488	7.638
Max Rot	533	4.COMBINATI	1.531	-0.116	-8.004	0.048	8.005

Beam Force Detail Summary

Sign convention as diagrams - positive above line, negative below line except Fx where positive is compression. Distance d is given from beam end A.

			Axial			Shear		Torsion		Bending	
	Beam	LIC	d (m)	Fx (kN)	Fy (kN)	Fz (kN)	Mx (kNm)	My (kNm)	Mz (kNm)		
Max	Fx	56	4.COMBINATI	2.512	1.33E+3	-0.829	0.000	-0.000	0.000	1.315	
Min	Fx	483	4.COMBINATI	0.000	-331.452	6.760	-0.000	-0.001	0.000	5.036	
Max	Fy	424	4.COMBINATI	0.000	458.009	8.122	0.001	0.001	-0.000	-11.566	
Min	Fy	434	4.COMBINATI	1.913	458.019	-8.122	0.001	-0.000	0.001	-11.566	
Max	Fz	480	4.COMBINATI	0.000	1.27E+3	0.713	0.010	-0.000	-0.013	1.292	
Min	Fz	471	4.COMBINATI	0.000	1.27E+3	0.713	-0.010	0.000	0.013	1.291	
Max	Mx	77	4.COMBINATI	0.000	1.999	3.657	0.001	0.001	-0.002	1.074	
Min	Mx	96	4.COMBINATI	0.000	458.021	8.110	0.003	-0.001	-0.003	-11.578	
Max	My	471	4.COMBINATI	0.000	1.27E+3	0.713	-0.010	0.000	0.013	1.291	
Min	My	480	4.COMBINATI	0.000	1.27E+3	0.713	0.010	-0.000	-0.013	1.292	
Max	Mz	483	4.COMBINATI	3.061	-331.452	-6.765	-0.000	-0.001	-0.000	5.043	
Min	Mz	95	4.COMBINATI	0.957	458.005	-0.004	-0.001	0.001	0.000	-15.455	

Plate Center Principal Stress Summary

	Plate	L/C	Principal		Von Mises		Tresca	
			Top (N/mm²)	Bottom (N/mm²)	Top (N/mm²)	Bottom (N/mm²)	Top (N/mm²)	Bottom (N/mm²)
Max (t)	438	4.COMBINATI	-2.728	-0.684	5.111	1.495	5.896	1.715
Max (b)	435	4.COMBINATI	-2.728	-0.684	5.111	1.495	5.896	1.715
Max VM (t)	435	4.COMBINATI	-2.728	-0.684	5.111	1.495	5.896	1.715
Max VM (b)	462	4.COMBINATI	2.168	1.910	2.602	4.698	2.885	5.352
Tresca (t)	435	4.COMBINATI	-2.728	-0.684	5.111	1.495	5.896	1.715
Tresca (b)	462	4.COMBINATI	2.168	1.910	2.602	4.698	2.885	5.352

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Job Title Design of Intze Tank		Ref			
Client		By		Date 23-May-21	
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			Horizontal	Vertical	Horizontal	Moment		
	Node	L/C	FX (kN)	FY (kN)	FZ (kN)	MX (kNm)	MY (kNm)	MZ (kNm)
Max FX	33	4-COMBINATI	131.185	1.32E+3	0.000	0.000	-0.000	1.315
Min FX	37	4-COMBINATI	-131.179	1.32E+3	-0.000	-0.000	-0.000	-1.324
Max FY	33	4-COMBINATI	131.185	1.32E+3	0.000	0.000	-0.000	1.315
Min FY	45	3-LOAD CASE	2.489	-0.000	-2.489	-0.103	-0.000	-0.103
Max FZ	38	4-COMBINATI	0.004	1.32E+3	131.184	-1.318	0.001	-0.006
Min FZ	35	4-COMBINATI	0.004	1.32E+3	-131.184	1.318	-0.001	-0.006
Max MX	35	4-COMBINATI	0.004	1.32E+3	-131.184	1.318	-0.001	-0.006
Min MX	38	4-COMBINATI	0.004	1.32E+3	131.184	-1.318	0.001	-0.006
Max MY	38	4-COMBINATI	0.004	1.32E+3	131.184	-1.318	0.001	-0.006
Min MY	35	4-COMBINATI	0.004	1.32E+3	-131.184	1.318	-0.001	-0.006
Max MZ	33	4-COMBINATI	131.185	1.32E+3	0.000	0.000	-0.000	1.315
Min MZ	37	4-COMBINATI	-131.179	1.32E+3	-0.000	-0.000	-0.000	-1.324

Failed Members

There is no data of this type.

Conclusion

- An Intze water is designed with 300000 litres capacity with 12m staging has designed with M30 grade of concrete.
- We design the tank by both manually and using STAAD Pro, the program results shown that design is safe
- After completion of Intze water tank design in STAAD Pro and from manual calculations we conclude that design is safe.
- Though design is safe but we observed that reinforcement is less when compared with manual calculations.

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