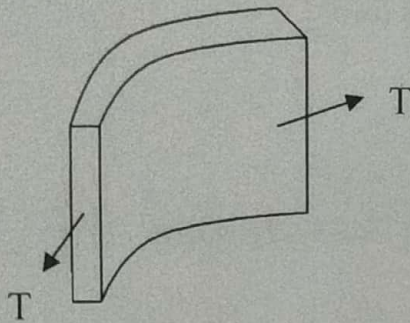


6.6.1.1 Design of Circular Tanks resting on ground with flexible base:

Maximum hoop tension in the wall is developed at the base. This tensile force T is computed by considering the tank as thin cylinder



$T = \gamma H \frac{D}{2}$; Quantity of reinforcement

required in form of hoop steel is computed

as $A_{st} = \frac{T}{\sigma_{st}} = \frac{\gamma H D / 2}{\sigma_{st}}$ or 0.3 % (minimum)

When the thickness of the wall is less than 225 mm, the steel placed at centre. When the thickness exceeds 225mm, at each face $A_{st}/2$ of steel as hoop reinforcement is provided

In order to provide tensile stress in concrete to be less than permissible stress, the stress in concrete is computed using equation

$$\sigma_c = \frac{T}{A_c + (m-1)A_{st}} = \frac{\gamma H D / 2}{1000t + (m-1)A_{st}} \quad \text{If } \sigma_c \leq \sigma_{cat}, \text{ where } \sigma_{cat} = 0.27\sqrt{f_{ck}}, \text{ then the}$$

section is from cracking, otherwise the thickness has to be increased so that σ_c is less than σ_{cat} . While designing, the thickness of concrete wall can be estimated as $t = 30H + 50$ mm, where H is in meters. Distribution steel in the form of vertical bars are provided such that minimum steel area requirement is satisfied. As base slab is resting on ground and no bending stresses are induced hence minimum steel distributed at bottom and the top are provided

Design Problem:

Design a circular water tank with flexible connection at base for a capacity of 4,00,000 liters. The tank rests on a firm level ground. The height of tank including a free board of 200 mm should not exceed 3.5m. The tank is open at top. Use M 20 concrete and Fe 415 steel. Draw to a suitable scale:

- Plan at base
- Cross section through centre of tank.

Solution:

Step 1: Dimension of tank

Depth of water $H = 3.5 - 0.2 = 3.3$ m

Volume $V = 4,00,000 / 1000 = 400 \text{ m}^3$

Area of tank $A = 400 / 3.3 = 121.2 \text{ m}^2$

Diameter of tank $D = \sqrt{\frac{4A}{\pi}} = 12.42 \text{ m} \approx 13 \text{ m}$

The thickness is assumed as $t = 30H + 50 = 149 \approx 160$ mm

Step 2: Design of Vertical wall

Max hoop tension at bottom $T = \gamma H \frac{D}{2} = \frac{10 \times 3.3 \times 13}{2} = 214.5 \text{ kN}$

Area of steel $A_{st} = \frac{T}{\sigma_{st}} = \frac{T}{\sigma_{st}} = \frac{214.5 \times 10^3}{150} = 1430 \text{ mm}^2$

Minimum steel to be provided

$A_{st \text{ min}} = 0.24\% \text{ of area of concrete} = 0.24 \times 1000 \times 160 / 100 = 384 \text{ mm}^2$

The steel required is more than the minimum required

Let the diameter of the bar to be used be 16 mm, area of each bar = 201 mm^2

Spacing of 16 mm diameter bar = $1430 \times 1000 / 201 = 140.6 \text{ mm c/c}$

Provide #16 @ 140 c/c as hoop tension steel

Step 3: Check for tensile stress

Area of steel provided $A_{st \text{ provided}} = 201 \times 1000 / 140 = 1436.16 \text{ mm}^2$

Modular ratio $m = \frac{280}{3\sigma_{cbc}} = \frac{280}{3 \times 7} = 13.33$

Stress in concrete $\sigma_c = \frac{T}{1000t + (m-1)A_{st}} = \frac{214.5 \times 10^3}{1000 \times 160 + (13.33 - 1)1436} = 1.2 \text{ N/mm}^2$

Permissible stress $\sigma_{cat} = 0.27\sqrt{f_{ck}} = 1.2 \text{ N/mm}^2$

Actual stress is equal to permissible stress, hence safe.

Step 4: Curtailment of hoop steel:

Quantity of steel required at 1m, 2m, and at top are tabulated. In this table the maximum spacing is taken as $3 \times 160 = 480 \text{ mm}$

Height from top	Hoop tension $T = \gamma H D / 2$ (kN)	$A_{st} = T / \sigma_{st}$	Spacing of #16 mm c/c
2.3 m	149.5	996	200
1.3 m	84.5	563.33	350
Top	0	Min steel (384 mm^2)	400

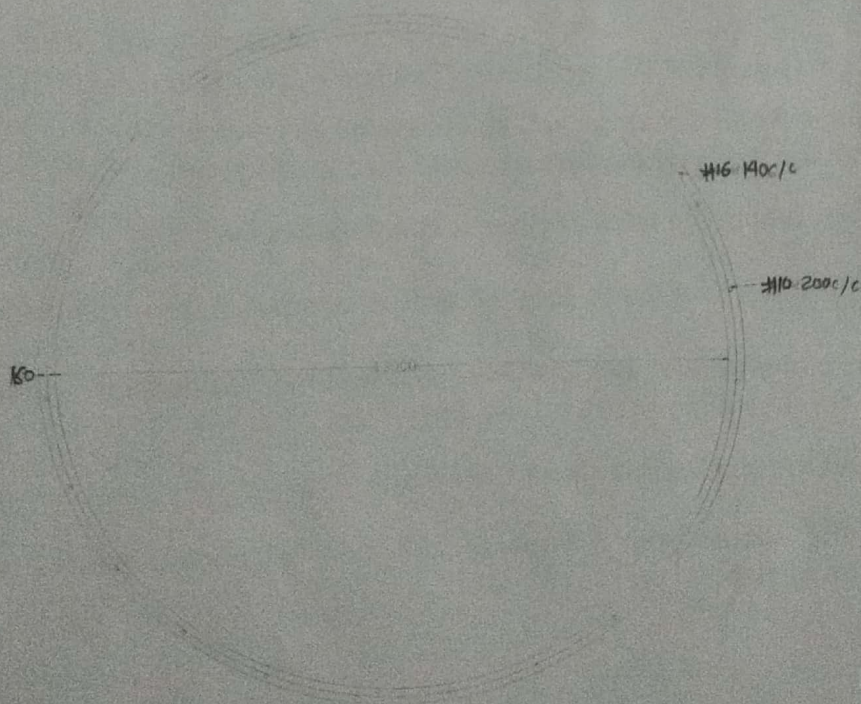
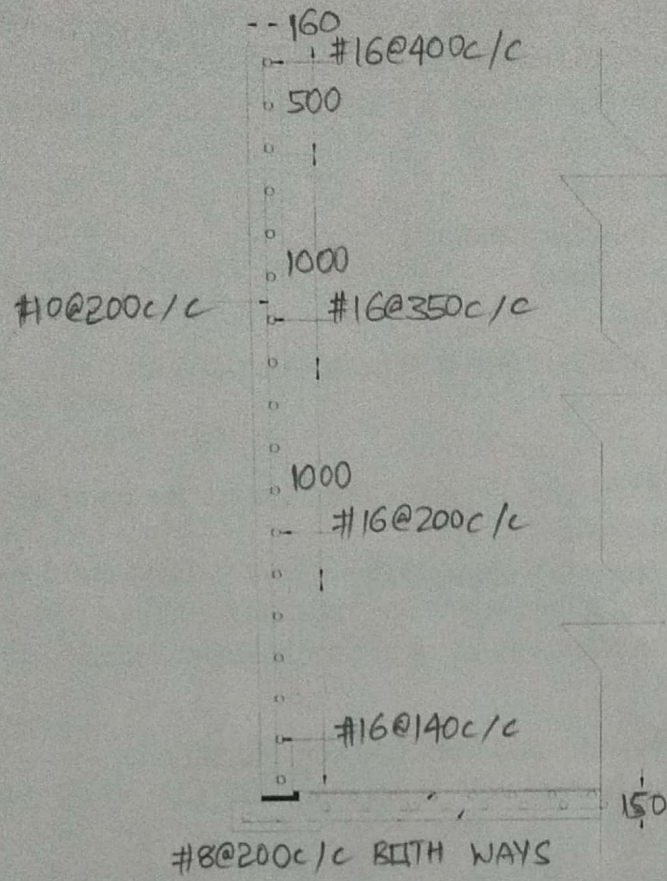
Step 5: Vertical reinforcement:

For temperature and shrinkage distribution steel in the form of vertical reinforcement is provided @ 0.24 % ie., $A_{st} = 384 \text{ mm}^2$.

Spacing of 10 mm diameter bar = $78.54 \times 1000 / 384 = 204 \text{ mm c/c} \approx 200 \text{ mm c/c}$

Step 6: Tank floor:

As the slab rests on firm ground, minimum steel @ 0.3 % is provided. Thickness of slab is assumed as 150 mm. 8 mm diameter bars at 200 c/c is provided in both directions at bottom and top of the slab.



6.6.1.2 Design of Circular Tanks resting on ground with rigid base:

Due to fixity at base of wall, the upper part of the wall will have hoop tension and lower part bend like cantilever. For shallow tanks with large diameter, hoop stresses are very small and the wall act more like cantilever. For deep tanks of small diameter the cantilever action due to fixity at the base is small and the hoop action is predominant. The exact analysis of the tank to determine the portion of wall in which hoop tension is predominant and the other portion in which cantilever action is predominant, is difficult. Simplified methods of analysis are

- i) Reissner's method
- ii) Carpenter's simplified method
- iii) Approximate method
- iv) IS code method

Use of IS code method for analysis and design of circular water tank with rigid base is studied in this course.

IS code method

Tables 9,10 and 11 of IS 3370 part IV gives coefficients for computing hoop tension, moment and shear for various values of H^2/Dt

Hoop tension, moment and shear is computed as

$$T = \text{coefficient} (\gamma_w H D / 2)$$

$$M = \text{coefficient} (\gamma_w H^3)$$

$$V = \text{coefficient} (\gamma_w H^2)$$

Thickness of wall required is computed from BM consideration ie.,

$$d = \sqrt{\frac{M}{Qb}}$$

where,

$$Q = \frac{1}{2} \sigma_{cbc} j k$$

$$k = \frac{m \sigma_{cbc}}{m \sigma_{cbc} + \sigma_{st}}$$

$$j = 1 - (k/3)$$

$$b = 1000 \text{ mm}$$

Providing suitable cover, the over all thickness is then computed as $t = d + \text{cover}$.

Area of reinforcement in the form of vertical bars on water face is computed as

$$\therefore A_{st} = \frac{M}{\sigma_{st} j d} \quad \text{Area of hoop steel in the form of rings is computed as } A_{st1} = \frac{T}{\sigma_{st}}$$

Distribution steel and vertical steel for outer face of wall is computed from minimum steel consideration.

Tensile stress computed from the following equation should be less than the permissible stress for safe design

$$\sigma_c = \frac{T}{1000t + (m-1)A_{st}} \quad \text{and the permissible stress is } 0.27 \sqrt{f_{ck}}$$

Base slab thickness generally varies from 150mm to 250 mm and minimum steel is distributed to top and bottom of slab.

Design Problem No.1:

A cylindrical tank of capacity 7,00,000 liters is resting on good unyielding ground. The depth of tank is limited to 5m. A free board of 300 mm may be provided. The wall and the base slab are cast integrally. Design the tank using M20 concrete and Fe415 grade steel. Draw the following

- i) Plan at base
- ii) Cross section through centre of tank.

Solution:**Step 1: Dimension of tank**

$$H = 5 - 0.3 = 4.7 \text{ and volume } V = 700 \text{ m}^3$$

$$A = 700 / 4.7 = 148.94 \text{ m}^2$$

$$D = \sqrt{(4 \times 148.94 / \pi)} = 13.77 \approx 14 \text{ m}$$

Step 2: Analysis for hoop tension and bending moment

One meter width of the wall is considered and the thickness of the wall is estimated as $t = 30H + 50 = 191 \text{ mm}$. The thickness of wall is assumed as 200 mm.

$$\frac{H^2}{Dt} = \frac{4.7^2}{14 \times 0.2} = 7.89 \approx 8$$

Referring to table 9 of IS3370 (part IV), the maximum coefficient for hoop tension = 0.575

$$T_{\max} = 0.575 \times 10 \times 4.7 \times 7 = 189.175 \text{ kN}$$

Referring to table 10 of IS3370 (part IV), the maximum coefficient for bending moment = -0.0146 (produces tension on water side)

$$M_{\max} = 0.0146 \times 10 \times 4.7^3 = 15.15 \text{ kN-m}$$

Step 3: Design of section:

For M20 concrete $\sigma_{cbc} = 7$, For Fe415 steel $\sigma_{st} = 150 \text{ MPa}$ and $m = 13.33$ for M20 concrete and Fe415 steel

The design constants are:

$$k = \frac{m\sigma_{cbc}}{m\sigma_{cbc} + \sigma_{st}} = 0.39$$

$$j = 1 - (k/3) = 0.87$$

$$Q = \frac{1}{2} \sigma_{cbc} j k = 1.19$$

Effective depth is calculated as **Step 3: Design of section:**

For M20 concrete $\sigma_{cbc} = 7$, For Fe415 steel $\sigma_{st} = 150 \text{ MPa}$ and $m = 13.33$ for M20 concrete and Fe415 steel

The design constants are:

$$k = \frac{m\sigma_{cbc}}{m\sigma_{cbc} + \sigma_{st}} = 0.39$$

$$j = 1 - (k/3) = 0.87$$

$$Q = \frac{1}{2} \sigma_{cbc} j k = 1.19$$

$$\text{Effective depth is calculated as } d = \sqrt{\frac{M}{Qb}} = \sqrt{\frac{15.15 \times 10^6}{1.19 \times 1000}} = 112.94 \text{ mm}$$

Let over all thickness be 200 mm with effective cover 33 mm $d_{\text{provided}} = 167 \text{ mm}$

$$A_{st} = \frac{M}{\sigma_{st} j d} = \frac{15.15 \times 10^6}{150 \times 0.87 \times 167} = 695.16 \text{ mm}^2$$

$$\text{Spacing of 16 mm diameter bar} = \frac{201 \times 1000}{695.16} = 289.23 \text{ mm/c (Max spacing } 3d = 501 \text{ mm)}$$

Provide #16@275 c/c as vertical reinforcement on water face

$$\text{Hoop steel: } A_{st1} = \frac{T}{\sigma_{st}} = \frac{189.275 \times 10^3}{150} = 1261 \text{ mm}^2$$

$$\text{Spacing of 12 mm diameter bar} = \frac{113 \times 1000}{1261} = 89.6 \text{ mm/c}$$

Provide #12@80 c/c as hoop reinforcement on water face

$$\text{Actual area of steel provided } A_{st} = \frac{113 \times 1000}{80} = 1412.5 \text{ mm}^2$$

Step 4: Check for tensile stress:

$$\sigma_c = \frac{T}{1000t + (m-1)A_{st}} = \frac{189.275 \times 10^3}{1000 \times 200 + (13.33-1) \times 1412.5} = 0.87 \text{ N/mm}^2$$

Permissible stress $= 0.27 \sqrt{f_{ck}} = 1.2 \text{ N/mm}^2 > \sigma_c$ Safe

Step 5: Distribution Steel:

Minimum area of steel is 0.24% of concrete area

$$A_{st} = (0.24/100) \times 1000 \times 200 = 480 \text{ mm}^2$$

$$\text{Spacing of 8 mm diameter bar} = \frac{50.24 \times 1000}{480} = 104.7 \text{ mm/c}$$

Provide #8 @ 100 c/c as vertical and horizontal distribution on the outer face.

Step 5: Base slab:

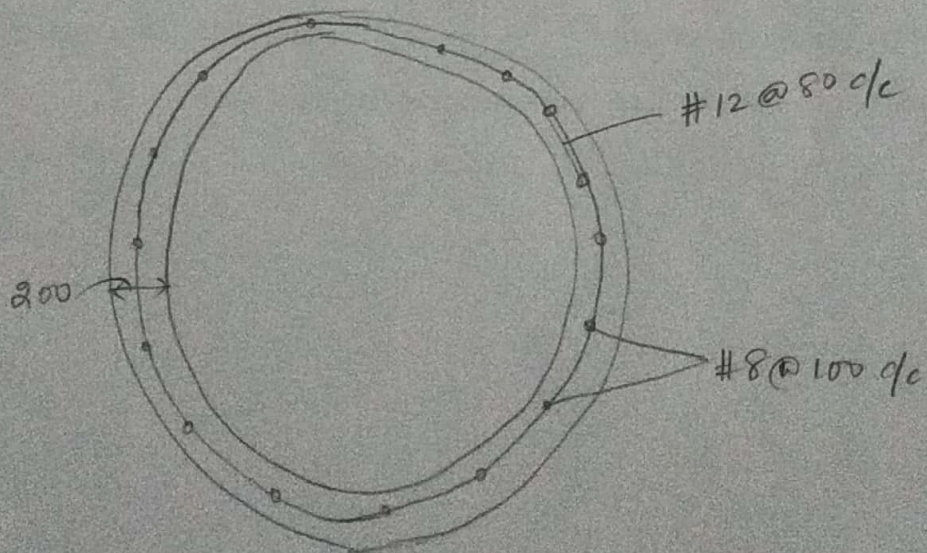
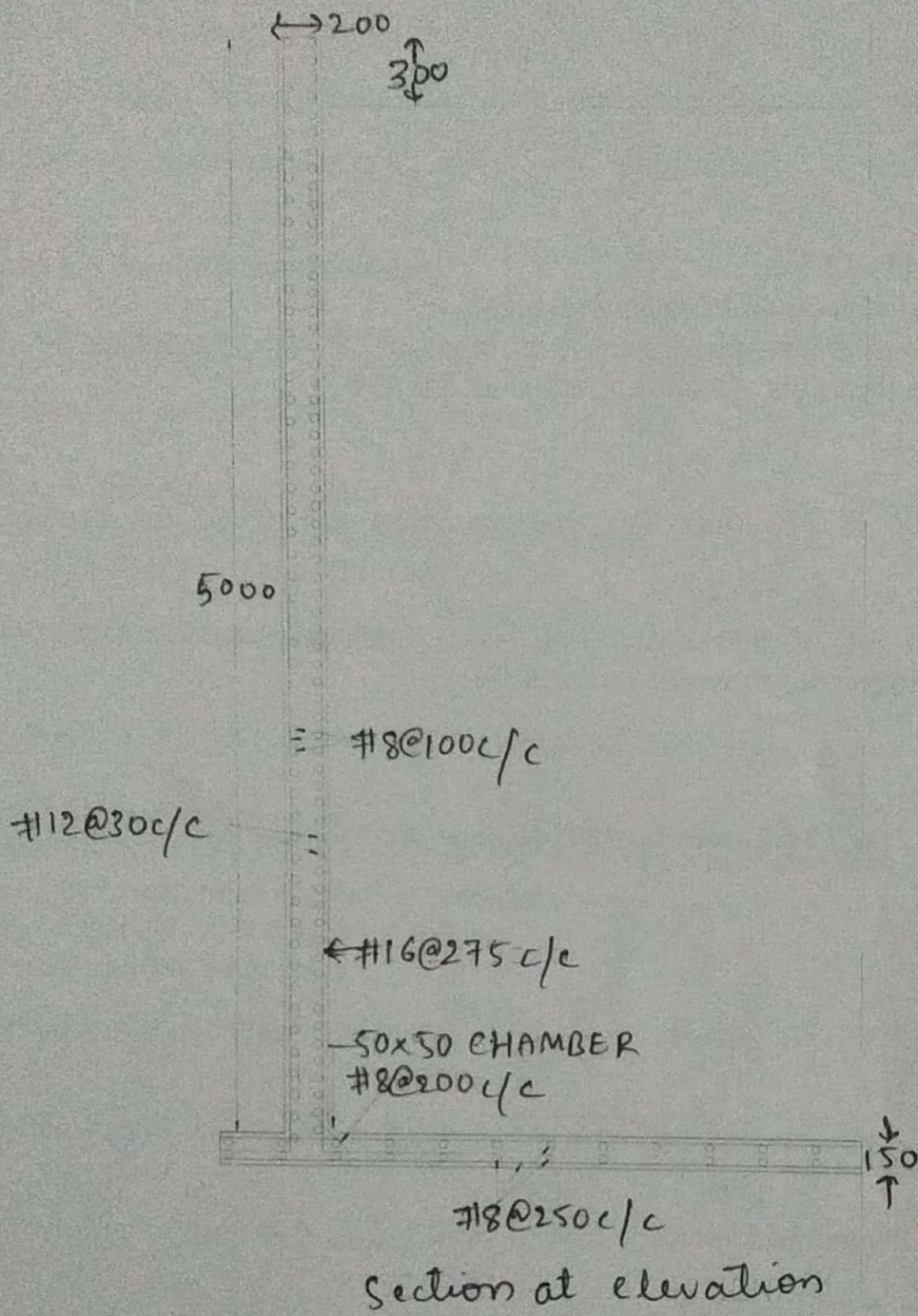
The thickness of base slab shall be 150 mm. The base slab rests on firm ground, hence only minimum reinforcement is provided.

$$A_{st} = (0.24/100) \times 1000 \times 150 = 360 \text{ mm}^2$$

Reinforcement for each face $= 180 \text{ mm}^2$

$$\text{Spacing of 8 mm diameter bar} = \frac{50.24 \times 1000}{180} = 279 \text{ mm/c}$$

Provide #8 @ 250 c/c as vertical and horizontal distribution on the outer face.



Design Problem No.2:

Design a circular water tank to hold 550,000 liters of water. Assume rigid joints between the wall and base slab. Adopt M20 concrete and Fe 415 steel. Sketch details of reinforcements.

Solution:**Step 1: Dimension of tank**

Volume of tank $V = 550 \text{ m}^3$

Assume $H = 4.5$

$$A = 550/4.5 = 122.22 \text{ m}^2$$

$$D = \sqrt{(4 \times 122.22/\pi)} = 12.47 \approx 12.5 \text{ m}$$

Step 2: Analysis for hoop tension and bending moment

One meter width of the wall is considered and the thickness of the wall is estimated as $t = 30H + 50 = 185 \text{ mm}$. The thickness of wall is assumed as 200 mm.

$$\frac{H^2}{Dt} = \frac{4.5^2}{12.5 \times 0.2} = 8.1 \approx 8$$

Referring to table 9 of IS3370 (part IV), the maximum coefficient for hoop tension = 0.575

$$T_{\max} = 0.575 \times 10 \times 4.5 \times 6.25 = 161.72 \text{ kN}$$

Referring to table 10 of IS3370 (part IV), the maximum coefficient for bending moment = -0.0146 (produces tension on water side)

$$M_{\max} = 0.0146 \times 10 \times 4.5^3 = 13.3 \text{ kN-m}$$

Step 3: Design of section:

For M20 concrete $\sigma_{cbc} = 7$, For Fe415 steel $\sigma_{st} = 150 \text{ MPa}$ and $m = 13.33$ for M20 concrete and Fe415 steel

The design constants are:

$$k = \frac{m\sigma_{cbc}}{m\sigma_{cbc} + \sigma_{st}} = 0.39$$

$$j = 1 - (k/3) = 0.87$$

$$Q = \frac{1}{2} \sigma_{cbc} j k = 1.19$$

$$\text{Effective depth is calculated as } d = \sqrt{\frac{M}{Qb}} = \sqrt{\frac{13.3 \times 10^6}{1.19 \times 1000}} = 105.7 \text{ mm}$$

Let over all thickness be 200 mm with effective cover 33 mm $d_{\text{provided}} = 167 \text{ mm}$

$$A_{st} = \frac{M}{\sigma_{st} j d} = \frac{13.3 \times 10^6}{150 \times 0.87 \times 167} = 610.27 \text{ mm}^2$$

$$\text{Spacing of 16 mm diameter bar} = \frac{201 \times 1000}{610.27} = 329.36 \text{ mm c/c (Max spacing } 3d = 501 \text{ mm)}$$

Provide #16@300 c/c as vertical reinforcement on water face

$$\text{Hoop steel: } A_{stl} = \frac{T}{\sigma_{st}} = \frac{161.72 \times 10^3}{150} = 1078.13 \text{ mm}^2$$

$$\text{Spacing of 12 mm diameter bar} = \frac{113 \times 1000}{1078.13} = 104 \text{ mm c/c}$$

Provide #12 @ 100 c/c as hoop reinforcement on water face

$$\text{Actual area of steel provided } A_{st} = \frac{113 \times 1000}{100} = 1130 \text{ mm}^2$$

Step 4: Check for tensile stress:

$$\sigma_c = \frac{T}{1000t + (m-1)A_{st}} = \frac{161.72 \times 10^3}{1000 \times 200 + (13.33-1) \times 1130} = 0.76 \text{ N/mm}^2$$

$$\text{Permissible stress} = 0.27 \sqrt{f_{ck}} = 1.2 \text{ N/mm}^2 > \sigma_c \text{ Safe}$$

Step 5: Distribution Steel:

Minimum area of steel is 0.24% of concrete area

$$A_{st} = (0.24/100) \times 1000 \times 200 = 480 \text{ mm}^2$$

$$\text{Spacing of 8 mm diameter bar} = \frac{50.24 \times 1000}{480} = 104.7 \text{ mm c/c}$$

Provide #8 @ 100 c/c as vertical and horizontal distribution on the outer face.

Step 5: Base slab:

The thickness of base slab shall be 150 mm. The base slab rests on firm ground, hence only minimum reinforcement is provided.

$$A_{st} = (0.24/100) \times 1000 \times 150 = 360 \text{ mm}^2$$

$$\text{Reinforcement for each face} = 180 \text{ mm}^2$$

$$\text{Spacing of 8 mm diameter bar} = \frac{50.24 \times 1000}{180} = 279 \text{ mm c/c}$$

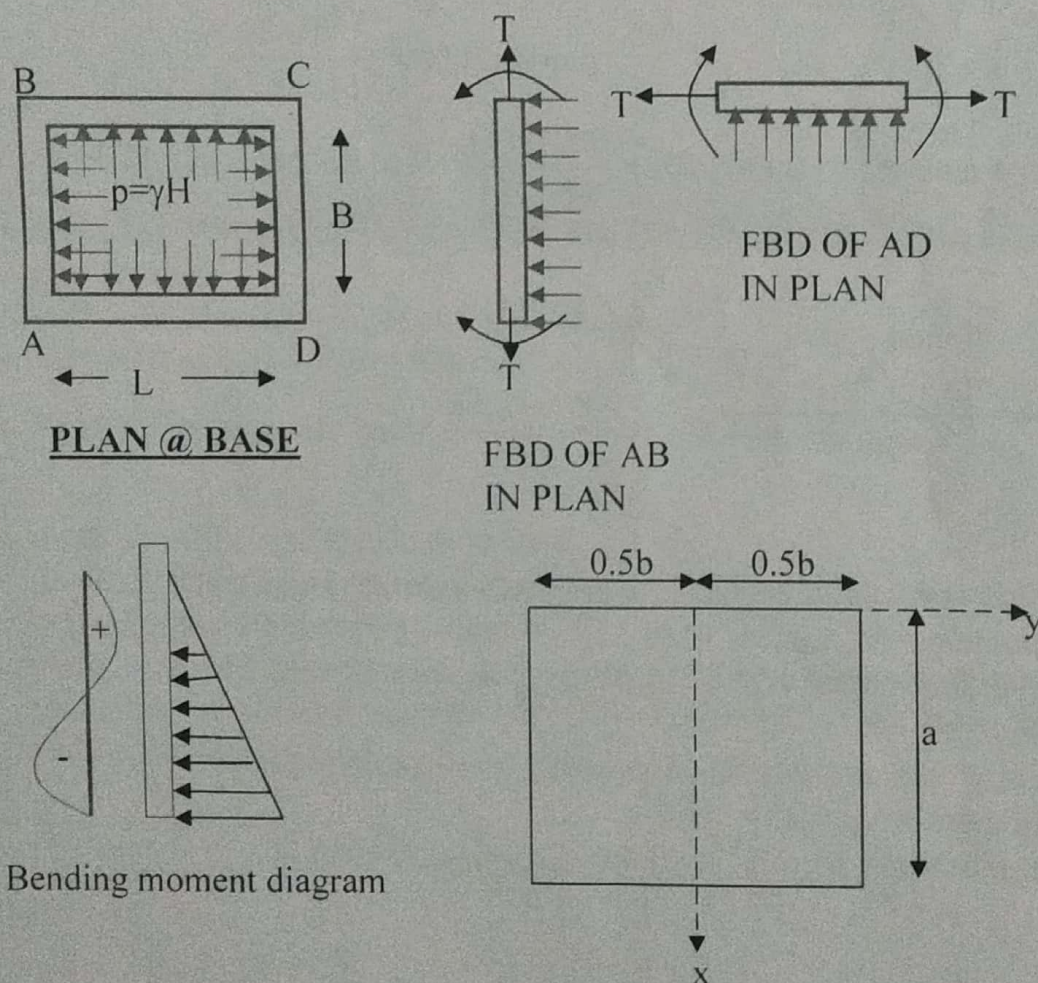
Provide #8 @ 250 c/c as vertical and horizontal distribution on the outer face.

6.6.2 Rectangular tank with fixed base resting on ground :

Rectangular tanks are used when the storage capacity is small and circular tanks prove uneconomical for small capacity. Rectangular tanks should be preferably square in plan from point of view of economy. It is also desirable that longer side should not be greater than twice the smaller side.

Moments are caused in two directions of the wall i.e., both in horizontal as well as in vertical direction. Exact analysis is difficult and such tanks are designed by approximate methods. When the length of the wall is more in comparison to its height, the moments will be mainly in the vertical direction, i.e., the panel bends as vertical cantilever. When the height is large in comparison to its length, the moments will be in the horizontal direction and panel bends as a thin slab supported on edges. For intermediate condition bending takes place both in horizontal and vertical direction.

In addition to the moments, the walls are also subjected to direct pull exerted by water pressure on some portion of walls. The walls are designed both for direct tension and bending moment.



IS3370 (Part-IV) gives tables for moments and shear forces in walls for certain edge condition. Table 3 of IS3370 provides coefficient for max Bending moments in horizontal and vertical direction.

Maximum vertical moment = $M_x \gamma_w a^3$ (for $x/a = 1$, $y=0$)

Maximum horizontal moment = $M_y \gamma_w a^3$ (for $x/a = 0$, $y=b/2$)

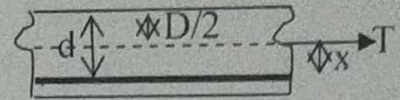
Tension in short wall is computed as $T_s = pL/2$

Tension in long wall $T_L = pB/2$

Horizontal steel is provided for net bending moment and direct tensile force

$$A_{st} = A_{st1} + A_{st2}; \quad A_{st1} = \frac{M'}{\sigma_{st} j d}; \quad M' = \text{Maximum horizontal bending moment} - T x; \quad x = d - D/2$$

$$A_{st2} = T / \sigma_{st}$$

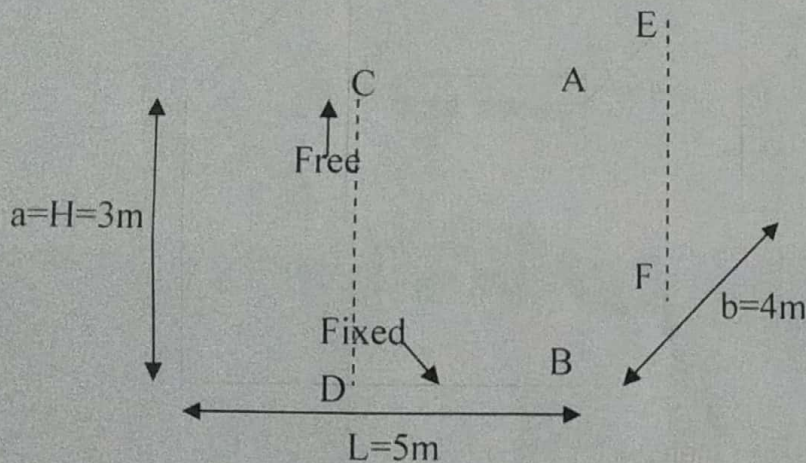


Design problem No.1

Design a rectangular water tank 5m x 4m with depth of storage 3m, resting on ground and whose walls are rigidly joined at vertical and horizontal edges. Assume M20 concrete and Fe415 grade steel. Sketch the details of reinforcement in the tank

Solution:

Step1: Analysis for moment and tensile force



i) Long wall:

$L/a = 1.67 \approx 1.75$; at $y=0, x/a=1, M_x = -0.074$; at $y=b/2, x/a=1/4, M_y = -0.052$

Max vertical moment = $M_x \gamma_w a^3 = -19.98$

Max horizontal moment = $M_y \gamma_w a^3 = -14.04$; $T_{\text{long}} = \gamma_w ab/2 = 60 \text{ kN}$

ii) Short wall:

$B/a = 1.33 \approx 1.5$; at $y=0, x/a=1, M_x = -0.06$; at $y=b/2, x/a=1/4, M_y = -0.044$

Max vertical moment = $M_x \gamma_w a^3 = -16.2$

Max horizontal moment = $M_y \gamma_w a^3 = -11.88$; $T_{\text{short}} = \gamma_w aL/2 = 75 \text{ kN}$

Step2: Design constants

$$\sigma_{cbc}=7 \text{ MPa}, \sigma_{st}=150 \text{ MPa}, m=13.33$$

$$k = \frac{m\sigma_{cbc}}{m\sigma_{cbc} + \sigma_{st}} = 0.38$$

$$j=1-(k/3)=0.87$$

$$Q = \frac{1}{2} \sigma_{cbc} j k = 1.15$$

Step3: Design for vertical moment

For vertical moment, the maximum bending moment from long and short wall

$$(M_{\max})_x = -19.98 \text{ kN-m}$$

$$d = \sqrt{\frac{M}{Qb}} = \sqrt{\frac{19.98 \times 10^6}{1.15 \times 1000}} = 131.8 \text{ mm}$$

Assuming effective cover as 33mm, the thickness of wall is

$$t = 131.88 + 33 = 164.8 \text{ mm} \approx 170 \text{ mm}$$

$$d_{\text{provided}} = 170 - 33 = 137 \text{ mm}$$

$$A_{st} = \frac{M}{\sigma_{st} j d} = \frac{19.98 \times 10^6}{150 \times 0.87 \times 137} = 1117.54 \text{ mm}^2$$

$$\text{Spacing of 12 mm diameter bar} = \frac{113 \times 1000}{1117.54} = 101.2 \text{ mm c/c (Max spacing } 3d = 411 \text{ mm)}$$

Provide #12 @ 100 mm c/c

Distribution steel

Minimum area of steel is 0.24% of concrete area

$$A_{st} = (0.24/100) \times 1000 \times 170 = 408 \text{ mm}^2$$

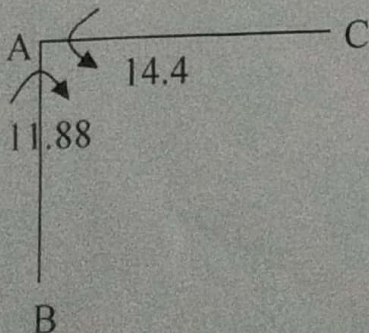
$$\text{Spacing of 8 mm diameter bar} = \frac{50.24 \times 1000}{408} = 123.19 \text{ mm c/c}$$

Provide #8 @ 120 c/c as distribution steel.

Provide #8 @ 120 c/c as vertical and horizontal distribution on the outer face.

Step4: Design for Horizontal moment

Horizontal moments at the corner in long and short wall produce unbalanced moment at the joint. This unbalanced moment has to be distributed to get balanced moment using moment distribution method.



$$K_{AC} = \frac{1}{5}; K_{AB} = \frac{1}{5}; \sum K = \frac{9}{20}$$

$$DF_{AC} = \frac{1/5}{9/20} = 0.44$$

$$DF_{AB} = \frac{1/4}{9/20} = 0.56$$

Moment distribution Table

Joint	A	
Member	AC	AB
DF	0.44	0.56
FEM	-14	11.88
Distribution	0.9328	1.1872
Final Moment	-13.0672	13.0672

The tension in the wall is computed by considering the section at height H_1 from the base.

Where, H_1 is greater of i) $H/4$, ii) 1m , ie., i) $3/4=0.75$, ii) 1m ; $\therefore H_1 = 1\text{m}$

Depth of water $h = H - H_1 = 3 - 1 = 2\text{m}$; $p = \gamma_w h = 10 \times 2 = 20 \text{ kN/m}^2$

Tension in short wall $T_s = pL/2 = 50 \text{ kN}$

Tension in long wall $T_L = pB/2 = 40 \text{ kN}$

Net bending moment $M' = M - Tx$, where, $x = d - D/2 = 137 - (170/2) = 52\text{mm}$

$M' = 13.0672 - 50 \times 0.052 = 10.4672 \text{ kN-m}$

$$A_{st1} = \frac{10.4672 \times 10^6}{150 \times 0.87 \times 137} = 585.46 \text{ mm}^2$$

$$A_{st2} = \frac{50 \times 10^3}{150} = 333.33 \text{ mm}^2$$

$$A_{st} = A_{st1} + A_{st2} = 918.79 \text{ mm}^2$$

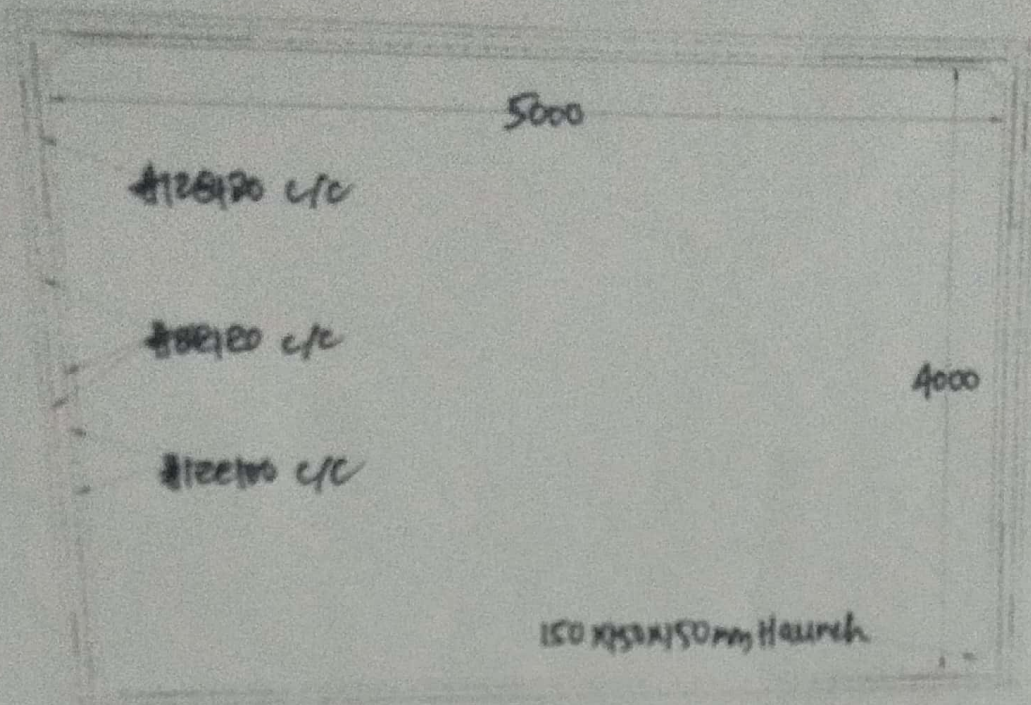
$$\text{Spacing of 12 mm diameter bar} = \frac{113 \times 1000}{918.74} = 123 \text{ mm c/c (Max spacing } 3d = 411 \text{ mm)}$$

Provide #12@120 mm c/c at corners

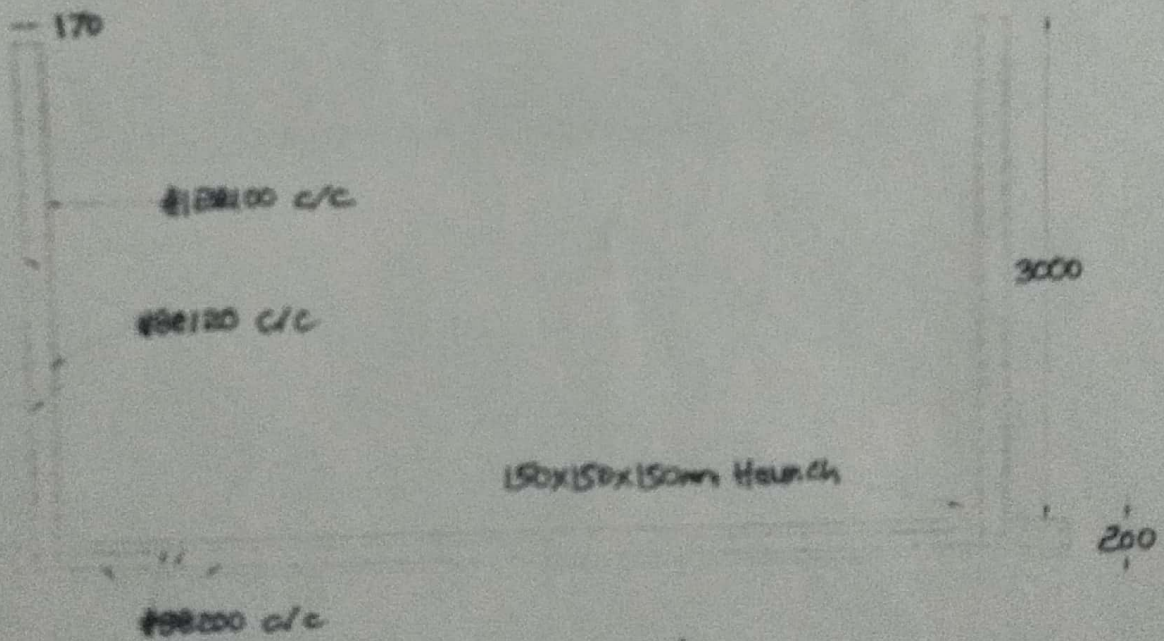
Step5: Base Slab:

The slab is resting on firm ground. Hence nominal thickness and reinforcement is provided. The thickness of slab is assumed to be 200 mm and 0.24% reinforcement is provided in the form of #8 @ 200 c/c. at top and bottom

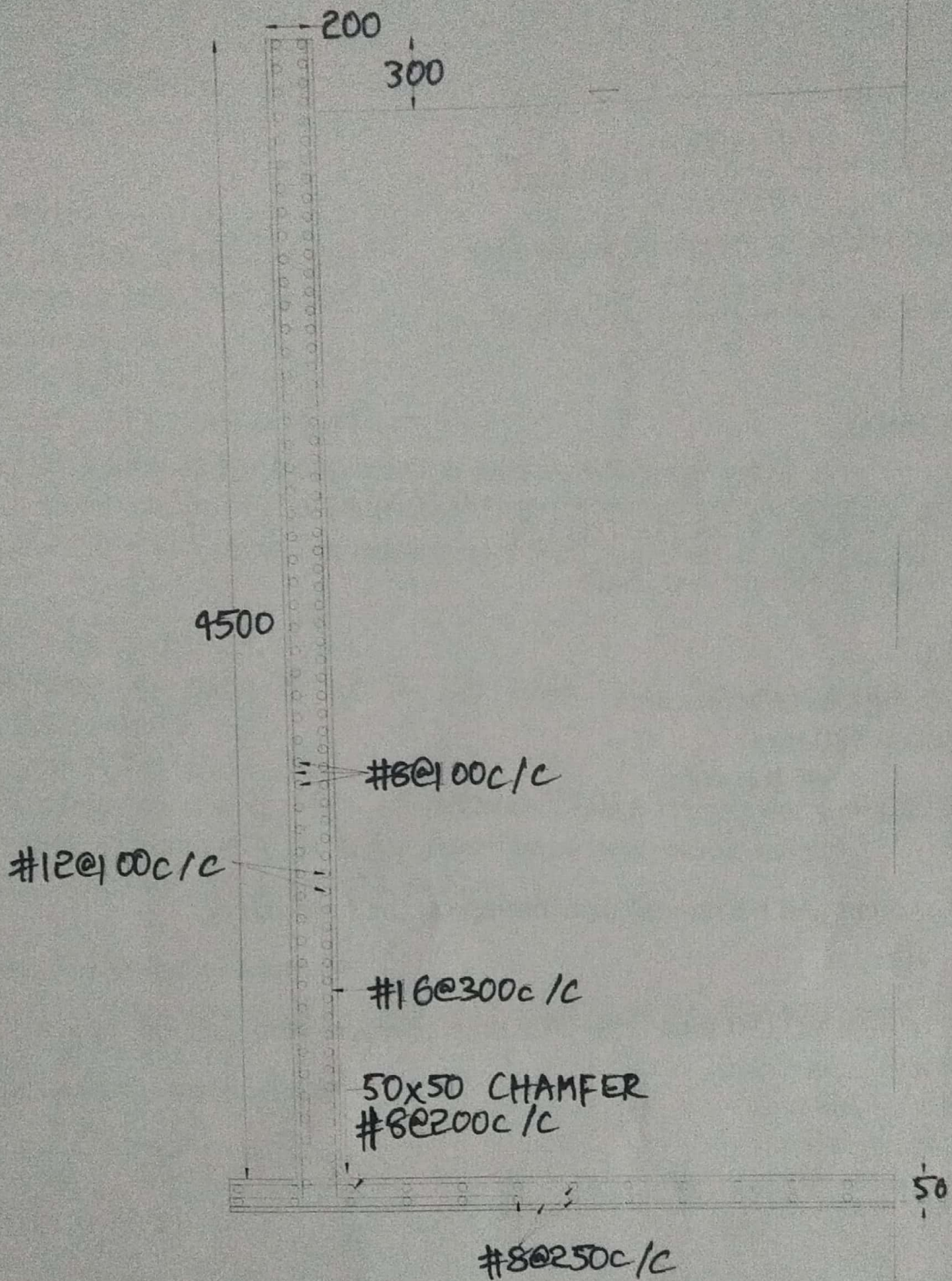
A haunch of 150 x 150 x 150 mm size is provided at all corners



PLAN



ELEVATION



SECTIONAL ELEVATION