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Annexure A- Design of the ferrocement lining

Design of the ferrocement lining-

General

As discussed in previous chapters, ferrocement lining is designed based on the **Strain compatibility criteria**. This Section focuses on designing the ferrocement lining to accommodate the strain occurring at the interface between the RCC and the ferrocement lining. The strain is categorized into three ranges: 0 to 0.0005, 0.0005 to 0.001, and 0.001 to 0.001583. The maximum strain that can occur is 0.001583.

The calculations involved include the following steps: determining the basic dimensions of the lining, estimating the average crack width, applying the theory of bending to evaluate stresses and strains, and checking the crack width under hoop stress. Section 3.3.2. is used for the design of the ferrocement lining.

Design of ferrocement lining-

- Strain at the interface of RCC and Ferrocement lining –0.0005
- Initially 1000 * 10 mm thick ferrocement lining is used
- Minimum Bars required = 1000/10= 100 Nos
- Minimum Mesh used = 3
- Area of bars used in one mesh of 1m x 1m = 78.53 mm^2
- Total Area of bars used= 471.8 mm^2
- Total Perimeter= 3.14*1*3*2*100= 1884 mm
- L=1.5*1000*t/1.6/p= 4.97 mm
- Hoop tension carrying Capacity of lining= N=1000*t*7 N/mm^2= 70000 N
- Stress in the Reinforcement= 70000/471.8= 148.3<=450 N/mm^2 **Hence safe**.
- Wav=4.97*(70000/(471.8*200000)-1884*3.9*4.97/(4*471.8*200000))+0.0004*4.97-4.97*0.0005 =0.0027 mm <=0.05 mm **Hence Safe.**

Check for the Theory of Bending-

- Clear space between the Meshes=(t-4)/(Mesh-1)= 3 mm
- 'c' is the depth of the neutral axis from the extreme compression fiber

$$b \times c \times c \times 0.5 + \sum (n-1) \times A_{ri} \times (c - d_i) = \sum (n) \times A_{rj} \times (d_j - c)$$

Solving the above equation c= 2.58 mm

- $f''^{c} = 0.0005 * c/(t-c)$ *5000*√50= 6.14 N/mm^2
- Compression Force in Concrete stress Block= $C_c = \{0.85 \times f'_c \times b \times \beta_1 \times c\}$= 10758 N
- Compression Force in Concrete stress Block due to reinforcement= $C_{ri} = \{(\varepsilon_{ri} \times E_r - 0.85 \times f'_c) \times A_{ri}\}$= (34.77-3.07) *78.5= 2484 N
- Tensile Forces at each layer of reinforcement= $T_{ri} = A_{ri} \times \varepsilon_{ri} \times 200000$

  Where $\varepsilon_{ri} = \frac{d_i - c}{c} \varepsilon_{mu}$ & $(\varepsilon_{ri} \times 200000) \leq 45$

  $T_r = T_{r1} + T_{r1}$= 13260 N

- Balancing Tension & Compressive Forces in the lining= $C_c + C_{ri} = \sum T_{ri}$

The difference between Total Compression and Total Tension is very less Hence Section provided is a Balanced Section. Similarly, C_c, C_{ri} & $\sum T_{ri}$ are calculated for the maximum strain at each layer and is equated to the Total force acting due to $f'_c = 0.45 * 50$ N/mm^2 . For this case, the difference between Total Compression and Total Tension is very less Hence Section provided is a Balanced Section.

Check for the Crack width for the Hoop tension- Although the Ferrocement lining is not supposed to bear any structural loadings, Still the check is applied for the general carrying capacity of the lining.

- Hoop tension which ferrocement plate can bear= $HT_{fl} = 1000 \times b_f \times f_{Ferrocement}$= 1000*10*7= 70000 N
- Reinforcement Area required= $Ast_f = \frac{HT_{fl}}{f_{tensile}}$= 70000/200= 350 mm^2
- Calculating the Number of bars and mesh numbers= $Nos = \frac{Ast_f}{\left(\frac{\pi \varnothing^2}{4}\right)}$ = 448 bars required. Providing 5 Mesh with 100 bars in each mesh.
- Actual Area provided= 392.6 mm^2
- Volume fraction= $V_r = \frac{2 \times A_{ri}}{1000 \times t}$= 0.0624
- Specific surface area reinforcement= $S_r = 4 \times V_r$ =0.24
- Estimated stress at crack stabilization$\sigma_{cr} = 345 \times (1 + S_r)$= 427.8 N/mm^2

- Actual stress $\sigma = 70000/392.6$= 178.9 N/mm^2

    $\sigma \leq \sigma_{cr}$ **Hence Safe.**
- Crack width check under Hoop force $W_{max}\ if \sigma \leq \sigma_{cr}$ =$^{3500}/_{E_r}$= 0.022 mm
- W_{max} Should be less than 0.05 for water retaining structure.
- Reducing the number of mesh by one and repeating the similar steps and checking the W_{max} values and finding the Optimum number of the Meshes required.

Cost calculations – Cost is calculated for per square meter Ferrocement lining of "t" thickness-

- Cost of Cement Mortar Plaster for 10 mm lining= Rs 233.9/ sqm. (Similarly for 12 mm Cost = Rs 249.5/ sqm; For 15 mm Cost = Rs 281.5/ sqm; For 20 mm Cost = Rs 319/ sqm;
- Total Cost= Cost of Cement mortar+ Cost of Meshes.

H.B. wire mesh is a non scheduled item.H.B bars are used cost of which is Rs 35-50 per Kg as per Market Rates (Verified from TMM Building Centre and Ferrocement Factory Tilothu Rohtas Bihar).

Table A.1: Cost of Ferrocement lining for Strain Value- 0.0 - 0.00005

Thickness	Mesh	Nos of bars in longitudinal direction per mesh	Wav	Wcr
10	3	100	0.0118	0.022
10	4	100	0.006	0.022
12	3	85	0.025	0.022
12	4	85	0.013	0.022
15	3	66	0.062	-
15	4	66	0.034	0.022

Wav in case of 15 mm Thickness and 3 mesh exceeds 0.05 mm Hence cannot be used Rest can be used as lining

Table A.2: Cost of Ferrocement lining for Strain Value- 0.00005- 0.0001

Thickness	Mesh	Number of bars in longitudinal direction per mesh	Wav	Wcr
10	3	100	0.0068	0.022
10	4	100	0.002	0.022
12	3	85	0.018	0.022
12	3	85	0.0085	0.022
15	3	66	0.051	-
15	4	66	0.026	0.022

Wav in case of 15 mm Thickness and 3 mesh exceeds 0.05 mm Hence cannot be used Rest can be used as lining.

Table A.3: Cost of Ferrocement lining for Strain Value- 0.0001- 0.00015

Thickness	Mesh	Nos. of bars in longitudinal direction per mesh	Wav	Wcr	Cost
10	3	100	0.00190	0.022	361.6
10	4	100	-0.00097	0.022	404.2
12	3	85	0.01000	0.022	358.0
12	3	85	0.00310	0.022	394.5
15	3	66	0.0400	-	365.5
15	4	66	0.0180	0.022	431.6
20	3	50	0.1600	-	361.6
20	4	50	0.0820	-	404.2

Wav in case of 15 mm Thickness and 3 mesh, 20 mm thick with 3 or 4 mesh exceeds 0.05 mm Hence cannot be used Rest can be used as lining.

Annexure B- Manual design of 600 kL hybrid Intze tank

Basic data provided for design of tank

- Quantity**- 600 kL**
- Staging Height**- 16 m**
- Net safe Bearing Capacity of soil in kN/m^2**: 80**
- Depth of the Foundation (m)**- 1.8 m**
- No of bays/ braces – **4**
- Seismic Zone **IV**
- Basic Wind Speed **47 m/sec**
- Terrain category & region type- **Non-Coastal region** and **Catergory II**

Basic Calculations of dimensions of tank-

- Inner Radius of the Top ring beam is taken as 6.6 m (Iterative process)
- Outer Radius of the Top ring beam is taken as 6.8 m
- Inner Diameter of the Top ring beam is taken as 13.2 m
- Outer Diameter of the Top ring beam is taken as 13.4 m
- h_1=D/7= 2*6.8/7= 1.9 m
- Inner Diameter of the Bottom ring beam is taken = 0.75 * 13.2 m =9.9 m
- Outer Diameter =10.1 m
- h_2=(9.9+0.2)/7= 2 m
- Radius of Top dome- $R_1 = 0.5 \times \{(r_1 + 0.1)^2 + {h_1}^2\}/h_1$=12.76 m.
- Radius of B Dome- $R_2 = 0.5 \times \{(r_2 + 0.1)^2 + {h_2}^2\}/h_2$=7.37 m.
- $V = \pi {r_1}^2 H + \pi \times l \times \frac{4{r_1}^2+4{r_2}^2+4r_1r_2}{12.0} - \pi \times h_2^2 \times \frac{3R_2-h_2}{3}$;
- l = $(r_1 - r_2) \times \tan A_r$= 1.65 m
- Volume of the conical part= 175.7 cum
- Volume of the Bottom dome= 84.2 cum
- Calculation of Height of Cylinder-

  600= 136.8* H+175.7-84.2

  H=3.8 m

  Height of the Cylindrical wall is taken as 3.9 m and FB =0.15 m

  Total H = 4.05 m.

Final dimensions of the tank are-

dimensions of RCC Over Head water tank body-

Top dome-

- Mean chord = 13.2 m
- Mean rise = 1.9 m

- Mean radius of curvature = 12.76 m
- Thickness = 100 mm
- Half of the angle subtended at the centre = 27.34 degrees

Top ring beam

- Cross Section of the beam = 200 x 200 mm
- Mean Diameter = 13.4 m

Cylindrical wall

- Outer diameter = 13.4 m
- Thickness = 100.00 mm
- Internal diameter = 13.2 m
- Mean diameter = 13.3 m
- water depth = 3.8 m

Balcony/ Middle Ring beam-

- Width of balcony = 1 m
- Depth of balcony at the face of wall = 150 mm
- Depth of balcony at free end = 120 mm

Conical dome -

- Angle of cone with vertical = 45.00 degrees
- Thickness = 150 mm
- Diameter at the top (middle joint) = 13.2 m
- Diameter at the bottom (bottom joint) = 9.9 m
- Mean height (from middle joint to bottom joint) = 1.15 m
- Mean length (from middle joint to bottom joint) = 1.65 m

Bottom dome-

- Mean chord = 9.90 m
- Mean rise = 2 m
- Mean radius of curvature =7.37 m
- Thickness = 120 mm
- Half of the angle subtended at the centre = 42.60 degrees

Main ring beam-

- Supported on 10 column of 400 mm dia
- Cross Section of beam= 400 mm x 600 mm
- Mean diameter = 10.3 m
- Half of angle subtended at the centre by the span = 18 degrees

Calculation of Stiffnesses-

Top dome

- $\lambda = \{3(R/t)^2\}^{0.25}$= 16.3

- $k = 1 - \cot\theta/2\lambda$= 0.95
- $MS1 = \frac{R_1 Et_{td}(k_{td}+k_{td}^{-1})}{4\times{\lambda_{td}}^3} = 112.5$
- $Corr\ TS1\ or\ MS1 = -\frac{Et_{td}}{2{\lambda_{td}}^2 k_{td} sin\theta_{td}} = -0.29$
- $TS1 = -\frac{Et_{td}}{\lambda_{td} R_1 k_{td} sin^2\theta_{td}} = 0.00146$

Top ring beam -

- $MS2 = \frac{Eb_1{d_1}^3}{12{r_1}^2} = 3.1$
- $TS2 = \frac{Eb_1 d_1}{{r_1}^2} = 0.001$

Cylindrical wall at Top

Wall thickness is uniform

- $\mu = \{\frac{3}{r_1 \times t_{3top}}\}^{0.25}$ =0.001620
- $Z_{top} = Z_{bottom} = \frac{t_{3top}^3}{12} = 83333;$
- $MS3t = 2\mu Z_{top} = 270;$
- $TS3t = 4\mu^3 Z_{top} = 0.001417;$
- $CorrMS3t = 2\mu^2 Z_{top} = 0.437;$
- $MS3b = 2\mu Z_{top} = 270;$
- $TS3b = 4\mu^3 Z_{top} = 0.001417;$
- $CorrMS3b = -2\mu^2 Z_{bottom} = -0.43$

Balcony/ Middle Ring beam

- $MS4 = \frac{Eb_2{d_2}^3}{12{r_1}^2} = 3.4$
- $TS4 = \frac{Eb_2 d_2}{{r_1}^2} = 0.0028$

Conical dome

At top of dome-

- Δ= $\{\cot^2\theta_{cd}/t_{5top}^2\}^{0.25}$=0.15
- $l_{cd1} = \frac{r_1}{sin(A_r)} = 9324$
- $\xi = 2\Delta\sqrt{l_{cd1}} = 29.3$
- Calculating k factors form Appendix D of Jain and Krishna Vol 2.
  $k_1 = 39.2;\ k_2 = k_3 = 8.67;\ k_4 = 406;\ K = 15700;$
- MS5t $= \frac{Et_{cd1}k_4}{l\tan^2\theta_{cd}K} = 35680;$
- $CorrMS5t = \frac{Et_{cd1}k_2}{l\tan^2\theta_{cd}K}$ =0.12;

- TS5t $= \frac{Et_{cd1}k_1}{l\tan^2\theta_{cd}K} = 0.00008$;

At bottom of dome-

- $\Delta' = \{\cot^2\theta_{cd}/t^2_{5bottom}\}^{0.25}$=0.15
- $l_{cd2} = \frac{r_2}{sin(A_r)} = 6990$
- $\xi' = 2\Delta'\sqrt{l_{cd2}} = 26.4$
- Calculating k' factors form Appendix D of Jain and Krishna Vol 2.
  $k'_1 = 2438;\ k'_2 = k'_3 = 158;\ k'_4 = 31;\ K' = 50615;$
- MS5b=633.4
- CorrMS5b=-0.639516
- TS5b=0.0019

Bottom dome

- $\lambda = \{3(R/t)^2\}^{0.25}$= 9.2
- $k = 1 - \cot\theta/2\lambda$= 0.95
- $MS6 = \frac{R_1Et_{td}(k_{td}+k_{td}^{-1})}{4\times\lambda_{td}{}^3} = 709$
- $Corr\ TS6\ or\ MS6 = -\frac{Et_{td}}{2\lambda_{td}{}^2k_{td}sin\theta_{td}} = -1.38$
- $TS6 = \frac{Et_{td}}{\lambda_{td}R_1k_{td}sin^2\theta_{td}} = 0.0052$

Bottom(Main) Ring beam

- $MS7 = \frac{Eb_7d_7{}^3}{12r_2{}^2} = 3.4$
- $TS7 = \frac{Eb_7d_7}{r_2{}^2} = 0.0098$

Membrane analysis

Top dome-

- Self-weight and live loads-$w_1 = (0.75 + 0.1 + t_1 \times 25$)=2.85 kN/m^2
- Total weight (SW1) = $w_1 \times (2\pi R_1h_1)$=148 kN
- Meridional Forces=$T_1 = \frac{w_1\times R_1}{1+\cos\theta_{td}}$= 19.3 kN/m
- Horizontal forces H1 = $\frac{w_1\times R_1\cos\theta_{td}}{1+\cos\theta_{td}}$ = 16.4 kN/m
- Horizontal displacement $x_{td} = \frac{wR_1^2\{(1+\cos\theta_{td})^{-1}-cos\,\theta_{td}\}}{Et_1}$ = -906
- Rotation $\psi_{td} = \frac{2wR_1\,sin\,\theta_{td}}{Et_1}$ = 0.47

Top ring beam -

- Self-weight and live loads $w_2 = 25b_1d_1$= 1 kN/m
- Total weight $SW2 = (w_2) \times (2\pi r_1)$= 41.5 kN

Cylindrical wall-

- Self-weight for uniform wall=$w_3 = (25 \times t_{3top})$ =2.5 kN/m^2
- Self-weight $SW3 = 2\pi r_1 w_3 (H + 0.5 \times t_{3top}) + 2\pi r_1 w_{31} H$=426 kN
- Horizontal displacement at bottom of wall $x_{wall} = \frac{\gamma_w \times H \times (r_1)^2}{Et_{3bottom}}$ = 17647
- Rotation at top/bottom of wall $\psi_{wall} = \frac{\gamma_w \times (r_1)^2}{Et_{3bottom}}$ = 4.66

Middle Ring beam-

- Self-weight and Live loads =$w_4 = (3 + 25 \times t_4)$=6 kN/m^2
- Self-weight $SW4 = SW4 = w_4 \times \{\pi(2r_1 + b_4)b_4\}$ = 268.12 kN
- Bending moment $BM\ at\ MRB = -w_4 \times b_4 \times (b_4 + t_{3bottom}) \times 0.5$ = -3300 N
- Total Vertical Load $TL_{MRB} = \frac{(SW1+SW2+SW3+WL_{Wall}+SW4)}{2\pi r_1}$= 1158 kN
- Hoop tension = $HT\ at\ MRB = 10 \times H \times t_4$= 4.9 kN/m
- Horizontal thrust at the top= $HThrust\ at\ MRB = TL_{MRB} / \cot\theta$=1158 kN

Conical dome

- Self-weight =$w_5 = 25 \times 0.5 \times (t_{5bottom} + t_{5top})$=1.875 kN/m^2
- Self-weight $SW5 = w_5 \times \pi(r_1 + r_2) \times l$ = 272.6 kN
- water load at Conical dome $WL_{Cd}\gamma_w\ (\pi {r_1}^2 H + \pi l \times \frac{{r_1}^2+{r_2}^2+r_1 r_2}{3} - \pi r_2^2 \frac{H+l}{3})$=2900 kN
- Total load per meter at Bottom of Conical dome $TL_{CD} = \frac{SW1+SW2+SW3+SW4+WL_{Wall}+SW5+WL_{Cd}}{(2\pi r_2 \cos\theta)}$ =4339 kN/m
- Meridional Force $T_{5Top} = TL_{CD}/\cos A_r$=4339 kN/m
- Horizontal thrust imposed on the bottom support $HThrust = TL_{CD} \times \sin\theta$=
- Horizontal force at Top of $HF_{CDTop} = \gamma_w \times H \times r_1 \sec A_r + 25 t_{5top} \times r_1 \tan A_r$= 404
- Horizontal force at Bottom of $HF_{CDBottom} = \frac{\gamma_w\, r_2 (H + r_1 - r_2)}{\cos A_r} + 25 r_2\, t_{5bottom} \tan A_r$ =419 kN
- Horizontal displacement at top $x_{cd1} = \frac{HF_{CDTop} \times r_1}{Et_{5top}}$ =17750
- Horizontal displacement at bottom $x_{cd2=} \frac{HF_{CDTop} \times r_2}{Et_{5bottom}}$ =13785 kN
- Rotation at Top $\psi_{cd1=} - \frac{2HF_{CDTop} + T_{5Top}}{Et_{5top}} \times (\tan A_r)$ = -5.66
- Rotation at Bottom $\psi_{cd2=} - \frac{(2HF_{CDBottom} + T_{5Bottom}) \tan A_r}{Et_{5Bottom}}$ = -6.89

Bottom dome

- Self-weight $w_6 = 25 \times t_6$ =3 kN/m^2
- Total weight $SW6 = w_6 \times 2\pi h_2 R_2$ = 335 kN
- water load at Bottom dome $WL_{BD} = \{\pi {r_2}^2(H + r_1 - r_2) - \pi \times h_2^2 \times \frac{3R_2 - h_2}{3}\} \times \gamma_w$ = 3600 kN
- Total load at Bottom dome per square meter $\text{TL}_{BD} = \{SW6 + WL_{BD}\}/\{2\pi R_2 h_2\}$= 43.6
- Horizontal thrust imposed at bottom support $HForce_{BD} = \frac{\{SW6+WL_{BD}\}\times R_2 \times cos\theta_2}{(1+cos\theta_2)\{2\pi h_2 R_2\}}$=159.2
- Horizontal displacement

  $x_{bd} = \frac{w_6 R_2^2 \sin\theta_{bd}\{(1+\cos\theta_{bd})^{-1} - cos\,\theta_{bd}\}}{Et_6} + \frac{w_6 R_2^3 \sin\theta_{bd}\{2\ \cos 2\theta_{bd} + \cos\theta_{bd} - 3\}}{(6(1+\cos\theta_{bd})Et_6)} - \frac{\gamma_w R_2^2 (H + r_1 - r_2 - h_2) cos\theta_{bd}}{2Et_6}$ = -2.15

  Rotation $\psi_{bd} = \frac{2w_6 R_2 \sin\theta_{bd}}{Et_6} - \frac{10R_2^2 \sin\theta_{bd}}{Et_6}$ = -10124

Main girder beam or Bottom Girder beam

- Self-weight $w_7 = 25b_7 d_7$ = 6 kN/m^2
- Total weight $SW7 = w_7 \times 2\pi r_2$=187.8
- Total load at Main girder beam $\text{TL}_{MGB} = SW1 + SW2 + SW3 + SW4 + SW5 + SW6 + SW7 + capacity \times 10;$ = 7956
- $Total\ Load\ per\ meter = (\frac{\text{TL}_{MGB}}{2\pi r_2})$=255.6
- Net Horizontal force at Bottom support H_{NET} =$HF_{CDBottom}$- $HForce_{BD}$=-4.49

REACTIONS IMPOSED BY THE JOINTS

BY TOP JOINT

Let the net rotation at the joint be Y radians and net horizontal displacement be X mm. The continuity deformation are tabulated below

Member	Clockwise Rotation (radian)	Outward Displacement (mm)
Edge of top dome	ψ_1 −(0.47/E)	x_1-(-906/E)
Top ring beam	ψ_1	x_1
Top edge of wall	ψ_1 −(4.66/E)	x_1

The continuity deformation obtained is multiplied by the Corresponding stiffness to give the reaction imposed by the joint on the individual members

Member	Clockwise Moment (Nmm/mm)	Outward thrust (N/mm)
Edge of top dome	{ψ_1 −(0.47/E)}*112.5+x_1-(-906/E)*(-0.29)	x_1-(-906/E)* 0.00146+ψ_1 −(0.47/E)*(-0.29)

Top ring beam	$3.1*\psi_1$	0.001*x_1
Top edge of wall	{ψ_1 −(4.66/E)}*270+ $x_1*0.437$	x_1*0.001417+{ψ_1 −(4.66/E)}*0.437

The sum of reaction imposed by the joint = The sum of external force imposed on the joint

- 385.1*ψ_1+0.143* x_1 −1493=0
- 0.143*ψ_1+0.0038* x_1-0.577= Horizontal forces H1 = 16.4 kN/m

  Solving the two equation -

  x_1 = 4329

  ψ_1 = 2.2

Member	Clockwise Moment (Nmm/mm)	Outward thrust (N/mm)	Hoop tension	Ast	fct
Edge of top dome	M1= -1338.13	T1=7.14	H1= 52.4 N/mm	120	0.64
Top ring beam	M2= 6.9	T2=3.97	H2=26241.8 N	60	0.64
Top edge of wall	M3= 1331.17	T3=5.22	H3t= 65.6 N/mm	150	0.64

BY MIDDLE JOINT

Let the net rotation at the joint be Y radians and net horizontal displacement be X mm. The continuity deformation are tabulated below

Member	Clockwise Rotation (radian)	Outward Displacement (mm)
Bottom edge of wall	ψ_2 −(4.35/E)	x_2-(17641/E)
Middle ring beam	ψ_2	x_2
Top Edge of C.D.	ψ_2 −(-5.6/E)	x_2-(17748/E)

The continuity deformation obtained is multiplied by the Corresponding stiffness to give the reaction imposed by the joint on the individual members

Member	Clockwise Moment (Nmm/mm)	Outward thrust (N/mm)
Bottom edge of wall	{ψ_2 −(4.35/E)}*270+ {x_2-(17641/E)}(-0.437)	ψ_2 −(4.35/E)(-0.437)+ x_2-(17641/E)(0.0014)
Middle ring beam	$3.3*\psi_2$	0.0027*x_2
Top Edge of Conical dome	{ψ_2 −(-5.6/E)}*35683 {x_2-(17748/E)}*0.116	{ψ_2 −(-5.6/E)}*0.116+ {x_2-(17748/E)}*0.00008

The sum of reaction imposed by the joint = The sum of external force imposed on the joint

- 35957.0 *ψ_2-0.32* x_2 +204300=BM at MRB= -3030
- 0.143*ψ_2+0.0038* x_2 -24.86= TL$_{MRB}$ $+ \ HFatMRB$

Solving the two equation -

x_2 = 12872.4

ψ_2 = 5.7

Member	Clockwise Moment (Nmm/mm)	Outward thrust (N/mm)	Hoop tension	Ast	Fct
Bottom edge of wall	M3b= -632.3	T3b=-2.35	H3t=195.0N/mm	448	1.83
Middle ring beam	M4= -18.89	T4=35.4	H4=302695 N	695	1.83
Top Edge of Conical dome	M5t= -2650	T5t=-0.39	H5t=292 N/mm	672	1.83

BY BOTTOM JOINT

Let the net rotation at the joint be ψ_3 radians and net horizontaldisplacement be x_3 mm. The continuity deformation are tabulated below

Member	Clockwise Rotation (radian)	Outward Displacement (mm)
Bottom Edge of CD	ψ_3 −(-6.9/E)	x_3-(13798/E)
Bottom ring beam	ψ_3	x_3
Bottom dome	ψ_3 −(-2.15/E)	x_3-(-10111/E)

The continuity deformation obtained is multiplied by the corresponding stiffness to give the reaction imposed by the joint on the individual members

Member	Clockwise Moment (Nmm/mm)	Outward thrust (N/mm)
Bottom Edge of Conical dome	{ψ_3 −(-6.9/E)}*633 {x_3-(13798/E)} *(-0.64)	{x_3-(13798/E)}*0.0019 {ψ_3 −(-6.9/E)} *(-0.64)
Bottom ring beam	ψ_3*293	x_3*0.0097

Bottom dome	{ψ_3 −(-2.15/E)}*708+ {x_3-(-10111/E)}*(-1.4)	{x_3-(-10111/E)}*0.005 {ψ_3 −(-2.15/E)} *(-1.4)

The sum of reaction imposed by the joint = The sum of external force imposed on the joint

- 1636 *ψ_3-2.02* x_3 +709=0
- -2.02*ψ_3+0.016* x_3 -26= HNET $= -4.5$

Solving the two equation -

x_3 = 1555

ψ_3 = -2.33

Member	Clockwise Moment (Nmm/mm)	Outward thrust (N/mm)	Hoop tension	Ast	Fct
Bottom Edge of CD	M5b=12683	T5b=-33.35	H5b=-47.05 N/mm	108	0.31
Bottom ring beam	M7=-700.1	T7=-15.2	H7=-75347 N	173	0.31
Bottom dome	M6=-11982	T6=-7.65	H6=-47.09 N/mm	108	0.31

Design of the Elements-

Top dome

- $H_u = 1.5 \times HTension1$=79 kN
- $T_u = 1.5 \times HTension1 \times sin\theta_{td}$=41.8 kN
- Meridional Stress = 0.52 N/mm^2
- Hoop Stress = 0.99 N/mm^2
- T_{stress} & $H_{stress} \leq 8N/mm^2$;
- Adopt nominal reinforcement of 0.28 percent
- A_{st}- 280 mm^2
- Adopt 8 mm bars with spacing 150 mm both way
- Concrete $A1 = 2\pi R_1 t_1 h_1$= 11.8 cum
- Steel $Q1 = 2R1 \times 0.28 \times s_w/100$= 0.58 t
- Surface Area S$A1 = 2\pi R_1 h_1$;

Top ring beam

- $H_u = 1.5 \times HTension2$;
- $M_u = 1.5 \times M_2$;
- $AstH_u = \frac{H_u}{435} = 91$;
- $AstM_u$=2.31;

- Nos of Bars provided in Top ring beam : 4 Nos 12 mm ∅.
- Adopt 10 mm ∅ stirrups at 200 mm centre to centre.
- Concrete $A2 = 2\pi b_2 d_2 r_1$=1.65 cum
- Steel estimation (Main) $Q21 = 2\pi r_1 \times Nos \times A_{\varphi main} s_w$;
- Steel estimation (Distribution) $Q22 = 4 * (t_2 - 2 \times 40) \times \frac{\pi(\varphi_d)^2}{4} \times s_w \times \frac{2\pi r_1}{spacing}$;
- Q=Q21+Q22=0.31
- Check for Crack width of Top ring beam as per equations- 3.2.3.2
  Fs: 58.0 N/mm^2
  e1: 0.000290
  e2: 0.00046
  wcr: -0.0.18
  wcr: 0.0006
- Design is safe for Crack width

Cylindrical wall

- Factored hoop tension at h Height $H_u = 1.5 \times HTension3b \times \frac{h}{H}$
- Factored hoop tension at 1 Height $H_u = 166.05$ kN
- Factored hoop tension at 2 Height $H_u = 333$ kN
- Factored hoop tension at 3 Height $H_u = 498$ kN
- Factored hoop tension at 4 Height $H_u = 664.5$ kN
- Factored Moment at Bottom $M_{u3b} = 1.5 \times M_{3b}$=993 Nmm/mm;
- Reinforcement to be provided-
  Main hoop steel is provided 12 mm diameter 180 mm centre to centre
  Distribution= 10 mm diameter 180 mm c-c
- Concrete $A3 = \pi H \times (2r_1 + t_{3bottom}) \times (t_{3bottom} + t_{3top})/2$;=16.95 cum
- Steel estimation (Main) $Q31 = 4\left\{2\pi r_1 \times \frac{\pi(\varphi_m)^2}{4} \times \frac{1000}{spacing} sw\right\}$ =0.4 tonnes
- Steel estimation (Distribution) $Q32 = 2\left\{\frac{\pi(\varphi_d)^2}{4} \times 2\pi r_1 swH \frac{1000}{spacing}\right\}$=0.229 tonnes
- Q=Q31+Q32=0.638 tonnes
- SA3:339.02 sqm
- Check for Crack width of Top ring beam as per equations- 3.2.3.2.
  Fs: 58.0
  e1: 0.000290
  e2: 0.00046
  wcr: -0.0.18

wcr1: 0.0006

Design is safe for Crack width

Middle Ring beam

- $H_u = 1.5 \times HTension4$= 454009 kN
- AstH4=1043 mm^2
- AstM4=168. 9 mm^2
- Reinforcement provided-
  Nos of Main Bars provided – 4 Nos 20 mm Diameter
  10 mm diameter stirrups at 200 mm centre to centre
- Concrete $A4 = \pi H \times (2r_1 + b_4) \times t_4 \times b_4$= 5.5 cum
- Steel estimation (Main) $Q41 = 2\pi r_1 \times \frac{\pi(\varphi_m)^2}{4} \times Nos \times$ sw =0.46;
- Steel estimation (Distribution) $Q42 = \frac{\pi(\varphi_d)^2}{4} \times b_4 \ \frac{2\pi r_1}{spacing} swH$ =0.177;
- Q=0.64 Tonnes
- Check for Crack width of Top ring beam
  wcr:0.0001
  wcr1:0.0001

design is safe for Crack width

Conical dome

- At Top $H_u = 1.5 \times HTension5t$=657720 kN
- At Bottom $H_u = 1.5 \times HTension5b$=-105900 kN
- AstH5t = 1008 mm^2
- AstH5b =162 mm^2
- Reinforcement provided-
  provide 10 mm diameter bar circumferentially both face @ 150c-c
  provide 10mm diameter bar radially both face @ 150.000000 c-c
- Concrete $A5 = \pi l \times (r_1 + r_1 + t_{5top}) \times (t_{5top} + t_{5bottom}) \times 0.5$ =1.35 cum
- Steel estimation (Main) $Q51 = \left\{2\pi(r_1 + r_1)l \times \frac{\pi(\varphi_m)^2}{4} \times \frac{1000}{spacing} sw\right\}$ =0.665 tonnes
- Steel estimation (Dist) $Q52 = \left\{2\pi(r_1 + r_1)l \times \frac{\pi(\varphi_{md})^2}{4} \times \frac{1000}{spacing_{dis}} sw\right\}$=0.7 tonnes
- Q5=Q51+Q52=0.135 tonnes
- Crack width check
  wcr=-0.118604
  wcr1:-0.118604

Design is safe for Crack width

Bottom dome

- $H_u = 1.5 \times HTension6$=-71 kN
- $T_u = 1.5 \times HTension6 \times sin\theta_{bd}$=-48.8 kN
- Meridional Stress = 0.31 N/mm^2
- Hoop Stress = 0.48 N/mm^2
- T_{stress} & $H_{stress} \leq 8N/mm^2$;
- **Dome is safe in stress**
- Adopt nominal reinforcement of 0.28 percent
- A_{st}- 430 mm^2
- Adopt 10 mm bars with spacing 150 mm both way
- Concrete $A6 = 2\pi R_2 t_6 h_2$= 13.6 cum
- Steel $Q6 = 2R1 \times 0.28 \times s_w/100$= 0.4 ton
- Surface Area S$A6 = 2\pi R_2 h_2$= 90 m^2
- Crack width-
  wcr=0.127631 mm
  wcr1=-0.127631 mm

Design is safe for Crack width

Main girder beam

Reinforcement Calculations at the End-

- Total load at Main ring beam= $SW1 + SW2 + SW3 + SW4 + SW5 + SW6 + SW7 + capacity \times 10$ =7960 kN
- Total load per span = TL$_{lps}$ = TL$_{MGB}/2\pi r_2$ =256
- The angle at the center in radian = $\propto_{centre} = \pi/N$= 0.314
- Distance of critical Section = $d_{critical} = \frac{2\pi r_2}{N} - \frac{D_c\sqrt{\pi}}{2}$= 2.71
- The angle at the center in radian = $\propto_{critical} = \frac{D_c\sqrt{\pi}}{2\times2\times r_2}$=0.0035
- B.M. at the critical Section
  $BM_{cr} = 2\pi r_2 \text{TL}_{lps}\left(\propto_{centre} \sin(\propto_{critical}) + \propto_{centre} \frac{\cos(\propto_{critical})}{tan(\propto_{centre})} - 1\right)$= -140.9 kNm
- Twisting Moment
  $M_t = r_2^2 \frac{2\pi r_2}{N}\left(+\propto_{centre} \cos(\propto_{critical}) - \propto_{centre} \frac{\sin(\propto_{critical})}{tan(\propto_{centre})} + \propto_{critical} - \propto_{centre}\right)$=6.21 kNm
- B.M. by continuity equations= $BM_{continuity} = M7 \times r_2\ /1000$=(-)3360 kNm

- Equivalent Moment $M_{EQ} = M_T \times \frac{1+d_7/b_7}{1.7}$ =9.12 kNm
- Design Moments M_{DM}=-($BM_{cr} + BM_{continuity}$)+ M_{EQ}=154 kNm
- Eccentricity $e = M_{DM} \times 1000000/Htension7$=(-)2038
- Distance of Hoop force $d_{hf} = e - (0.5 \times d_7 - 40)$ = (-)1998 mm
- Depth of neutral axis = $la = d_7 - 50 - \varphi_d - 0.42 \times 0.48 \times d_7$=410 mm
- Force of Tension = $F_T = Htension7 \times \frac{la+d_{hf}}{la}$ =292468 kN
- Force of Compression = $F_C = F_T - Htension7$= 367820 kN
- AstH7= 292468/435*1.5= 1008 mm^2
- Main Reinforcement Provided at the Top-
  Adopt 4 bars of 20 mm diameter

Reinforcement Calculations at the Centre

- B.M. at the critical Section
  $BM_{mid} = 2\pi r_2 \mathrm{TL}_{lps}(\propto_{centre} / \sin(\propto_{centre}) - 1)$= -104.9 kNm
- Design Moment at the centre M_{DM}= ($BM_{mid} + BM_{continuity}$) =153.4 kNm
- Eccentricity1= (-) 1340 mm
- Distance of Hoop force= (-) 1280 mm
- Force of Tension at midspan =163660 kN
- AstH7= 163660/435*1.5= 564 mm^2
- Calculation of reinforcement at the Mid span-
  Adopt 2 bars of 20 mm diameter

Design For Shear and Twisting Moment

- Critical Section for shear is at a distance equal to effective depth from face of support =
  $d_{shearcr} = 0.5\, d_{critical} - d_7 - clearcover$=0.77 m
- Shear force s $SF_{MGB} = \mathrm{TL}_{lps} \times d_{shearcr}$ = 197.8 kN
- Angle for Twisting Moment $\propto_{Twist}$= $\frac{\propto_{centre} d_{shearcr}}{r_2}$=0.15 kN
- Twisting Moment $M_{tcr} = r_2^2 \frac{2\pi r_2}{N}\left(\propto_{Twist} - \propto_{centre} + \propto_{centre} \cos(\propto_{Twist}) - \propto_{centre} \frac{\sin(\propto_{Twist})}{tan(\propto_{centre})}\right)$= 12.25 kNm
- Design Shear force s $SF_{Design} = SF_{MGB} + 1.6 M_{tcr}/b_7$= 249 kN
- Maximum Shear Stress= $\tau_{max} = SF_{Design}/(b_7 \times d_7)$ = 1.03 N/mm^2
- Calculation of shear is done as per equations- 10 mm diameter bar is to be provided at 200 mm c-c
- Concrete $A7 = (2\pi r_2) \times b_7 \times d_7$= 7.48 cum

- Steel estimation at top of beam Q71= $2\pi r_2 \times \frac{\pi(\varphi_m)^2}{4} \times Nos \times$ sw=0.69tonnes
- Steel estimation at Bottom of beam $Q72 = 2\pi r_2 \times \frac{\pi(\varphi_m)^2}{4} \times Nos \times$ sw= 0.7 tonnes
- Steel estimation at Shear of beam $Q73 = \left\{(3 \times d_7 - 200) \times \frac{\pi(\varphi_s)^2}{4} \times sw \times \frac{2\pi r_2}{spacing}\right\} = 0.4$ tonnes

Design of the staging-

- Height of staging=16.00 m
- Depth of Bottom beam= 0.60 m
- Depth of foundation = 1.80 m
- H_{Total} =16-0.6+1.8= 16.6 m
- Clear length of each panel above G.L.= $C.l._{Panel} = \frac{H_{staging} - d_7 - 4*d_{10}}{5}$ =2.68 m
- $c - c\ dis\ of\ column = N \times sin\left(\frac{\pi}{N}\right) = 3.09$ m
- Clear length of brace= $Cl_{brace} = N \times \sin\left(\frac{\pi}{N}\right) - D_c$ =2.69 m

Computation of Vertical loads

- Load per span: 795.3 kN as per above calculations
- Self-weight of Single Column (Dc= 400 mm)- SW8 $= 25 \times \frac{\pi D_2^2}{4} \times H_{Total}$= 52.24 kN
- Self-weight of Brace (200 mm x 500 mm)- S W9 $= 25 \times 4 \times b_9 \times d_9 \times Cl_{brace}$= 26.9 kN
- Adding additional weight of Stairs SW12= 40- 50 kN
- Self Weight upto bracings=795.3+ 52.2+26.9+45=921 kN

analysis of Columns-

Wind analysis-

- Basic Wind speed- 47 m/sec
- k_1=1.07
- k_2=1.07
- k_3=1.00
- k_4=1.00

(k_1–k_4: Modification factors Calculated from IS 875:2015)

- $V_z = V_z = V_b \times k_1 \times k_2 \times k_3 \times k_4 = 53.8$ m/sec
- $P_z = 0.6 \times V_z^2$ =1.73 kN/m^2

Wind Load analysis-

- Wind pressure acting at the body of tank-0.7 $P_z\left(\frac{2}{3}\mathrm{h}_1 + \mathrm{d}_2 + \mathrm{H} + \mathrm{d}_4\right) \times 2\mathrm{r}_1 +$ 0.7 $P_z(\mathrm{r}_1 + \mathrm{r}_2)(\mathrm{r}_1 - \mathrm{r}_2)\tan(\mathrm{A}_r) = 94$ kN
- Position of the load acting at the water tank container $\mathrm{h}_{\mathrm{tankcg}} = \frac{H+\mathrm{h}_1+\mathrm{d}_2+(\mathrm{r}_1-\mathrm{r}_2)\tan(\mathrm{A}_r)}{2} = 3.9$ m
- Effective number of columns=8;
- Wind pressure at each panel except lower panel= 0.7 $P_z \times N_{Eff} \times \mathrm{D}_c \times C.l._{Panel}$ =13.03 kN
- Wind pressure at lower panel 0.7 $P_z N_{Eff} \times \mathrm{D}_c\left(C.l._{Panel} - \mathrm{D}_f + \mathrm{d}_{10}\right) = 8.5$ kN
- Wind pressure at brace= $P_z\, d_9(\mathrm{D}_c + 2\mathrm{r}_2) = 8.9$ kN
- Shear force at Panel I= 94+13.03= 99.03 kN
- Shear force at Panel II= 99.03 +13.03+8.9=120.9 kN
- Shear force at Panel III= 120.9 +13.03+8.9=142.9 kN
- Shear force at Panel IV= 142.9 +13.03+8.9=164.8 kN
- Shear force at Panel V= 164.8 + (13.03+8.5)*0.5+8.9= 184.5 kN

Earthquake analysis of tank

- Effective weight for Full tank condition=10*(795.5+(52+26.9+45)/3)= 8371 kN
- Effective weight for Empty tank condition=8371-6000= 2371 kN
- Deflection in Full tank=$Def_1 = \frac{(n_2+1)\{1000(C.l._{Panel}+b_9)^3+D_f{}^3\}EWT_1(1+\cos\frac{2\pi}{N})}{\{12\times5000\sqrt{f_{ck}}\times\frac{\pi\times D_C^2}{4}\times\frac{N}{64}\}}$= 827 mm
- Deflection in Empty tank = 2371*827 /8371= 234 mm
- $T_{Full} = 2\pi\sqrt{\frac{827}{9810}}$ = 1.83 sec
- $T_{Empty} = 2\pi\sqrt{\frac{234}{9810}}$ = 0.97 sec
- $Z = 0.24\ for\ Zone\ IV$ and R=4 and I = 1.5
- Sa/g is calculated as per IS 1893 Fig 2(b) in Full and Empty tank for 80 kN/m^2 =0.743 and 1.4 in Full and Empty tanks
- Calculation of design horizontal earthquake acceleration coefficient $A_h$in Full and Empty tank=
  $A_{HFull} = \frac{Z\times0.5\times(S_a/g)_{Full}}{[^R/_I]}$= 0.5*0.91*0.24/(4/1.5)=0.04
  $A_{HEmpty} = \frac{Z\times0.5\times(S_a/g)_{Empty}}{[^R/_I]}$ =0.5*1.72*0.24/(4/1.5)= 0.0774
- Base Shear Calculation V_B in Full and Empty tank=
  $V_{BFull} = A_{HFull}\ \times 8371$ =342.3 kN

$V_{BEmpty} = A_{HEmpty} \times 2371$=184 kN

Calculation of Maximum Lateral force and Overturning Moments for design of Columns

- Max Lateral Force=
  Shear force at Panel V= 184.5 kN
  V_{BFull} =342.3 kN
  V_{BEmpty} =184 kN
  In Both Full and Empty tank condition Seismic Load is dominant.
- Overturning Moments =92*(16+3.9)+13.03*(16-0.5/2-2.69) + 13.03*(16-0.5-0.5/2-2*2.69) + 13.03*(16-1-0.5/2-3*2.69) + 13.03*(16-1.5-0.5/2-4*2.69)+8.5(16-2-0.5/2-5*2.69) + 8.9*(16-0.6-2.69-0.5/2)+ 8.9*(16-0.6-2*2.69-0.5)+ 8.9*(16-0.6-3*2.69-0.5)+ 8.9*(16-0.6-4*2.69-0.5/2)=2510 kNm
- Maximum Thrust on Leeward Column= 4*2510/2/4.9/10=102.4 kN

Calculation of the Final design forces for Full tank Conditions

- Seismic Forces dominates in Full tank conditions
- Axial Force on the column (Pu)= 102.4*100/921= 11.11<=32.22
  Pu= SW upto brace =921 kN

Calculation of the Final design forces for Empty tank Conditions

- Wind Load is critical

Column design-

- Maximum Bending moment in Column = {104.2*(1+cos 36)*2.69}/2/10=104.2 kN
- $a = \frac{1.2 \times P_u \times 1000}{f_{ck} D_c^2 \times 1000000} = 0.23;$
- $b = \frac{1.2 \times BM_{MaxinCol} \times 10^6}{f_{ck} D_c^3 \times 10^9} 0.065;$
  Percentage of the reinforcement is calculated from **the charts 56 of SP Charts**
- Reinforcement Calculation= $A_{stCol} = p_c \times \frac{\pi D_c^2}{400} \times 10^6$= 1510 mm^2

  Provide 6 No of bars of 20 diameter of bar
  Provide lateral bars of 10mm diameter at 300 mm c-c
- Concrete Calculations- $A8 = \frac{\pi D_c^2}{4} \times N \times H_{Total}$=20.9 cum
- Main Steel calculations= $Q81 = \frac{\pi(\varphi_m)^2}{4 \times 10^6} \times H_{Total} \times N_8 \times sw$= 0.324 tonnes
- Distribution Steel calculations= Q82= $2\pi(D_c - clearcover) \times \frac{\pi(\varphi_d)^2}{4} \times \frac{H_{Total}}{0.3} \times$ sw= 0.08 tonnes
- Q8=N*(Q81+Q82)= 5.1 tonnes

Design of Bracings-

- BM1= ((1+cos38))/10*(165+184.8)*0.5(2.69+0.5)= 122.3 kNm
- BM2= 0.8*122.3*2.69/4cos36 kNm
- BM= 1.2*0.5*(122.3+53.8) kNm
- Reinforcement Calculations =
  Ast for BM = 609 mm^2
  Provide 6 bars of 12 mm dia at top
  Provide 6 bars of 12 mm dia at bottom
  Shear reinforcement of 8 mm diameter at 200 mm c-c
- Concrete Estimation= 4*10*0.2*0.5*2.7= 10.78 cum
- Steel estimation Main $Q91 = 2 \times \frac{\pi(\varphi_m)^2}{4\times10^6} \times Nos \times Cl_{brace} \times 4 \times N \times sw$ =1.14 tonnes
- Steel estimation Main $Q92 = 2 \times \frac{\pi(\varphi_m)^2}{4\times10^6} \times Nos \times Cl_{brace} \times 4 \times N \times sw$ =0.595 tonnes
- Total Steel Q9=10 (Q91+Q92)= 1.78 tonnes

Design of the Foundation beam-

- Max Negetive B.M. calculations at the support of Foundation beam-
- BM=(921+102.4) *154 /(7960/10)= 178 kN
- $d_{eff10} = \sqrt{\frac{178\times10^6}{30\times100\times1000}}$= 178 mm<=500 mm as provided
  Depth of the Foundation is safe
- Reinforcement Calculations-
  Ast required for BM at the edge Ast= 1286 mm^2
  Ast required for BM at the Centre Ast= 810 mm^2
  Provide 5 bars of 20mm diameter at bottom
  Provide 3 bars of 20mm diameter at top
  Adopt 10mm 4-legged stirrups at 200 mm spacing
- Concrete $A7 = (2\pi r_2) \times b_7 \times d_7$= 7.47 cum
- Steel estimation (Top) $Q71 = 2\pi r_2 \times \frac{\pi(\varphi_m)^2}{4} \times Nos \times$ sw=0.38 tonnes
- Steel estimation (Bottom) $Q72 = 2\pi r_2 \times \frac{\pi(\varphi_m)^2}{4} \times Nos(b) \times$ sw= 0.002 tonnes
- **Raft Foundation-**
- Total load from above= 9206 kN
- Total load with F.L= 1.1*9206= 10126 kN
- Raft area= 10126/80= 126.58 mm^2

- Width of the Raft= $\frac{RaftArea}{2\pi r_2} =$
- Inner Diameter of Raft $D_i = 2r_2 - Widthofraft + 0.1$ =5.94 m
- Outer Diameter of Raft $D_o = 2r_2 + Widthofraft = 13.95$ m
- CCR Calculations = 5.24 m
- Final Inner Radius= 2.9 m
- Final Outer Radius= 7 m
- Area of raft Provided= 137.2 mm^2
- Upward Pressure Full=10126/80 = 73.7 kN/m^2
- Overturning Moment = 2625 kNm
- Max Pressure on soil due to Lateral forces at outer edge= {2629 x 4.1 / (π / 4 x (13.95^4 -6^4))} =10.1 kN/m^2
- Max downward pressure, when tank is full= 26.62 + 52.87
  This is less than 80 kN/m2. Safe
- Upward pressure when tank is empty (2340-1000) / 44.26
- Overturning moment due to critical lateral force about the bottom of raft=2624 kNm
- Max Pressure on soil due to Lateral forces at outer edge = 83.87 kN
- Max downward pressure, when tank is empty 26.62 + 30.28
  This is less than 80 kN/m2. Hence O.K.
- Min downward pressure, when tank is empty-= 40.16 kN
- Maximum Upthrust at outer edge= 83.9
- BM at inner face of F. B. =172.65 kNm
- BM at outer face of FB= 249 kNm
- Provide overall depth 415 mm at the face of beam and reducing to 150 mm at free edge as shown
  Reinforcement provided= Ast11:1819.9 mm^2
  Provide 10 Nos 16 mm diameter bars circumferentially
  provide 16 mm diaameter bars radially at 110 mm c-c
- Concrete A11= $= \{\pi(R_o^2 - R_i^2)(d_{11} + 0.15) \times 0.5\} - A10 = 33$ cum
- Steel estimation Main Q111= $\pi(R_o - R_i) \times \frac{\pi(\varphi_m)^2}{4\times10^6} \times Nos \times sw = 2.56$ tonnes
- Steel estimation Distribution $Q112 = 2\pi(R_o - R_i)4N \times \frac{\pi(\varphi_d)^2}{4} \times \frac{1000}{spacing} \times$ sw= 2.53 tonnes
- Steel Total Q11== $Q111 + Q112$= 5.15 tonnes

Evaluation of various quantities-

- Total concrete volume is 140.7 cum

- Total quantity of steel is 16.15 tons

- Ferrocement lining of 12 mm or 15 mm with 4 mesh for additional safety can be provided. Cost =1.1 lkhs approx
- Cost= 30.2 Lakh Rs

Annexure B- Manual design of 600 kL hybrid Intze tank

Annexure C- Manual design of 200 kL hybrid circular tank

200 kL Hybrid Circular water tanks

Basic data provided for design of tank

- Quantity- 200 kL
- Staging Height- 14
- Net safe Bearing Capacity of soil in kN/m^2: 80
- Depth of the Foundation (m)- 1.8
- No of bays/ braces – 4
- Seismic Zone III
- Basic Wind Speed 39 m/sec
- Terrain category & region type- Non Coastal region and Catergory II

Basic Calculations of dimensions of tank-

- Inner Radius of the Top and bottom beam is taken as 3.7 m (Iterative process)
- Outer Radius of the Top and bottom beam is taken as 3.8 m
- Inner Diameter of the Top and bottom ring beam is taken as 7.4 m
- Outer Diameter of the Top ring beam is taken as 7.6 m
- h_1=D/7= 1.05 m
- h_2=D/5= 1.48 m
- Radius of Top dome- $R_1 = 0.5 \times \{(r_1 + 0.1)^2 + {h_1}^2\}/h_1$= 7 m.
- Radius of B Dome- $R_2 = 0.5 \times \{(r_2 + 0.1)^2 + {h_2}^2\}/h_2$= 5.36 m.
- $V = \pi {r_1}^2 H - \pi \times h_2^2 \times \frac{3R_2 - h_2}{3}$;
- Volume of the Bottom dome = 33.48 cum
- Calculation of Height of Cylinder-

  200= 43* H-33.48

  H=5.43 m

  Height of the Cylindrical wall is taken as 5.45 m and FB =0.15 m

  Total H = 5.6 m.

Final dimensions of the tank are-

Dimensions of RCC Over Head water tank body-

Top dome-

- Mean chord = 7.4 m
- Mean rise = 1.05 m
- Mean radius of curvature = 7 m
- Thickness = 80 mm
- Half of the angle subtended at the centre = 31.9 degrees

Top ring beam

- Cross Section of the beam = 200 x 200 mm
- Mean Diameter = 7.4 m

Cylindrical wall

- Outer diameter = 7.6 m
- Thickness = 100.00 mm
- Internal diameter = 7.8 m
- Mean diameter = 7.5 m
- water depth = 5.45 m

Balcony/ Middle Ring beam-

- Width of balcony = 1 m
- Depth of balcony at the face of wall = 120 mm
- Depth of balcony at free end = 120 mm

Bottom dome-

- Mean chord = 7.4 m
- Mean rise = 1.48 m
- Mean radius of curvature =5.36 m
- Thickness = 120 mm
- Half of the angle subtended at the centre = 43.60 degrees

Main ring beam-

- Supported on 6 column of 400 mm diameter
- Cross Section of beam= 400 mm x 500 mm
- Mean diameter = 7.4 m
- Half of angle subtended at the centre by the span = 30 degrees

Calculation of Stiffnesses-

Top dome

- $\lambda = \{3(R/t)^2\}^{0.25} = 12.3$
- $k = 1 - \cot\theta/2\lambda = 0.93$
- $MS1 = \frac{R_1 E t_{td}(k_{td} + k_{td}^{-1})}{4 \times \lambda_{td}^{3}} = 150.3$
- $Corr\ TS1\ or\ MS1 = -\frac{E t_{td}}{2\lambda_{td}^{2} k_{td} sin\theta_{td}} = -0.534$
- $TS1 = -\frac{E t_{td}}{\lambda_{td} R_1 k_{td} sin^2\theta_{td}} = 0.0036$

Top ring beam -

- $MS2 = \frac{E b_1 d_1^{3}}{12 r_1^{2}} = 9.7$
- $TS2 = \frac{E b_1 d_1}{r_1^{2}} = 0.0029$

Cylindrical wall at Top

Wall thickness is uniform

- $\mu = \{\frac{3}{r_1 \times t_{3top}}\}^{0.25}$ =0.002
- $Z_{top} = Z_{bottom} = \frac{t_{3top}^3}{12} = 83333$
- $MS3t = 2\mu Z_{top} = 360$
- $TS3t = 4\mu^3 Z_{top} = 0.0034$
- $CorrMS3t = 2\mu^2 Z_{top} = 0.78$
- $MS3b = 2\mu Z_{top} = 360$
- $TS3b = 4\mu^3 Z_{top} = 0.0034$
- $CorrMS3b = -2\mu^2 Z_{bottom} = -0.78$

Balcony beam

- $MS4 = \frac{Eb_2 {d_2}^3}{12{r_1}^2} = 10.5$
- $TS4 = \frac{Eb_2 d_2}{{r_1}^2} = 0.0087$

Bottom dome

- $\lambda = \{3(R/t)^2\}^{0.25}$= 10.7
- $k = 1 - \cot\theta/2\lambda$= 0.95
- $MS6 = \frac{R_1 Et_{td}(k_{td} + k_{td}^{-1})}{4 \times {\lambda_{td}}^3} = 171.5$
- $Corr\ TS6\ or\ MS6 = -\frac{Et_{td}}{2{\lambda_{td}}^2 k_{td} sin\theta_{td}} = -0.53$
- $TS6 = \frac{Et_{td}}{\lambda_{td} R_1 k_{td} sin^2\theta_{td}} = 0.0032$

Bottom (Main) Ring beam

- $MS7 = \frac{Eb_7 {d_7}^3}{12{r_2}^2} = 321$
- $TS7 = \frac{Eb_7 d_7}{{r_2}^2} = 0.0154$

Membrane analysis

Top dome-

- Self-weight and live loads-$w_1 = (0.75 + 0.1 + t_1 \times 25)$=2.85 kN/m^2
- Total weight (SW1) $= w_1 \times (2\pi R_1 h_1)$=132 kN
- Meridional Forces=$T_1 = \frac{w_1 \times R_1}{1+\cos\theta_{td}}$= 10.7 kN/m

- Horizontal forces H1 = $\frac{w_1 \times R_1 \cos\theta_{td}}{1+\cos\theta_{td}}$ = 9.1 kN/m
- Horizontal displacement $x_{td} = \frac{wR_1^2\{(1+\cos\theta_{td})^{-1} - \cos\theta_{td}\}}{Et_1}$ = -284.5
- Rotation $\psi_{td} = \frac{2wR_1 \sin\theta_{td}}{Et_1}$ = 0.26

Top ring beam -

- Self-weight and live loads $w_2 = 25b_1d_1$= 1 kN/m
- Total weight $SW2 = (w_2) \times (2\pi r_1)$= 23.3 kN

Cylindrical wall-

- Self-weight for uniform wall=$w_3 = (25 \times t_{3top})$ =2.5 kN/m^2
- Self-weight $SW3 = 2\pi r_1 w_3(H + 0.5 \times t_{3top}) + 2\pi r_1 w_{31} H$=350 kN
- Horizontal displacement at bottom of wall $x_{wall} = \frac{\gamma_w \times H \times (r_1)^2}{Et_{3bottom}}$ = 8090
- Rotation at top/bottom of wall $\psi_{wall} = \frac{\gamma_w \times (r_1)^2}{Et_{3bottom}}$ = 1.36

Middle Ring beam-

- Self-weight and Live loads =$w_4 = (3 + 25 \times t_4)$=6 kN/m^2
- Self-weight $SW4 = SW4 = w_4 \times \{\pi(2r_1 + b_4)b_4\}$ = 156.12 kN
- Bending moment $BM\ at\ MRB = -w_4 \times b_4 \times (b_4 + t_{3bottom}) \times 0.5$ = -3300 N
- Total Vertical Load $\mathrm{TL}_{MRB} = \frac{(\mathrm{SW1+SW2+SW3}+WL_{Wall}+\mathrm{SW4})}{2\pi r_1}$= 664.2 kN
- Hoop tension = $HT\ at\ MRB = 10\times H \times t_4$= 7.09 kN/m
- Horizontal thrust at the top= $HThrust\ at\ MRB = \mathrm{TL}_{MRB}/\cot\theta$=662.2 kN

Bottom dome

- Self-weight $w_6 = 25 \times t_6$ =3 kN/m^2
- Total weight $SW6 = w_6 \times 2\pi h_2 R_2$ = 99.95 kN
- water load at Bottom dome $WL_{BD} = \{\pi {r_2}^2(H + r_1 - r_2) - \pi \times h_2^2 \times \frac{3R_2 - h_2}{3}\} \times \gamma_w$ = 2115.4 kN
- Total load at Bottom dome per square meter $\mathrm{TL}_{BD} = \{SW6 + WL_{BD}\}/\{2\pi R_2 h_2\}$= 44.2 kN
- Horizontal thrust imposed at bottom support $HForce_{BD} = \frac{\{SW6+WL_{BD}\}\times R_2 \times cos\theta_2}{(1+cos\theta_2)\{2\pi h_2 R_2\}}$=118.9 kN
- Horizontal displacement $x_{bd} = \frac{w_6 R_2^2 \sin\theta_{bd}\{(1+\cos\theta_{bd})^{-1} - \cos\theta_{bd}\}}{Et_6} + \frac{w_6 R_2^3 \sin\theta_{bd}\{2\ \cos 2\theta_{bd} + \cos\theta_{bd} - 3\}}{(6(1+\cos\theta_{bd})Et_6)} - \frac{\gamma_w R_2^2(H+r_1-r_2-h_2)cos\theta_{bd}}{2Et_6}$ = -9847

- Rotation $\psi_{bd=}\frac{2w_6R_2\sin\theta_{bd}}{Et_6}-\frac{10R_2^2\sin\theta_{bd}}{Et_6}$ = -2.23

Main girder beam or Bottom Girder beam

- Self-weight $w_7 = 25b_7d_7$ = 6 kN/m^2
- Total weight $SW7 = w_7 \times 2\pi r_2$=187.8
- Total load at Main girder beam $\text{TL}_{MGB} = SW1 + SW2 + SW3 + SW4 + SW5 + SW6 + SW7 + capacity \times 10 =$ 2877 kN
- $Total\ Load\ per\ meter = (\frac{\text{TL}_{MGB}}{2\pi r_2})$=127.2 kN
- Net Horizontal force at Bottom support H_{NET} =-$HForce_{BD}$=-136.5*0.741= 101.2 kN

REACTIONS IMPOSED BY THE JOINTS

BY TOP JOINT

Let the net rotation of the joint be Y radians and net horizontal displacement be X mm. The continuity deformation are tabulated below

Member	Clockwise Rotation (radian)	Outward Displacement (mm)
Edge of top dome	ψ_1 −(0.26/E)	x_1-(-284.5/E)
Top ring beam	ψ_1	x_1
Top edge of wall	ψ_1 −(1.36/E)	x_1

The continuity deformation obtained is multiplied by the corresponding stiffness to give the reaction imposed by the joint on the individual members

Member	Clockwise Moment (Nmm/mm)	Outward thrust (N/mm)
Edge of top dome	{ψ_1 −(0.26/E)}150.3+x_1-(-284/E) (-0.53)	x_1-(-284.5/E))(0.003)+ {ψ_1 −(0.26/E)} (-0.534)
Top ring beam	9.7ψ_1	0.0029x_1
Top edge of wall	360{ψ_1 −(1.36/E)} + 0.78x_1	(x_1)0.0034+{ψ_1 −(1.36/E)} 0.78

The sum of reaction imposed by the joint = The sum of external force imposed on the joint

- 521*ψ_1+0.24* x_1 −899.3=0
- 0.24*ψ_1+0.009* x_1-0.068 = Horizontal forces H1 = 9.16 kN/m

  Solving the two equation -

  x_1 = 899.9

ψ_1 = 0.8891

Member	Clockwise Moment (Nmm/mm)	Outward thrust (N/mm)	Hoop tension	Ast	Fct
Edge of top dome	M1= -538	T1=3.87	H1= 19.44 N/mm	44.7	0.21
Top ring beam	M2= 8.67	T2=2.62	H2=9723 N	22.3	0.21
Top edge of wall	M3= 529.3	T3=2.66	H3t= 24.3 N/mm	55.8	0.21

BY BOTTOM JOINT

Let the net rotation of the joint be Y radians and net horizontal displacement be X mm. The continuity deformation are tabulated below

Member	Clockwise Rotation (radian)	Outward Displacement (mm)
Bottom edge of wall	ψ_2 −(1.36/E)	x_2-(8090/E)
Middle ring beam	ψ_2	x_2
Bottom ring beam	ψ_2	x_2
Bottom dome	ψ_2 −(-2.23/E)	x_2-(-9847/E)

The continuity deformation obtained is multiplied by the corresponding stiffness to give the reaction imposed by the joint on the individual members

Member	Clockwise Moment (Nmm/mm)	Outward thrust (N/mm)
Bottom edge of wall	360{ψ_2 −(1.36/E)}-0.78{x_2-(8090/E)}	{ψ_2 −(1.36/E)}(-0.78)+{x_2-(8090/E)}(0.0034)
Middle ring beam	10.5ψ_2	0.008 x_2
Bottom ring beam	321ψ_3	0.0154 x_3
Bottom dome	171.5{ψ_3 −(-2.23/E)} -0.53 {x_3-(-9847/E)}	0.0032{x_3-(-9847/E)}-0.53{ψ_3 −(-2.23/E)}

The sum of reaction imposed by the joint = The sum of external force imposed on the joint

- 864.2 *ψ_2-1.31$*x_2+927$=BM at MRB= -3300
- -1.31*ψ_2+0.03$*x_2$+ 6.24= $Hnet + HT\ at\ MRB$ =

Solving the two equation -

x_2 = 3129
ψ_2 = -0.03

Member	Clockwise Moment (Nmm/mm)	Outward thrust (N/mm)	Hoop tension	Ast	Fct
Bottom edge of wall	M3b= 3317.4	T3b=-15.5	H3t=86.26 N/mm	198.4	0.83
Middle ring beam	M4= -0.32	T4=27.9	H4=103534 N	238	0.83
Bottom ring beam	M7=286.2	T7=49.2	H7=177350 N	407	0.83
Bottom dome	M6=-6448	T6=8.5	H6=70.9 N/mm	163	0.83

So Far the basics of analysis, mensuration and geometric calculation etc are different in Circular tanks than Intze tanks. Rest the design of the elements and design of Staging and Foundation steps are similar as in Annexure A.

Values for the Conical domes like thickness etc not taken into consideration and are assigned Zero values and the Nomenclature of the rest of the elements are kept same for example the Bottom ring beam is the seventh element in case of Intze tank (b_7 x d_7) and it is sixth element in the Circular tank but is denoted as b_7 x d_7 only.

Annexure C- Manual design of 200 kL hybrid circular tank

Annexure D- Software output for 600 kL hybrid Intze tank

```
*******************************************************************
        PROGRAMME   OUTPUT
*******************************************************************
---------------------------------------Module I---------------------------------------------
DETERMINATION OF VARIOUS DIMENSIONS
Enter quantity qu: 600
Enter the height H2 of column :    16
Enter Bearing Capacity of soil in KN/m2:  80
Enter Bearing Capacity test depth  in m:  1.8
Enter the No of bays/ braces stagging :    4
you are designing Intze tank
Select ratio of Height/Dia of circular cylinder c1:   0.4
Angle of conical dome from vertical in degree Ad: 45

calculated quantity of water is   605 cum
Radius of top ring beam is  6.60 m
radius of bottom girder is 4.95 m
radius of top Dome is 12.49 m
radius of B Dome is  7.29 m
height of top dome is 1.89 m
height of bottom dome is 1.96 m
Height of cylindrical wall is  4.05 m

Suggested Number of Columns are 10-12 columns
select Nos of columns N1: 10

Enter Earthquake Zone 2/3/4/5:    4

Please Check your city wind speed
{Bengaluru, Mysore is 33
Ahmedabad, Kozhikode, Kumool, Lakshadweep Aurangabad Mangalore is 39
Bhilai Bhopal Nasik Panjim Coimbatore Pune Raipur Mandi Madurai is 39
Rajkot Ranchi Roorkee Rourkela Gaya  Shimla Shimla  Trivandrum is 39
Nagpur Alibag Kohima Port Blair  Hyderabad Vadodara Delhi  is 44
Jhansi Varanasi Jodhpur Jaipur  Udaipur Imphal Surat Gangtok Agra is 47
Trruchirappalli Jabalpur Jamshedpur Gorakhpur Durgapur Dehradun Patna  is 47
Darjeeling Patiala Bokaro  Nainital Bikaner Chandigarh  Kanpur Ajrner is 47
Asansol Amritsar Lucknow Bahraich Ludhiana Barauni Almora Bhatinda Nloradabad
Bareiily is 47
Vijayawada Guwahati Vishakapatnam Chennai Bhuj Bhubaneshwar Dwaraka Cuttack
Puducherry  NeHore is 50
Darbhanga is 55}

Please enter your city wind speed:     47
```

Please enter your Terrain category :category 1 : Exposed open terrain with a few or no obstructions and in which the average height of any object surrounding the structure is less than1.5
category 2 : Open terrain with wellscattered obstructions having height generally between 1.5 and 10 m.
category 3 : Terrain with numerous closely spaced obstructions having the size of building-structures up to 10 min height with or without a few isolated tall structures.
category 4 : Terrain with numerous high closely spaced obstructions.

Please enter your Terrain category: 2

Please enter your region type (For Coastal Area: enter 1.36 ; For Non Coastal region: enter 1): 1 Non Coastal region Opted

----------------------------Module II-----------------------------------
----
STIFFNESSES FOR TOP DOME
----
lemda1 =16.446218
S/M =0.622222
KforTD1 =0.951139
MS1 =112.478127
CorrTS1 =-0.294308
TS1 =0.001467
CorrMS1 =-0.294308

STIFFNESSES FOR TOP RING BEAM

TS2 =0.000918
MS2 =3.060916

STIFFNESSES FOR CYLINDRICAL WALL AT TOP
----
meu1 =0.001620

Ztopwall =83333.335938

MS3 =269.995941
CorrTS3 =0.437387
TS3 =0.001417
CorrMS3 =0.437387

MEMBRANE ANALYSIS FOR TOP DOME

R1:12.492849
m:0.849057
s:0.528302
W1:2.850000
T1:19.255560
H1:16.349058
SA1:147.943802
SW1:421.639832
hd1 =-905.418396
rd1 =0.470250

MEMBRANE ANALYSIS FOR TOP RING BEAM

SW2=41.447975
t2=0.200000

MEMBRANE ANALYSIS FOR WALL
----
pi*(2*r1)*t3top*(H+t2/2)*25:425.788788pi*25*(2*r1)*0.54*H*(t3bottom-t3top)/2:0.000000SW3=425.788788
waterloadonwall ::0.000000
hd3 =17641.775391
rd3 =4.35995

STIFFNESSES FOR CYLINDRICAL WALL AT Bottom
----
meu2 =0.001620
Zbottomwall =83333.335938
MS3b =269.995941
CorrTS3b =-0.437387
TS3b =0.001417
CorrMS3b =-0.437387

STIFFNESSES FOR MIDDLE RING BEAM

TS4 =0.002755
MS4 =3.305789

STIFFNESSES FOR CONICAL DOME TOP EDGE
----
lcd1:9321.211914
delta1:0.151762
Eta1:29.304127
r:30.000000

ij:0.000000
z:490.000000
z1:396.000000
K1:39.156979
K2:8.673758
K3:8.673758
K4:405.122559
MS51:35683.761719
CorrTS51:0.116071
TS51:0.000080
CorrMS51:0.116071

MEMBRANE ANALYSIS FOR MIDDLE RING BEAM

SW1:421.639832
SW2:41.447975
SW3:425.788788
waterloadonwall0.000000
W4:6.000000
SW4:268.124237
BMatMRB =-3300.000000
TLatMRB =1157.000854
TLpmLatMRB =27.852442
HTatMRBpermwater =4.859999

MEMBRANE ANALYSIS FOR CONICAL DOME

WLatCD:2901.440674
H:4.049999
r1:6.599996
r2:4.949997
cos:0.706150
tan:1.002707
t5top:0.150000
t5bottom:0.150000
r1:6.599996
r2:4.949997
x:1.649999
H:4.049999
t5top:0.150000
W5 =272.622498
WLatCD =2901.440674
TLatMRB =1157.000854
TLatBottomofCD =4331.063965
T52:196.863785

HTatcdtop:403.348053
HTatcdbottom:418.173309
hd51:17747.302734
hd52:13799.709961
rd51:-5.656198
rd52:-6.906718

STIFFNESSES FOR CONICAL DOME BOTTOM EDGE
----

r2:4.949997
sin(Ar):0.708062
Ad:45.000000
lcd2:6990.908691
delta2:0.151762
Eta2:25.378119
r:26.000000
ij:0.000000
z:169.000000
z1:17.240000
K1:2437.747070
K2:158.791855
K3:158.791855
K4:31.863073
MS52:633.493103
CorrTS52:-0.639516
TS52:0.001989
CorrMS52:-0.639516

STIFFNESSES FOR MAIN RING BEAM

TS7 =0.009795
MS7 =293.847961
m2:0.734466
R2:7.293931

STIFFNESSES FOR BOTTOM DOME
----

lemda2 =9.177312
S/M =0.924000
KforTD2 =0.949658
MS6 =708.688721
CorrTS6 =-1.381719
TS6 =0.005123
CorrMS6 =-1.381719

MEMBRANE ANALYSIS FOR BOTTOM DOME

R2:7.293931SA6:89.979637
SW6:337.423676
WLatBD:3592.412598
R2:7.293931SA6:89.979637
SW6:337.423676
TLpm2atBD:43.674728
MaxHFatBd:159.280212
merT6:183.664886
HT6:134.895523
hd6:-10111.047852
hd6:-10111.047852
rd6:-2.159495

MEMBRANE ANALYSIS FOR MAIN GIRDER BEAM

TLatMGB:7953.978516
SW7:186.931702
LperunitlengthatMGB:255.870270
T52:196.863785
sin(Ar):0.708062
merT6:183.664886
m2:0.734466
netHForces:-4.496246

Reactions Imposed at Joint 1

KG1:
385.534973 0.143079
0.143079 0.003802

P1:
1495.465210
16.787899

Inverse of KG1:
0.00263054 -0.09899057
-0.09899057 266.73568726

Result of matrix multiplication:
2.27203083
4329.89453125

y:4329.894531
theta:2.272031

RESULTS OF REATIONS AT TOP JOINT

Element	Clockwise Moment	Outward thrust	Hoop tension	Ast	fct
Top dome	-1338.13	7.14	52.48	120.65	0.64
Top ring beam	6.95	3.97	26241	60.32	0.64
Wall top	1331.17	5.224	65.60	150.81	0.64

Reactions Imposed at Joint 2

KG2:
35957.062500 -0.321316
-0.321316 0.004252

P2:
-209614.640625
56.563858

Inverse of KG2:
0.00002783 0.00210327
0.00210327 235.36763000

Result of matrix multiplication:
-5.71455240
12872.42480469

y2:12872.424805
theta2:-5.714552

RESULTS OF REATIONS AT MIDDLE JOINT

Element	Clockwise Moment	Outward thrust	Hoop tension	Ast	fct
Wall bottom	-632.95	-2.35	195.0	448.36	1.83
MRB	-18.89	35.46	302697	695.85	1.83
Cone Top	-2648.150	-0.39	292.5	672.5	1.83

--

Reactions Imposed at Joint 3

KG3:
1636.029785 -2.021235
-2.021235 0.016907

P3:
-760.287109
-21.454388

Inverse of KG3:
0.00071716 0.08573586
0.08573586 69.39639282

Result of matrix multiplication:
-2.38465643
-1554.04089355

y:-1554.040894
theta:-2.384656

RESULTS OF REATIONS AT BOTTOM JOINT

Element	Clockwise Moment	Outward thrust	Hoop tension	Ast	fct
Cone Bot.	12683.67	-33.42	-47.1	108.25	0.31
Bottom dome	-11982.9	-7.65	47.09	-108.2	0.31
Main ring beam	-700.72	-15.22	-75347.48	-173.2	0.31

---

fct2:0.641911
t3bottom:0.100000
t4:0.120000
t5top:0.150000
t2:0.200000
AstH3:448.360596
AstH4:695.855591
AstH5t:672.540955
fct3b:1.830540
fct4:1.830540
fct5t:1.830540
t5bottom:0.150000d7:0.600000
b7:0.400000
---------------------------------Module III--

--------------------------------DESIGN OF MEMBERS--------------------------------

------------------------------ 1.DESIGN OF TOP DOME------------------------------
Thickness of top dome is 0.080000 mm

HTension1:52.483601
Hu:78.725403
Tu:41.590782
s:0.528302
Circumferential Force LSM = 78.725403 N/mm
Meridional Thrust Tu LSM = 41.590782 N/mm
Meridional Stress = 0.519885 N/mm2
Hoop Stress = 0.984068 N/mm2
adopt nominal reinforcement of 0.28 percent
Ast: 280.000000
adopt 8 mm bars with spacing 150 mm both way

A1:11.861890
Q1:0.584665
---------------------------2.DESIGN OF TOP RING BEAM----------------------------------
Size of Top ring beam : 0.200000 x 0.200000
AstH2:90.488983
AstM2:2.311817
Nos of Bars provided in top ring beam: 4.000000
A2:1.661615
SA2:24.924227
Q2:0.309981
adopt 0 bars of 12mm dia as main reinforcement
adopt 8 mm dia stirrups at 200 mm centre to centre

Check for Crack width of Top ring beam
Fs: 58.057091
e1: 0.000290
e2: 0.000476
wcr: -0.019718
--**Design is safe**--

-----------------------------3.DESIGN OF WALL--
Thickness of Wall at top: 0.100000
Thickness of Wall at bottom: 0.100000

Distance from top	Hoop steel (each face)	Vertical steel	Q31	Q32	wcr	wcr1	em	emm	Remark
1	12 -180	10 - 180	0.101968	0.057357	0.122647	0.122647	0.001	0.001	OK
2	12 -180	10 - 180	0.2039	0.114713	0.12264	0.1226	0.0010	0.001	OK
3	12 -180	10 - 180	0.305903	0.172070	0.122647	0.122647	0.001	0.001	OK

4 12 -180 10 - 180 0.407870 0.229427 0.122647 0.122647 0.001 0.001OK

A3:16.951303
SA3:339.026062
Q3:0.637297
Q31:0.407870
Q32:0.229427
Fs1:-5.261259
Strain (Tension) e11:0.000013
Strain (Bending) e22:0.000198

*******************4.DESIGN OF MIDDLE RING BEAM*********
Size of Middle Ring beam: 1000.000000 mm x 120.000000 mm
M4:3300.000000
AstH4:1043.783447
AstM4:168.738251
Nos of Bars provided : 4
A4:5.350557
SA4:51.395489
Q4:0.637297
adopt 4 bars of 20 mm dia as main reinforcement
adopt 8 mm dia stirrups at 200 mm centre to centre

x:50588.890625
Fs1:-0.000000
e11:-0.000000
e22:-0.000067
wcr:0.000106
wcr:0.000106
Safe in Crack
**************************5.CONICAL DOME*********************
t5top x t5bottom -0.150000 x 0.150000
AstH5t:1008.811401
AstH5b:-162.386826
provide 10 mm dia bar circumferentially both face @ 160 c-c
provide 10mm dia bar radially both face @ 150.000000 c-c
Lc:2.330303
r1:6.599996
r2:4.949997
spacing:155.628693
Q5:1.358055
Q51:0.665010
Q52:0.693044
wcr:-0.118604
wcr1:-0.118604

Safe in Crack
*******************6.DESIGN OF Bottom DOME*********************
thickness of top dome is 0.150000 mm
HTension6:-47.092175
Hu:-70.638260
Tu:-47.938370
s2:0.678646
Circumferential Force LSM = -70.638260 N/mm
Meridional Thrust Tu LSM = -47.938370 N/mm
Meridional Stress = -0.319589 N/mm2
Hoop Stress = -0.470922 N/mm2
adopt nominal reinforcement of 0.28 percent
Ast6: 420.000031
adopt 10mm bars with spacing 167 mm both way

A6:13.496945
SA6:89.979637
Q6:0.341356
wcr:-0.127631
wcr1:-0.127631
Safe in Crack
************ 7.DESIGN OF MAIN GIRDER BEAM *******************
b7 x d7 : 0.400000 x 0.600000
TLatMGB:7953.978516
Angleatcentre:0.314000
Lperunitlength:255.870270
BMatcriticalsecMGB:-140.841354
Angleatcriticalsec:0.035798
TwistingMoment:6.210197
EquivalentMoment:9.132643
DesignMomentAtMGB:153.442596
Eccentricity:-2036.466064
DisofHoopForce:-1996.766113
Lever arm:409.040009
Force of Tension:292468.125000
Force of Comp:367815.625000
Safe
Adopt 4 bars of 20mm diameter
wcr:-0.397384
wcr1:0.136118
wcr1:0.136118
----------------------Design BM for Midspan---------------------------------

BM at mid span of MGB:104.221359
Design Moment At MGB:153.442596

Eccentricity1:-1337.174805
Dis of Hoop force at midspan :-1297.474854
Force of Tension at midspan:163654.718750
AstH7atmid:564.326599
adopt 2 bars of 20mm diameter
---------------------_Design For Shear and Twisting Moment_----------------------------_
dis:0.777099
SF:198.836411
angle3:0.157010
TwistingMoment:12.256643
DesignSF:247.862976
MaxShearstress:1.032762
xi:0.500000
i:1
tc:0.274468
spacing:300.000000
A7:7.477268
Q7:1.85034
Q71:0.695903
Q72:0.6951
Q73:0.4181

>>>>>>>>>>>>>>>Module IV<<<<<<<<<<<<<<<<<<<<<<<<<
** **************** DESIGN OF STAGING*****************
Size of Bracing: 0.200000 x 0.500000
H2:16.000000
d7:0.600000
dofbctestbelowgl:1.800000
Htotal:16.599998
cllofeachpanelabovegl:3.350000
ccdisofcol:3.095312
clofbrace:2.695312
Computation of Vertical loads
Loadperspan:795.397827
SW8:52.240196
SW9:26.953123
SWuptobrace:920.591125
kw1:1.070000
kw2:1.070000
kw3:1.000000
kw4:1.000000
Vz:53.810303
Pz:1.737329
Wind Load analysis
WPattankbody 93.390343:

wpateachuppanel 13.036919:
wpatlowestpanel: 8.366978
wpatbrace: 8.947240
htankcg: 3.895089
SFat1panel:99.908798
SFat2panel:121.892960
SFat3panel:143.877106
SFat4panel:165.861267
SFat5panel:185.510452
Earthquaqe analysis
EffWTforeqfull:8371.290039
Def1:827.962463
EffWTforeqEmpty:2371.290039
Def2:234.532440
Tfull:1.828511
Tempty:0.973181
Ahfull:0.041099
Ahfull:0.041099
Zi:0.240000
Sag:1.716022
Ie:1.500000
Re:4.000000
SeismicForce:344.051758
SFempty:183.113312
Pu:920.591125
OverTurningMoment:1858.009277
In empty case Wind Load is critical
>>>>>>>>>>>>>>>>Module V<<<<<<<<<<<<<<<<<<<<<<<<<<

******************DESIGN OF COLUUMS***************
MaxBMinCol:104.214577
a:0.230148
b:0.065134
N8:6
AstCol:1510.560181
N3:4
COLUMN DETAILS
Diameter of column: 0.400000
Provide 6 No of bars of 20 diameter of bar
Provide lateral bars of 10mm diameter at 300 mm c-c
Htotal:16.599998
Q81:0.243940
Q82:0.080145
Q of 1 col : 0.324085
Q of N col : 3.240852

Htotal of N col : 16.599998
SA8 of N col : 208.960785
A8 of N col : 20.896078
-----------------------------------DESIGN OF BRACING---------------------------------
Mbrace1 122.317162
Mbrace2 53.865692
MbraceF 105.709717
Ast9 608.968689
No9:6provide 6 bars of 12 mm dia at top
provide 6 bars of 12 mm dia at bottom
size of Braces : 0.200000 X 0.500000
A9 : 10.781249
SA9 : 64.687492
adopt 10mm 4-legged stirrups at   200 mm spacing
Q91:1.143258
Q92:0.595447
Q9:1.738705
>>>>>>>>>>>>>>>>Module VI <<<<<<<<<<<<<<<<<<<<<<<<

DESIGN OF FOUNDATION

DESIGN OF FOUNDATION BEAM

MAxNegBMatSuppofFB:177.594009
deff10req:172.043610
foundation beam depth is OK
Ast10:1286.064941
provide 5 bars of 20mm dia at bottom
Ast10centre:810.746582
provide 3 bars of 20mm dia at top
provide 0.600000 mm deep and 0.400000 mm wide ring beam
LoadpermatFB:295.484772
SFatCricSecatFB:203.223801
maxtwistingMomentatFB:22.784616
EQshearonFB:294.362274
tv:1.839764
xi:2.000000
i:7
tc:0.480720
spacing 200.000000:

adopt 10mm 4-legged stirrups at   200 mm spacing
Q10 0.382640:
Q101 0.382378:
Q102 0.000262:
A10 7.477268:

SA10 37.386337:
-------------------------------Design of Raft Foundation---------------------------
TotalLoadFromAbove:9205.911133
TLwithFoundationLoad:10126.501953
RaftArea:126.581276
widthofraft:4.062916
Diofraft:5.937078
Doutofraft:13.962910
Riofraft:2.968539
Routofraft:6.981455
CCRnew:5.244737
Ri:2.103519
Ro:6.931455
CCRnew:4.948836
Ar1:74.088539
Ar2:63.118172
AreaofRaftPro:137.272995
Dimensions of Raft Pro:6.931455 x 2.103519
_____________Raft Dimensions are SAFE__________
UpwardPressureFull:73.769073
OverTurningMomentraft:2624.322021
SeismicForce:344.051758
htankcg:3.895089
Htotal:16.599998
OverTurningMomentraft:2624.322021
MaxpronsoilduetoLatF:10.101980
MaxDownPresFulltank:83.871056
UpwardPressureEmpty:30.060551
OverTurningMomentraft:2624.322021
MaxDownPresEmptytank:40.162529
_____________SAFEEEEE_____________
MindownpresEmptytank:19.958570
Maxupthrustfulltank:83.871056
RadatinnerfaceofBeam:4.649997
RadatouterfaceofBeam:5.249997
BMatinnerfaceofFB:172.653854
BMatouterfaceofFB:249.290756
BMMAxatRAft:249.290756
deffRaft:245.387772

Provide Overall Depth 0.415388 m at face of beam & reducing to 0.15 m at free edge
d11:0.415388
deffRaft:345.387787
Ast11:1819.893188

provide 10 Nos 16 mm dia bars circumferentially
aa:5.249997
provide 16 mm dia bars radially at 110.446045 mm c-c
xi:0.250000
i:0
tc:1.622281
tv:2166632192.000000
spacing 0.000000:

A10 :7.477268
A11 :33.000000
SA11 :23.621494
Q111 :2.53004
Q112 :2.59510
Q11:4.502514

Module VII

DESIGN OF FERROCEMENT WALL
(pi*r1*2*H+pi*R1*h1+pi*(r1+r2)*Lc/2+pi*R2*h2):329.715820
Max em= 0.0006
costofcplining:82593.812500
costofwiremesh:13037.112305
Total Cost of lining:95630.921875

>>>>>>>>>>>>>>>Module VII<<<<<<<<<<<<<<<<<<<<<<<<<

Q1: 0.584665 A1: 11.861890
Q2: 0.309981 A2: 1.661615
Q3: 0.637297 A3: 16.951303
Q4: 0.637297 A4: 5.350557
Q5: 1.805534 A5: 12.870221
Q6: 0.513565 A6: 13.496945
Q8: 3. 408525 A8: 20.896078
Q9: 1.738705 A9: 10.781249
Q10: 0.382640 A10: 7.477268
Q11: 5.102514 A11: 40.2000000
******************10.Evaluation of various quantities***********

The total cost of Steel + Concrete+ lining = 30.2 Lakh Rs
Total concrete volume is 140.7 cum

tank concrete volume is 69.67 cum
Total quantity of steel is 16.10 tons
tank qty of steel is 4.47 cum
Total Cost of lining: 1.1 lkhs.

The total cost of Steel + Concrete+ lining = Rs 30.2 lakh Rs

Note: Diameter of the bars or the Spacings in the drawings at the but the Reinforcement is kept the same as calculated.

Annexure D- Software output for 600 kL hybrid Intze tank

Annexure E- Software output for 200 kL hybrid circular tank

****

PROGRAMME OUTPUT

****

---Module I--

DETERMINATION OF VARIOUS DIMENSIONS

Enter quantity qu: 200
Enter the height H2 of column : 14
Enter Bearing Capacity of soil in KN/m2: 80
Enter Bearing Capacity test depth in m: 2
Enter the No of bays/ braces staging : 4

You are designing CIRCULAR tank
select ratio of height/dia of circular cylinder c1: 0.8

Height of cylindrical wall is 5.9 m
calculated quantity of water is 201 cum
radius of top ring beam is 3.70 m
radius of bottom girder is 3.60 m
radius of top Dome is 7.00 m
radius of B Dome is 5.36 m
height of top dome is 1.06 m
height of bottom dome is 1.48 m
there should be 6-8 columns
Select Nos of columns N1: 6

Enter Earthquake Zone 2/3/4/5: 3

Please Check your city wind speed
{Bengaluru, Mysore is 33; Ahmedabad, Kozhikode, Kumool, Lakshadweep Aurangabad Mangalore Bhilai Bhopal Nasik Panjim Coimbatore Pune Raipur Mandi Madurai Rajkot Ranchi Roorkee Rourkela Gaya Shimla Shimla Trivandrum is 39; Nagpur Alibag Kohima Port Blair Hyderabad Vadodara Delhi is 44; Jhansi Varanasi Jodhpur Jaipur Udaipur Imphal Surat Gangtok Agra Trruchirappalli Jabalpur Jamshedpur Gorakhpur Durgapur Dehradun Patna Darjeeling Patiala Bokaro Nainital Bikaner Chandigarh Kanpur Ajrner Asansol Amritsar Lucknow Bahraich Ludhiana Barauni Almora Bhatinda Nloradabad Bareiily is 47; Vijayawada Guwahati Vishakapatnam Chennai Bhuj Bhubaneshwar Dwaraka Cuttack Puducherry is 50 Darbhanga is 55}

Please enter your city wind speed: 39

Please enter your Terrain category :

category 1 : Exposed open terrain with a few or no obstructions and in which the average height of any object surrounding the structure is less than1.5
category 2 : Open terrain with wellscattered obstructions having height generally between 1.5 and 10 m.
category 3 : Terrain with numerous closely spaced obstructions having the size of building-structures up to 10 min height with or without a few isolated tall structures.
category 4 : Terrain with numerous high closely spaced obstructions.
Please enter your Terrain category: 2
Please enter your region type (For Coastal Area: enter 1.36 ; For Non Coastal region: enter 1): 1

--Module II--

STIFFNESSES FOR TOP DOME

----

lemda1 =12.313884
S/M =0.622222
KforTD1 =0.934743
MS1 =150.377365
CorrTS1 =-0.534190
TS1 =0.003556
CorrMS1 =-0.534190

STIFFNESSES FOR TOP RING BEAM

TS2 =0.002922
MS2 =9.739477

STIFFNESSES FOR CYLINDRICAL WALL AT TOP

----

meu1 =0.002164

Ztopwall =83333.335938

MS3 =360.602142
CorrTS3 =0.780203
TS3 =0.003376
CorrMS3 =0.780203

MEMBRANE ANALYSIS FOR TOP DOME

R1:7.003569
m:0.849057

s:0.528302
W1:2.850000
T1:10.794785
H1:9.165384
SA1:46.495678
SW1:132.512680
hd1 =-284.554413
rd1 =0.263625

MEMBRANE ANALYSIS FOR TOP RING BEAM

SW2=23.235991
t2=0.200000

MEMBRANE ANALYSIS FOR WALL
----
pi*(2*r1)*t3top*(H+t2/2)*25:349.898956pi*25*(2*r1)*0.54*H*(t3bottom-t3top)/2:0.000000SW3=349.898956
waterloadonwall ::0.000000
hd3 =8090.781250
rd3 =1.368999

STIFFNESSES FOR CYLINDRICAL WALL AT Bottom
----
meu2 =0.002164
Zbottomwall =83333.335938
MS3b =360.602142
CorrTS3b =-0.780203
TS3b =0.003376
CorrMS3b =-0.780203

STIFFNESSES FOR MIDDLE RING BEAM

TS4 =0.008766
MS4 =10.518635

MEMBRANE ANALYSIS FOR MIDDLE RING BEAM

SW1:132.512680
SW2:23.235991
SW3:349.898956
waterloadonwall0.000000
W4:6.000000

SW4:158.608749
BMatMRB =-3300.000000
TLatMRB =664.256409
TLpmLatMRB =28.523804
HTatMRBpermwater =7.091997

STIFFNESSES FOR MAIN RING BEAM

TS7 =0.015432
MS7 =321.502289
m2:0.741443
R2:5.364998

STIFFNESSES FOR BOTTOM DOME

---

lemda2 =10.777552
S/M =0.905013
KforTD2 =0.958014
MS6 =171.580765
CorrTS6 =-0.535692
TS6 =0.003207
CorrMS6 =-0.535692

MEMBRANE ANALYSIS FOR BOTTOM DOME

R2:5.364998SA6:49.975582
SW6:99.951164
WLatBD:2115.370605
R2:5.364998SA6:49.975582
SW6:99.951164
TLpm2atBD:44.328083
MaxHFatBd:118.910034
merT6:136.564957
HT6:101.255127
hd6:-9847.154297
hd6:-9847.154297
rd6:-2.234249

MEMBRANE ANALYSIS FOR MAIN GIRDER BEAM

TLatMGB:2877.499512
LperunitlengthatMGB:127.277977
T52:0.000000
sin(Ar):0.000000

merT6:136.564957
m2:0.741443
H5atbottom:0.000000
netHForces:101.255127

Reactions Imposed at Joint 1

KG1:
520.718994 0.246013
0.246013 0.009854

P1:
685.313293
9.080880

Inverse of KG1:
0.00194334 -0.04851916
-0.04851916 102.69700623

Result of matrix multiplication:
0.89120311
899.32836914

y:899.328369
theta:0.891203

RESULTS OF REATIONS AT TOP JOINT

Element	Clockwise Moment	Outward thrust	Hoop tension	Ast	fct
Top dome	-538.044	3.874	19.4	44.70	0.24
Top ring beam	8.67	2.627	9722	22.35	0.24
Wall top	529.36	2.66	24.30	55.8	0.24

Reactions Imposed at Joint 2

KG2:
864.203857 -1.315895
-1.315895 0.030781

P2:
-4227.103516
98.303421

Inverse of KG2:

0.00123770 0.05291165
0.05291165 34.74930573

Result of matrix multiplication:
-0.03049564
3192.31250000

y2:3192.312500
theta2:-0.030496

RESULTS OF REATIONS AT II JOINT

Element	Clockwise Moment	Outward thrust	Hoop tension	Ast	fct
Wall bottom	3317.1	-15.4	86.2	198.34	0.83
MRB	-0.320	27.98	103534.5	238.	0.83
Bottom dome	-6448.87	8.564	70.940	163.0	0.86
Main ring beam	286.5	49.26	177350.7	407.7	0.861

Rest the output prototype is same as same as that of Annexure D.

Annexure F- Detail drawings of hybrid tanks

600 kL Intze HWTs

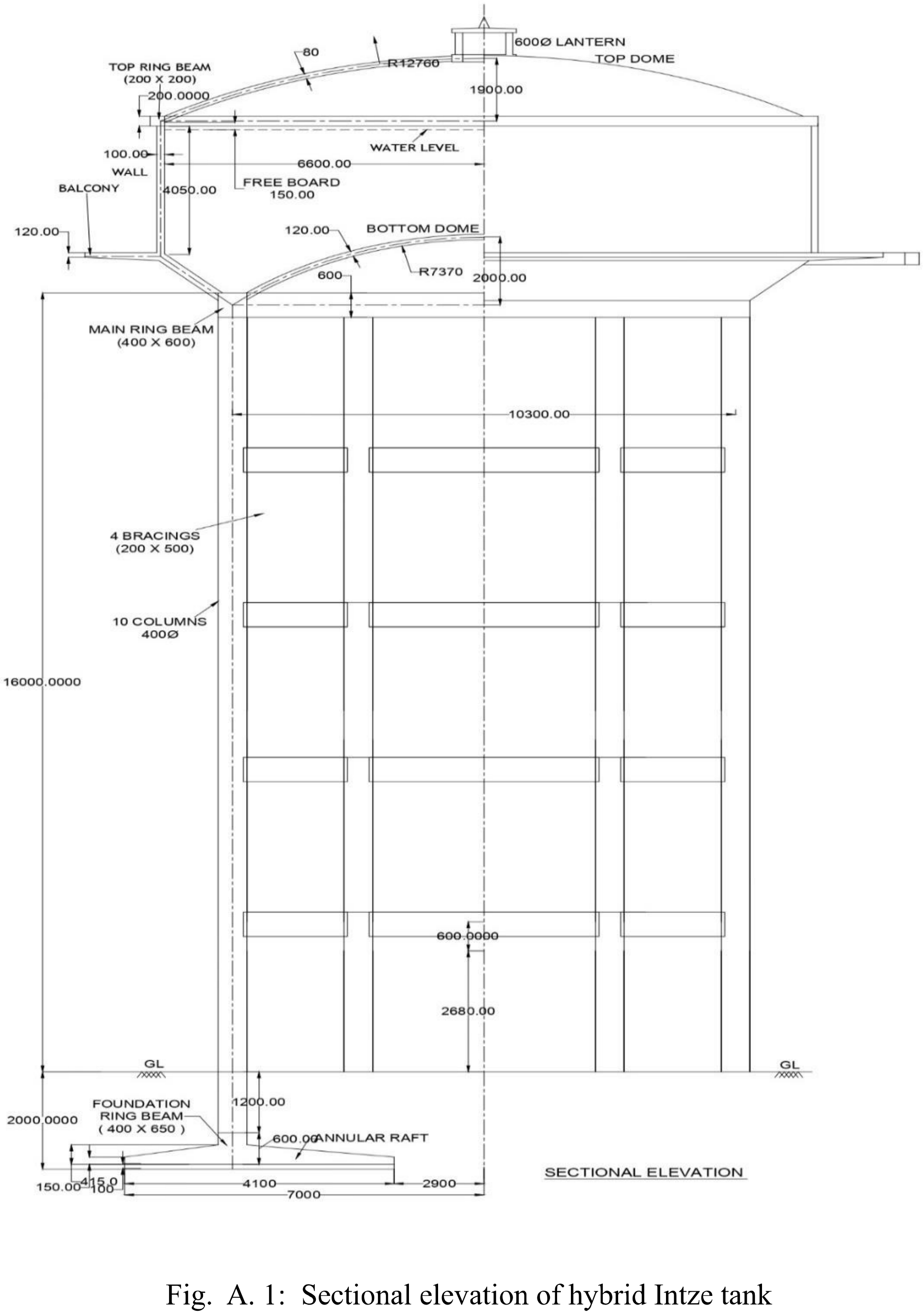


Fig. A. 1: Sectional elevation of hybrid Intze tank

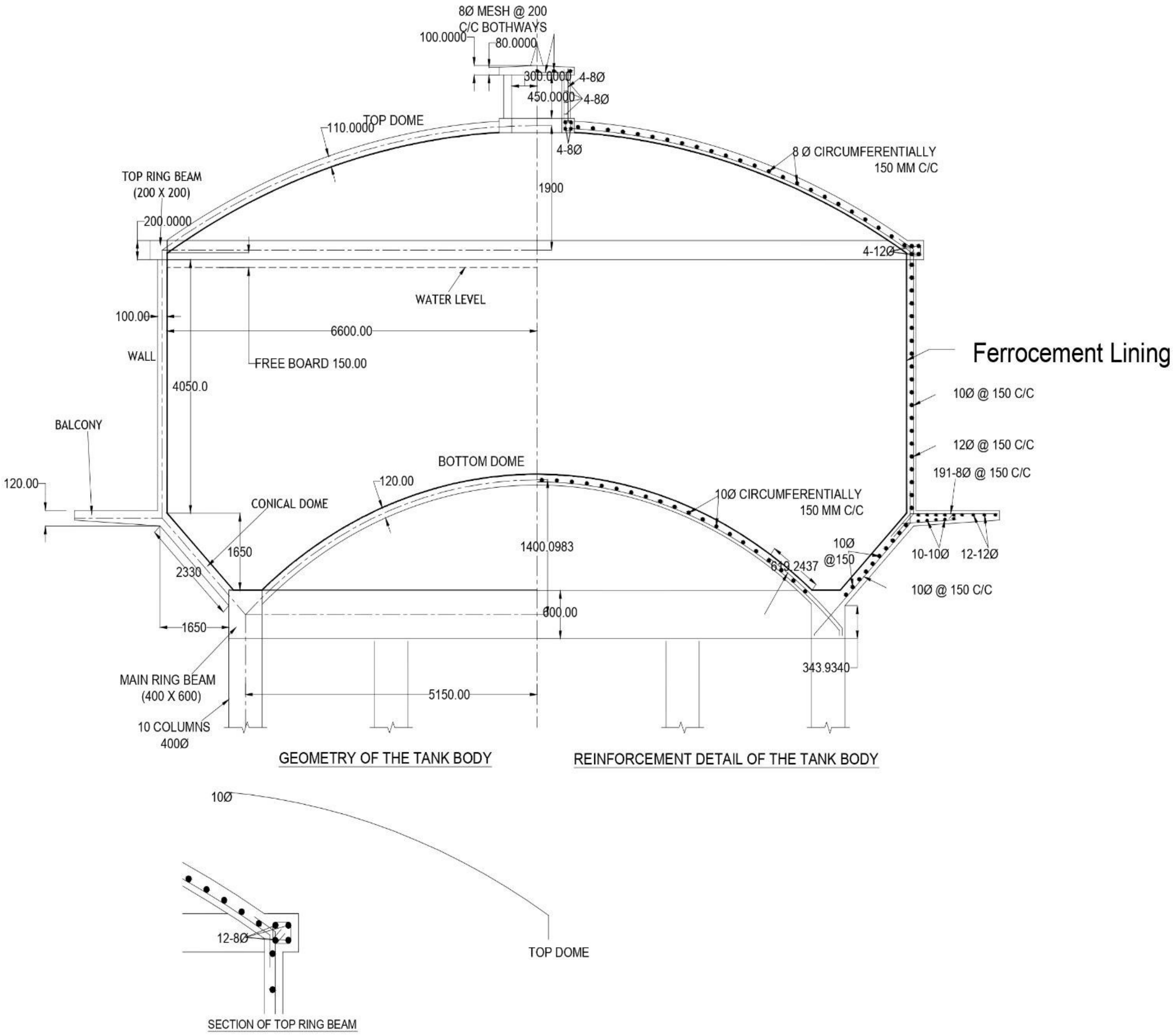
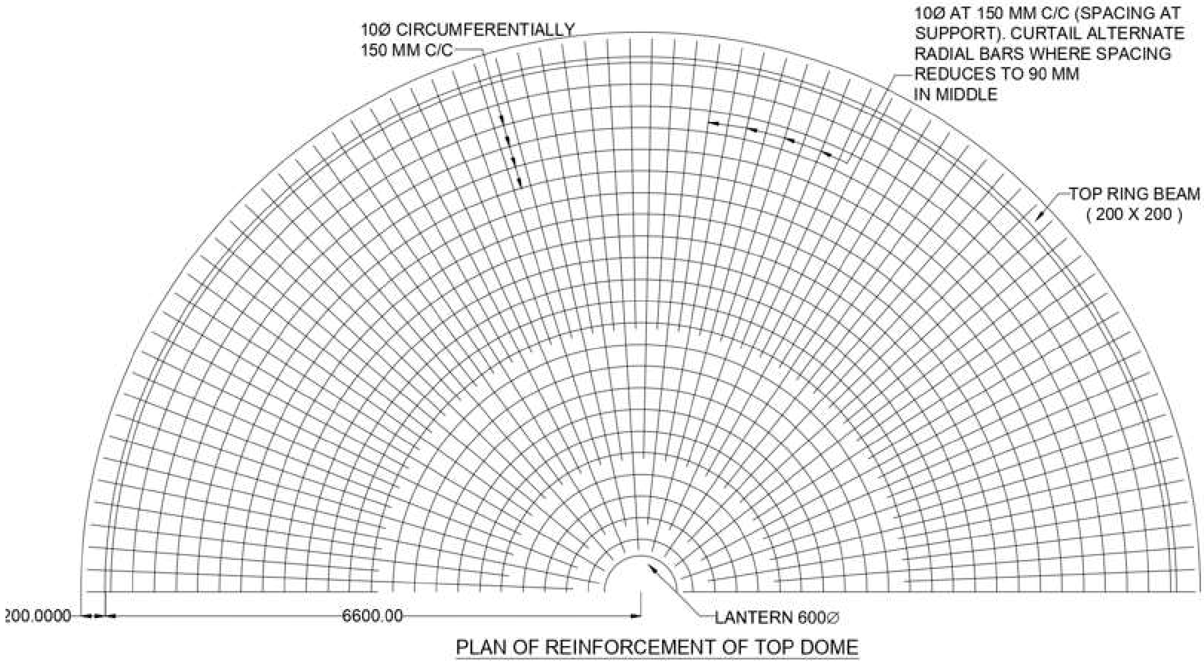


Fig. A.2: Reinforcement details of tank body of hybrid Intze tank



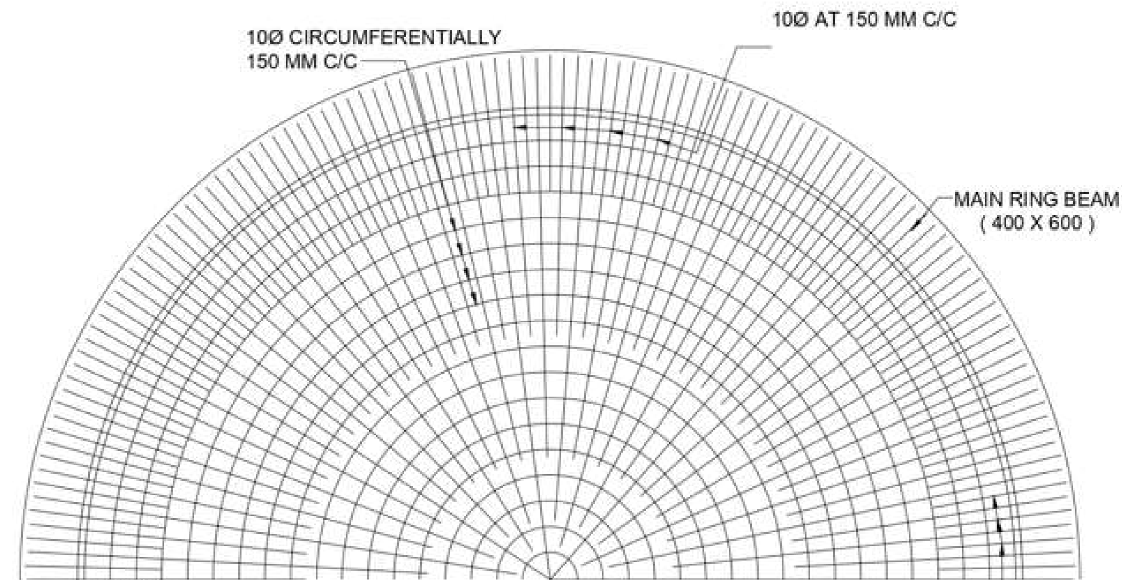


Fig. A.3: Reinforcement plan of top and bottom dome of hybrid Intze tank

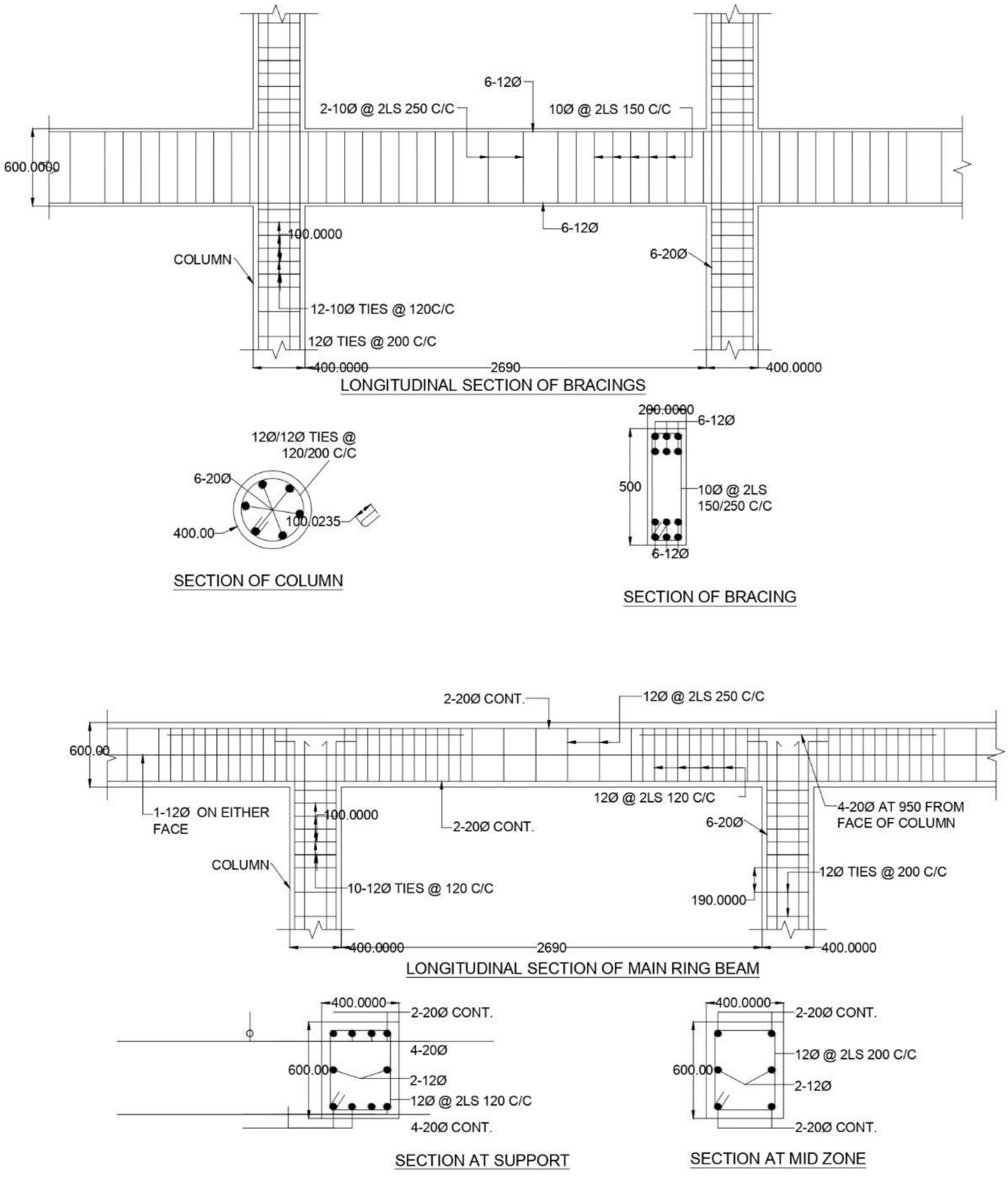


Fig. A.4: Reinforcement plan of main ring beam and bracings of hybrid Intze tank

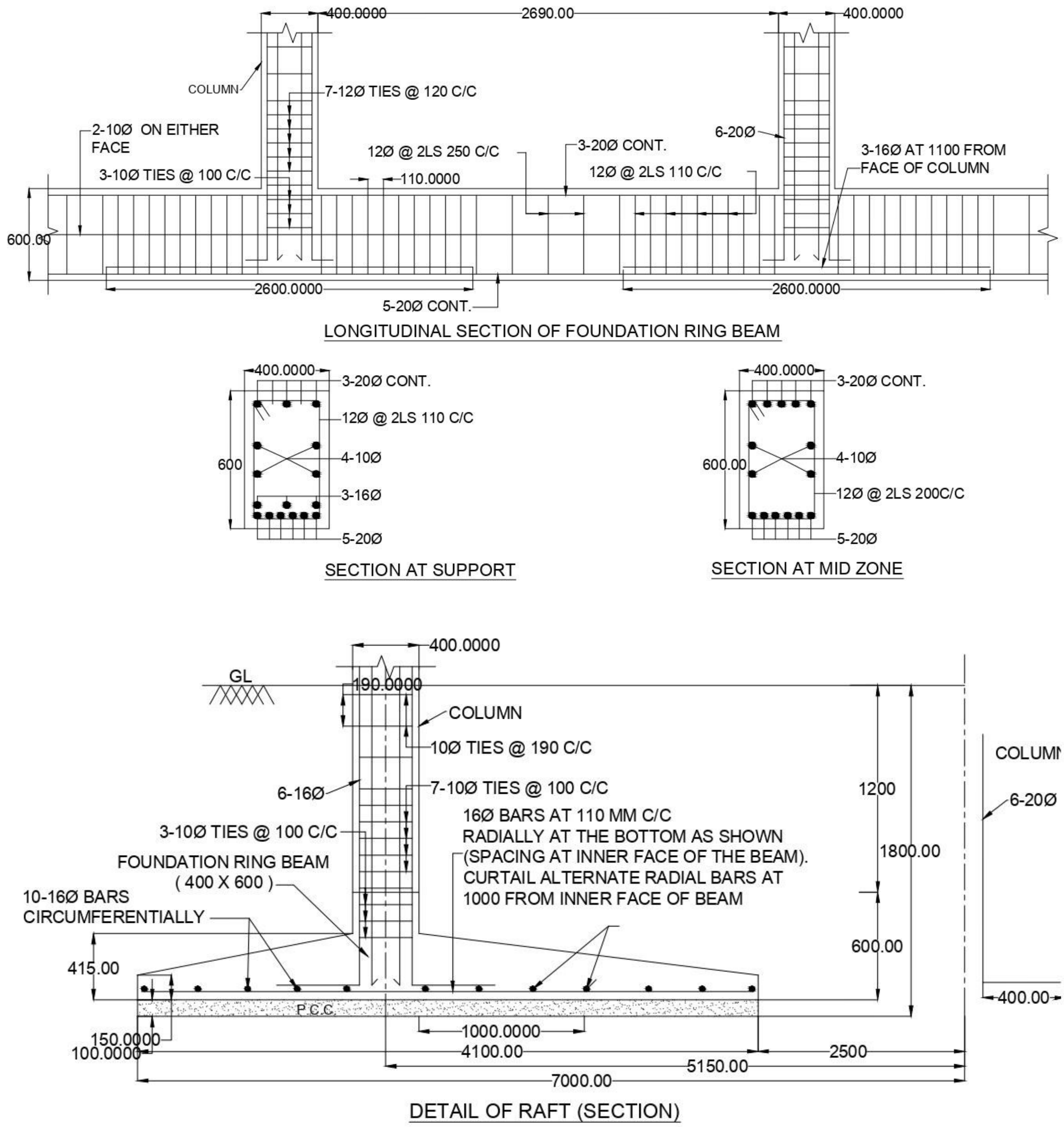


Fig. A.5: Reinforcement plan of foundation ring beam and raft foundation of hybrid Intze tank

Drawings of 200 kL Hybrid Circular tank

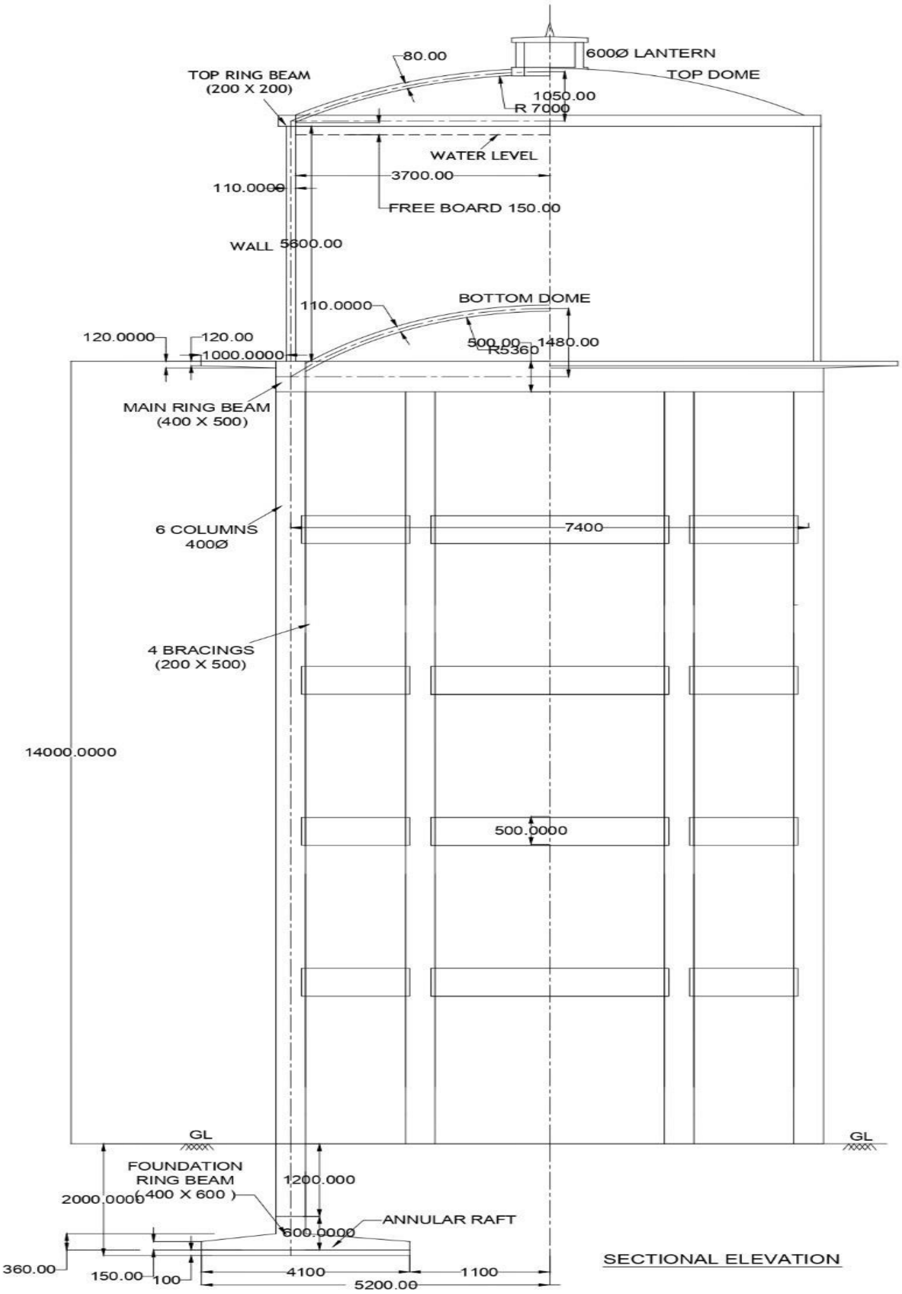


Fig. A.6: Sectional elevation of hybrid circular tank

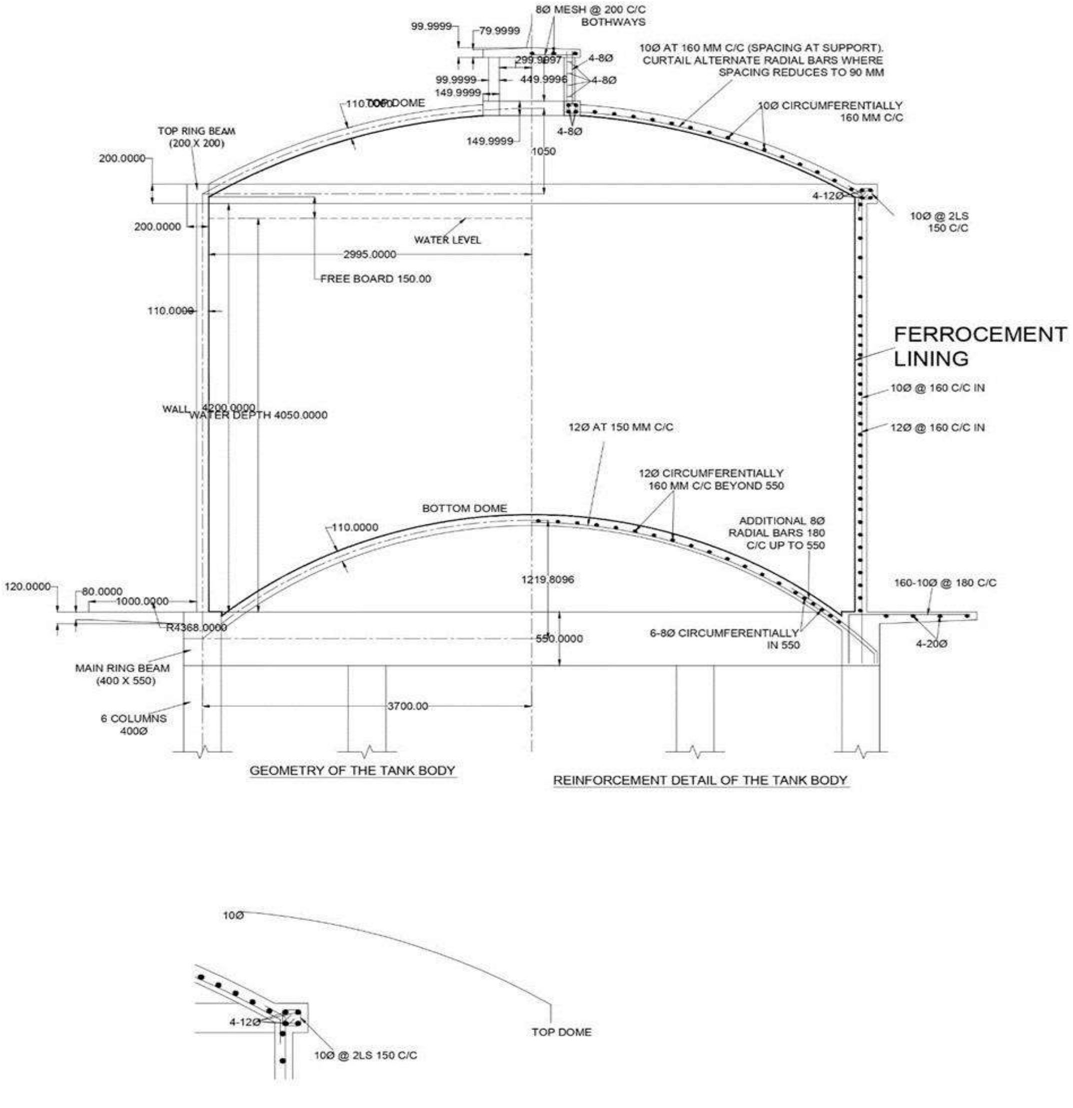
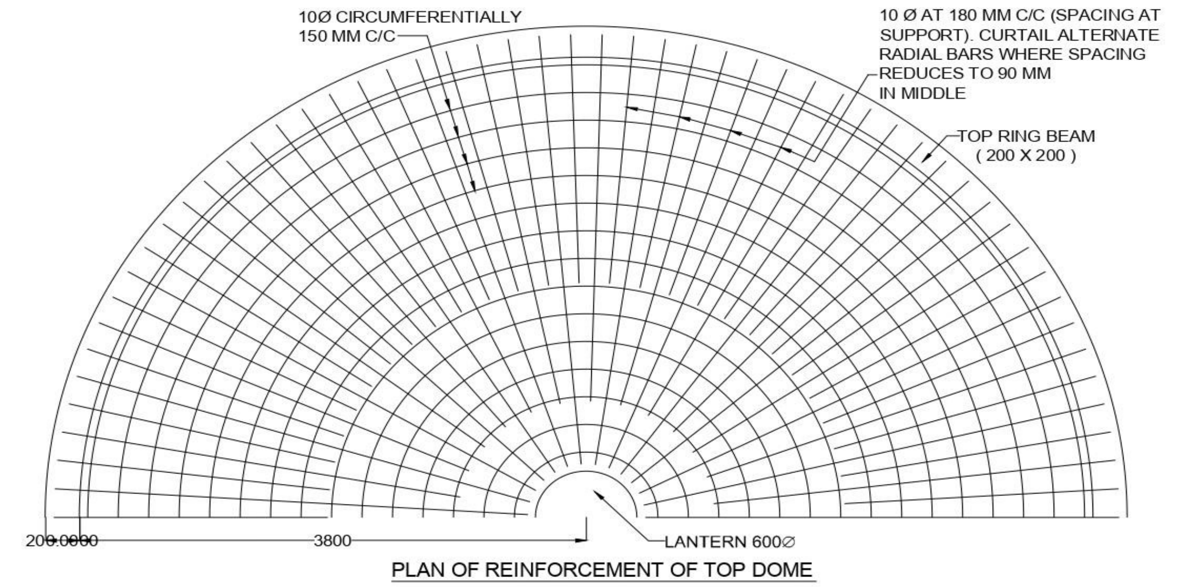


Fig. A.7: Reinforcement plan of tank body and lining (15 mm lining) of hybrid Circular tank



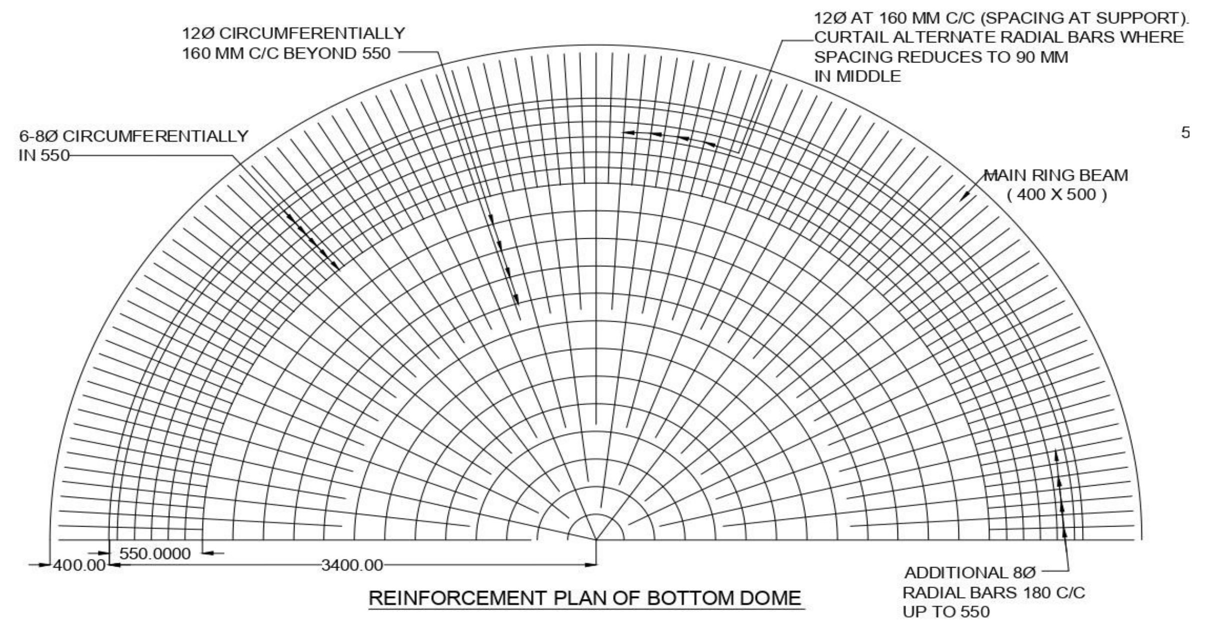


Fig. A.8: Reinforcement plan of top and bottom dome of hybrid Circular tank

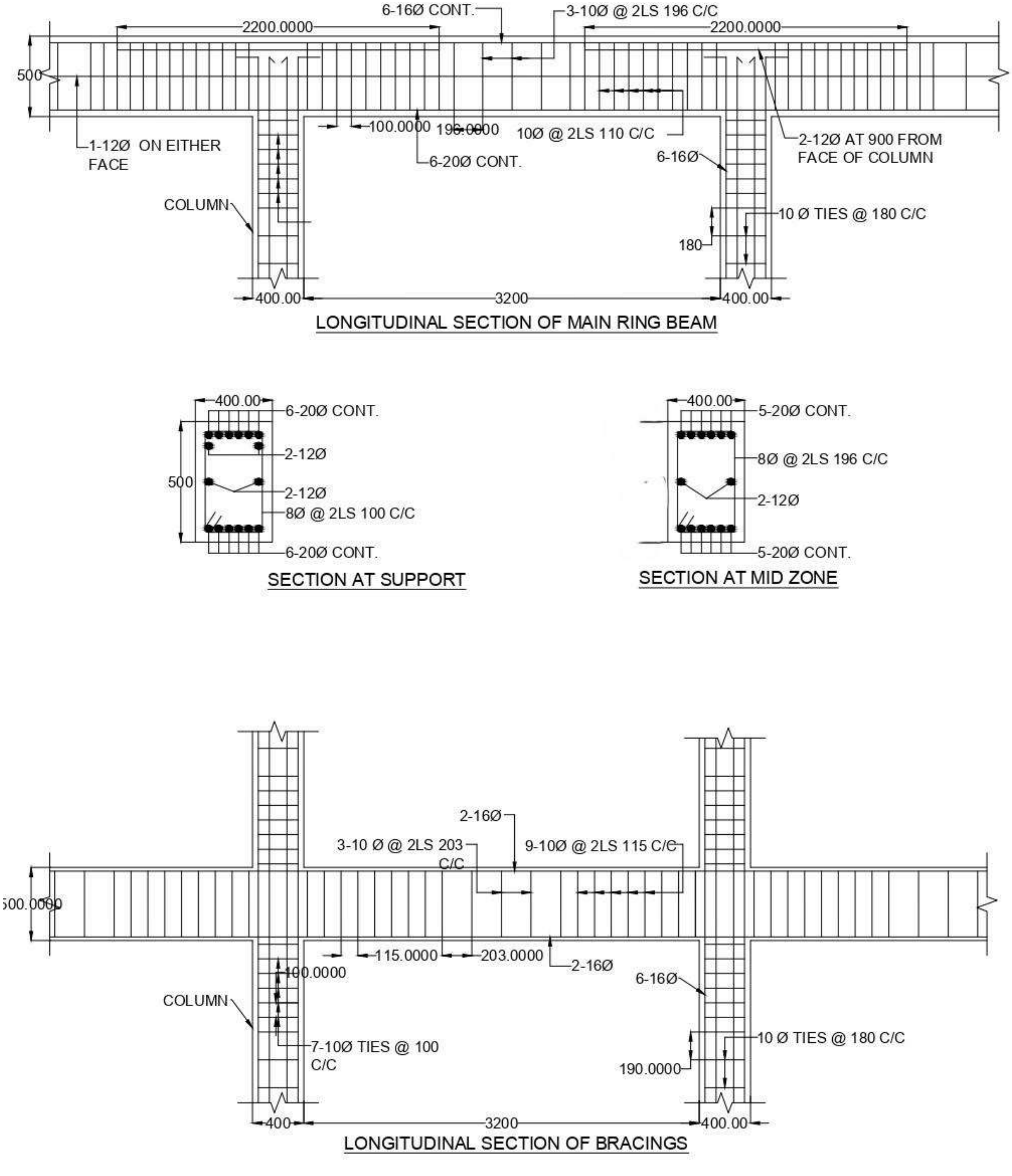


Fig. A.9: Reinforcement plan of main ring beam and bracings of hybrid Circular tank

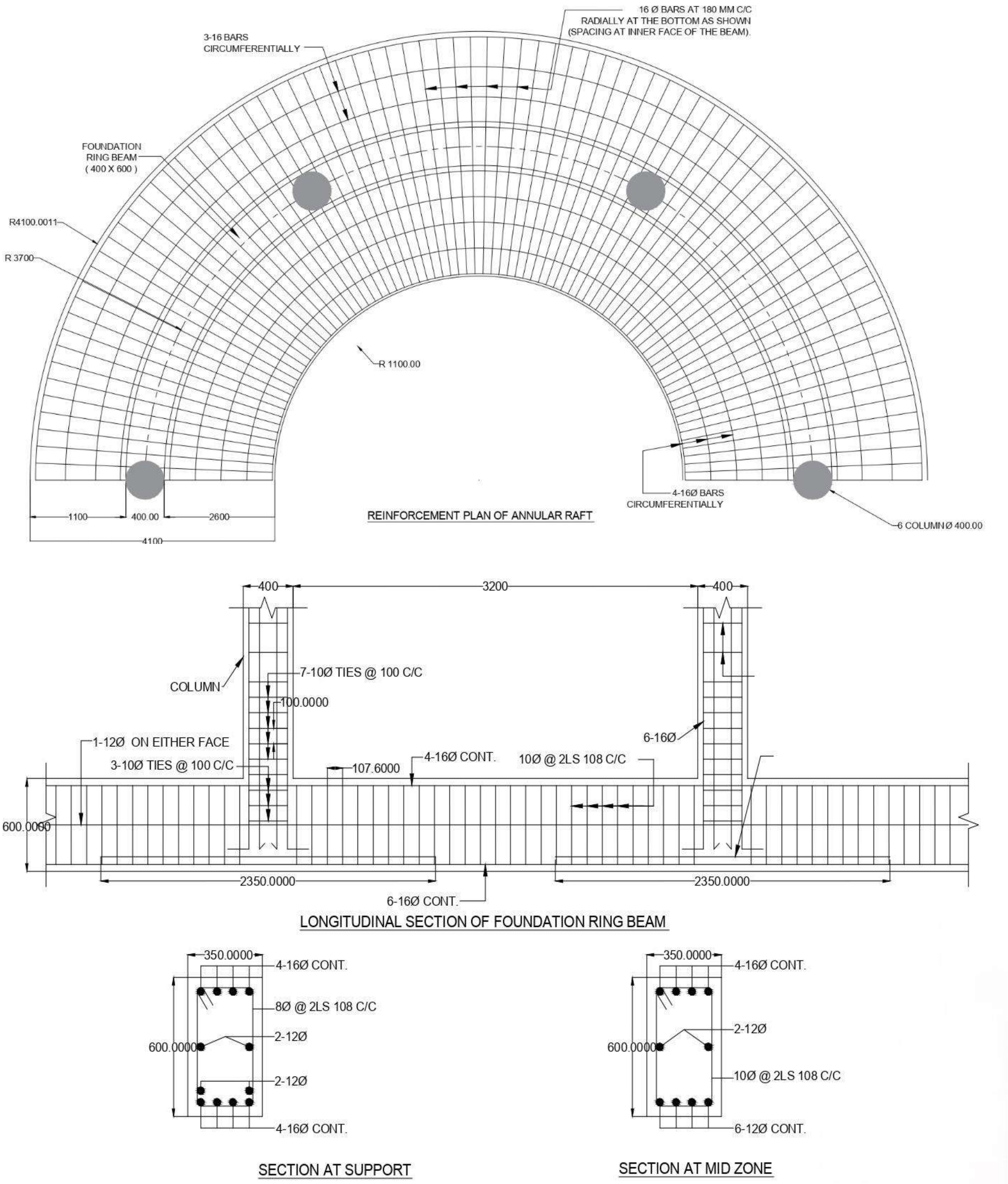


Fig. A.10: Reinforcement plan of foundation ring beam and raft of hybrid circular tank

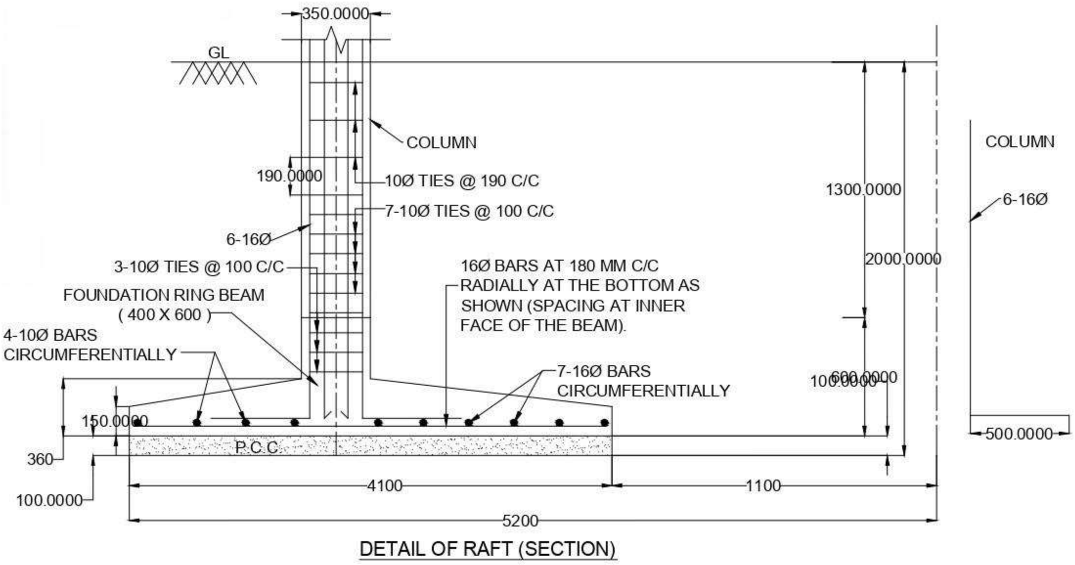


Fig. A.11: Sectional reinforcement plan of raft foundation of hybrid circular tank

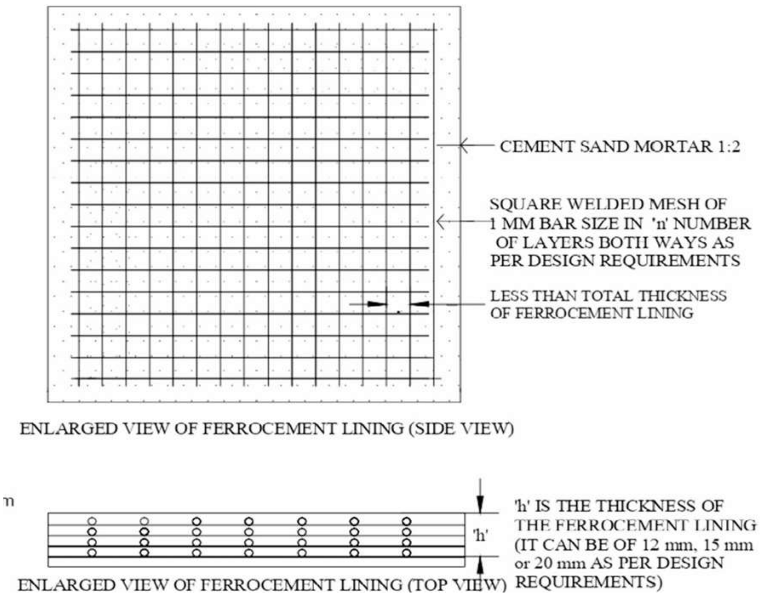


Fig. A.12: General ferrocement lining plan to be provided in tanks.

(In this tank 15 mm lining in 3 layers is to be provided).

List of publications

[1]. Saxena, S., & Pathak, K. K. (2024). Conventional and ferrocement-based hybrid design of RCC tanks: a comparative study. *Innovative Infrastructure Solutions*, *9*(4), 122.https://doi.org/10.1007/s41062-024-01435-3 (Published)

[2]. Saxena, S., & Pathak, K. K. (2024). Comprehensive study of cost, seismic & wind impacts on circular water tanks with varying cylindrical height-to-diameter ratio. *Indian Journal of Engineering and Materials Sciences (IJEMS)*, *31*(2), 224-231. https://or.niscpr.res.in/index.php/IJEMS/article/view/5368 . (Published)

[3]. Saxena, S. and Pathak, K.K. (2025). Hybrid Water Tanks: A Novel Design Approach Integrating Ferrocement Lining with Reinforced Cement Concrete for Enhanced Structural Performance and Cost efficiency. *Journal of Structural Design and Construction Practice*, *30*(1), p.04024080. https://ascelibrary.org/doi/abs/10.1061/JSDCCC.SCENG-1559 (Published)

[4]. Saxena, S. and Pathak, K.K., (2024). Parametric Optimization of Intze water tanks with respect to the latest guidelines of IS 3370: 2021. *Indian Journal of Engineering and Materials Sciences (IJEMS)*, *31*(5), pp.679-686. https://or.niscpr.res.in/index.php/IJEMS/article/view/9781 (Published)

[5]. Saxena, S. and Pathak, K.K., (2025). Comparative Analysis of Performance under Seismicity, Wind Variability, and Coastal Environments Across 16 Prominent Indian Urban Centers: Hybrid Tanks vs Standard RCC Water Tanks. *Indian Journal of Engineering and Materials Sciences (IJEMS)*. (Accepted and is under publication)