Design of water tank (as per IS 3370-2009)

- Tanks are widely used for storing liquids like water, chemicals and petroleum etc.
- The tanks are generally circular or rectangular in shape.
- They are broadly categorised into following 3 types.

i) Tanks resting on ground

ii) Underground tank

iii) Elevated or overhead ~~ted~~ tanks.

- The tanks ~~are~~ resting on ground are supported on the ground directly.
- The sedimentation tanks, aeration tanks, filtration tanks and clear water storage reservoirs are generally of this type.
- While the septic tank, imhoff tanks and simple water tanks collecting water from the mains are generally constructed as underground tank.
- Elevated or overhead water tanks, supported on staging, are commonly used in water distribution system.
- For ~~any~~ ~~condu~~ constructing any type of liquid

retaining structure it is much ensure that concrete is dense and impervious.

- It is essential not only from the leakage point of view, but also effects the durability, cracking and resistance against chemical attack and corrosion.
- The Indian Standard code of practice for design of liquid retaining concrete structure is,

i) IS 3370 - 2009 (Part 1) - code of practice for concrete structures for storage of liquids - general requirements.

ii) IS 3370 - 2009 (part 2) - code of practice for concrete structures for storage of liquids - reinforced concrete structures.

iii) IS 3370 - ~~2009~~ 1967 (part 3) - code of practice for concrete structures for storage of liquids - prestressed concrete structures.

iv) IS 3370 - 1967 (part 4) - Design tables for design of reinforced or prestressed concrete structures for storage structure.

Analysis of water tank.

- The exact analysis of water tank is very complicated and time consuming.
- It requires thorough knowledge of theory of plates and cylinders based on finite element method, with the appropriate boundary conditions and constraints. ~~to simply~~ ~~with~~
- To simplify the analysis, IS 3370 - (part 4) 1967 is ready to use design tables for moments, hoop tension and shear coefficient values for cylindrical and rectangular tanks for different boundary condition and various types of loading.

Circular tanks resting on the ground.

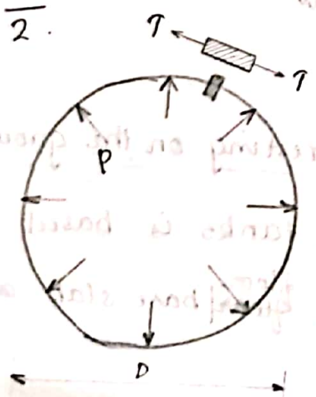
- Design of such tanks is based on the type of joint provided b/w the ~~floor~~ floor/base slab and the walls of the tank.

~~omitted~~

Circular water tank with flexible joints between the floor and the wall (Approximate method)

- In this type of tank the flexible joint provided b/w the floor and wall is flexible.
- Thus allowing the horizontal outward movement of the wall.
- Hence, no moments are developed at the joints.
- In such tanks, walls are subjected to hoop tension only which is developed because of the hydrostatic water pressure.

$$T = \gamma H \frac{D}{2}$$



$P = \gamma H$
Pressure due to water.

Circular water tank

where,

γ = unit wt of water
H = Height of water
D = Diameter of the tank
T = Hoop tension

- The reinforcement for the hoop tension is to be provided all along the height of the wall in the form of hoops or rings suitably spaced apart.
- The area of steel required for carrying the hoop tension T is calculated as follows

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

$$\gamma H \frac{D}{2} = \sigma_{st} A_{st}$$

$$A_{st} = \frac{\gamma H D}{2 \sigma_{st}}$$

- The thickness (t) of the tank wall may be calculated from the requirement that tensile stress in concrete should be within the permissible limit.
- If σ_{ct} is the permissible tensile stress in concrete, then

$$\sigma_{ct} > \frac{T}{\text{Area}_{\text{equivalent}}}$$

where,

$A_{equivalent}$ = Area of the transformed section

$$\sigma_{ct} > \frac{T}{A+(m-1)A_{st}}$$

$$\sigma_{ct} > \frac{T}{1000t+(m-1)A_{st}}$$

IS code recommendations regarding detailing in water tanks.

i) The minimum reinforcement in walls, floors and roofs in each of 2 directions at right angles within each surface zone should not be less than 0.35% of the surface zone cross-section of surface zone, for HYSD bars and 0.64% for mild steel bars.

ii) The minimum reinforcement can be further reduced to 0.24% for deformed bars and 0.4% for plain bars, for tanks not having any dimension more than 15m.

iii) In tank walls and slabs, having thickness less than 200mm, the reinforcement can be placed in one ~~plate~~ face only.

iv) For base slab having thickness less than 300mm, the reinforcement should be placed on one face as near as possible to the upper face consistent with the cover.

v) The spacing of reinforcing bars should not exceed 300mm or thickness of the section which ever is less.

vi) Size of bars, distance between bars, laps and bends should be as per IS 456 - 2000.

2 Design a circular water tank with a flexible base for a tank of 1,00,000 l capacity. The depth of water in the tank is 5m. Use M_{25} concrete and Fe_{415} steel. Take unit wt of water as 9.8 kN/m².

Solution

Given volume of water ~~tank~~ in tank = 1,00,000 l

$$= \frac{1,00,000}{1000}$$

$$= 100 m^3$$

Height of water in tank (H) = 5m.

Permissible tensile stress in steel = ~~150 Ks~~ 150N/mm² for HYSD bars

Permissible ~~tens~~ direct tensile stress in concrete = 1.3 N/mm² for M 25 concrete

If D is the diameter of the tank then, ~~volum~~

Volume of tank = $\frac{10.000}{100.0}$ = 100m³

$\frac{\pi}{4} D^2 H = 100 m^3$

$\frac{\pi}{4} D^2 \times 5 = 100 m^3$

$D^2 = 25.46$

$D = 5.05 m.$

Hence providing a diameter of 5.1m.

Maximum hoop tension (T)

$T = \gamma H \frac{D}{2}.$

$= \frac{9.8 \times 5 \times 5.1}{2} = 124.95$ kN/m ht of wall.

Area of steel.

$A_{st} = \frac{T}{\sigma_{st}} = \frac{\gamma H D}{2 \sigma_{st}} = \frac{124.95 \times 10^3}{150}$

$= 0.833 m^2$

$= 833 mm^2$

Using 12mm diameter bars,

Spacing required $= \frac{\frac{\pi}{4} \times (12)^2 \times 1000}{833} = 135.77 mm$

Hence provide 12 mm diameter hoops (rings) at 135mm c/c.

A_{st} provided $= \frac{\frac{\pi}{4} \times (12)^2 \times 1000}{135} = 837.75 mm^2$

At a distance 2.5m from top,

$T = \frac{124.95}{2} = 62.5$ KN/m

And $A_{st\,req} = \frac{62.5}{150} = \frac{833}{2} = 416.5 mm^2$

∴ Spacing required $= \frac{\frac{\pi}{4} \times (12)^2 \times 1000}{416.5} = 271.54 mm$

Provide 12mm diameter bars 270mm c/c.

Thickness of tankwall.

The thickness of the wall should be such that the tensile

∘ The thickness of the wall should not exceed the permissible stress ~~g~~ in concrete should not exceed the permissible value σ_{ct}.

$\sigma_{cbc} = \frac{25}{3} = 8.33$

$\sigma_{ct} > \frac{T}{1000 \times t + (m-1) A_{st}}$

$m = \frac{280}{3 \sigma_{cbc}} = \frac{280}{3 \times 8.33} = 11.2$

Scanned with CamScanner

$$1.3 > \frac{124.95 \times 10^3}{1000 \times t + (11.2-1)831.75}$$

$$1.3 > \frac{124.95 \times 10^3}{1000t + 8545.05}$$

$$1300t + 11108.565 > 124.95 \times 10^3$$

$$t = \underline{87.57\ mm}$$

Hence providing a thickness of 100mm for tank wall.

Ast_{min} = 0.35% of crosssectional area.

$$= \frac{0.35}{100} \times \frac{\pi}{4} \times (75 \times 10^3)^2 - R$$

$$= \frac{0.35}{100} \times 100 \times 1000 = \underline{350\ mm^2}$$

$Ast_{min} < Ast$ provided.

Hence it is safe.

Distribution reinforcement

Ast_{min} = 0.35% crosssectional area

$$= \frac{0.35}{100} \times 100 \times 1000$$

$$= \underline{350\ mm^2}$$

Providing 8mm diameter bars

$$\text{Spacing} = \frac{\frac{\pi}{4} \times 8^2 \times 1000}{350} = \underline{143.6\ mm}$$

Hence provide 8 mm diameter bars 140mm c/c [Vertical direction].

Design of base or floor slab.

- Since the tank floor is resting on the ground, the loads gets directly transferred to the soil.
- Hence providing a minimum thickness of 150mm and 0.35% minimum steel in each direction.

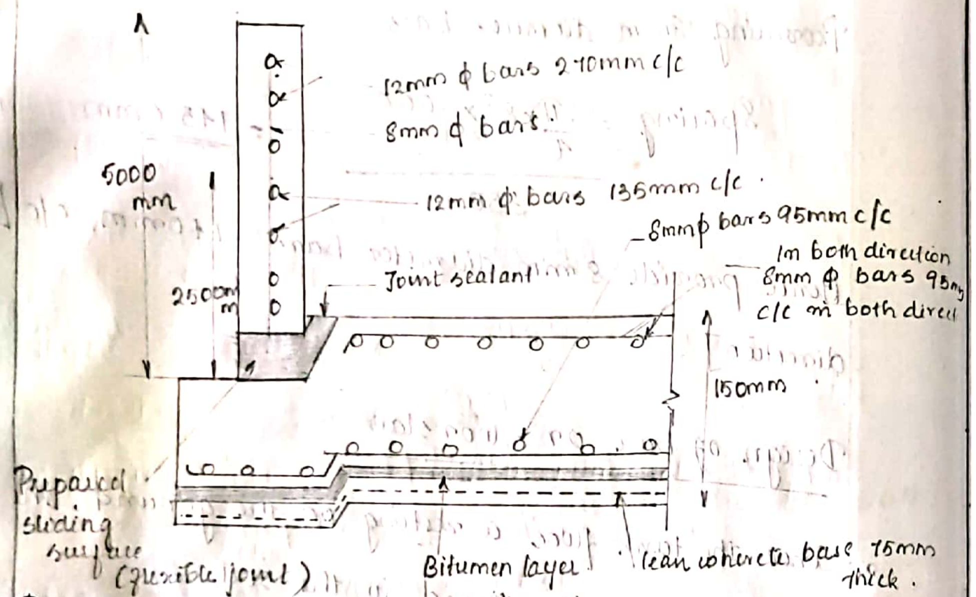
$$\therefore Ast_{min} = \frac{0.35 \times 150 \times 1000}{100}$$

$$= \underline{525\ mm^2}$$

Hence provide 8mm diameter bars.

$$\text{Spacing} = \frac{\frac{\pi}{4} \times 8^2 \times 1000}{525} = \underline{95.743\ mm}$$

Provide 8mm diameter bars @ 95mm c/c in both direction.



3 Design a circular water tank with flexible base for a capacity of 450 KL. The depth of water is 4.5m. Allow suitable free board.

Using M_{30} concrete, Fe 415 steel

Capacity of tank = 450KL = 45,0000 l $= \frac{450000}{1000}$

$= 450 m^3$

Taking 200mm as free board,

Effective depth of water in tank = 4.5 − 0.2

= 4.3 m

Diameter of tank,

Volume of tank, $\frac{\pi}{4} D^2 H = 450$

$\frac{\pi}{4} \times D^2 \times 4.3 = 450$

$D = 11.54$ m

Take $D = 11.6$ m

Maximum hoop tension,

$T = \frac{\gamma H D}{2}$

$= \frac{9.8 \times 4.3 \times 11.6}{2} = 244.412$ kN/m height of wall.

Area of steel, $A_{st} = \frac{T}{\sigma_{st}} = \frac{244.412 \times 10^3}{150} = 1629.41 mm^2$

Using 12mm diameter bars, spacing required $= \frac{\frac{\pi}{4} \times 12^2 \times 1000}{1629.41}$

$= 69.409$ mm

Hence provide 12mm diameter hoops (rings) at 69mm c/c.

A_{st} provided $= \frac{\frac{\pi}{4} \times 12^2 \times 1000}{69} = 1639.09 mm^2$

At a distance 2.15m from top,

$T = \frac{244.412}{2} = 122.206$ kN/m

$Ast_{req} = \frac{1629.41}{2} = 814.705 mm^2$

Spacing required $= \frac{\frac{\pi}{4} \times 12^2 \times 1000}{814.705} = 138.81mm$

Provide 12mm diameter bars @ 138mm c/c.

Thickness of tank wall.

The thickness of wall should be such that the tensile stress in concrete should not exceed the permissible value.

$$\sigma_{ct} > \frac{T}{1000t + (m-1)Ast}$$

Permissible direct tensile stress in concrete $= 1.5 N/mm^2$.

$$1.5 > \frac{244.412 \times 10^3}{1000t + (9.33-1)1639}$$

$$t = 149.28mm$$

Hence providing a thickness of 150mm for tank wall.

$Astmin = 0.35\%$ of cross sectional area.

$$= \frac{0.35}{100} \times 1000 \times 150 = 525mm^2$$

$Astmin < Ast_{prov}$.

Hence. Ok.

Distribution reinforcement.

$Ast_{min} = 0.35\%$ of cross sectional area $= 525mm^2$

~~Providing 8mm diameter bars at 95mm.~~

Providing 8mm diameter bars,

Spacing required $= \frac{\frac{\pi}{4} \times 8^2 \times 1000}{525} = 95.74mm$

Hence providing 8mm diameter bars at 95mm c/c.

Design of base / floor slab.

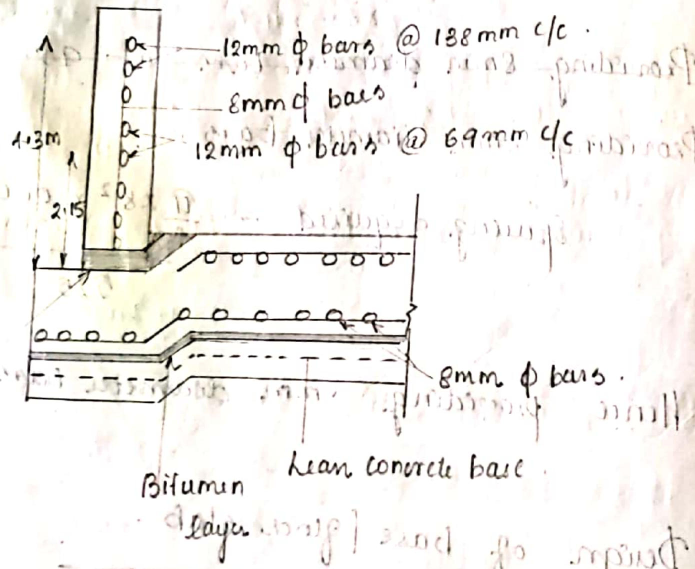
$Ast_{min} = \frac{0.35}{100} \times 150 \times 1000$

$= \underline{525 mm^2}$

Providing 8mm diameter bars

Spacing required $= \frac{\frac{\pi}{4} \times 8^2 \times 1000}{525} = \underline{95.74mm}$

Providing 8mm diameter bars at 95mm c/c in both direction.



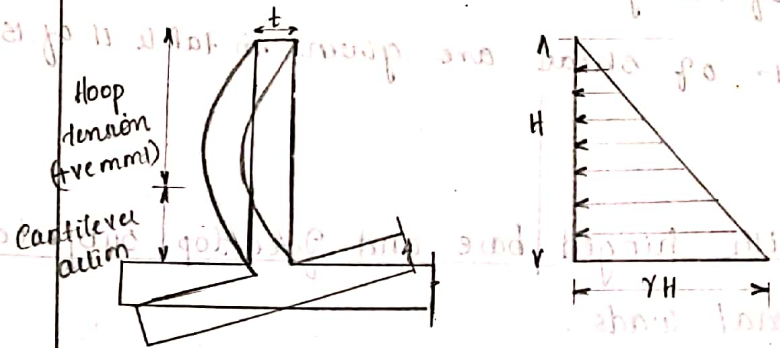
IS code method for design of circular tank.

(Rigid joint between floor and the wall).

- IS 3370 (part IV, 1967) gives the design table for calculation of moments and hoop tension in circular tank of various condition of joints and various types of loading like triangular loading and trapezoidal loading.
- Some common cases of cylindrical tank given in IS 3370 are as below:

Case I - Wall with fixed base and free top subjected to triangular loading.

- Circular tanks are generally cast monolithic with their base/footing and hence, some times designed as the base is fixed and the top is free.



Refer table 9, page no: 35 in IS 3370 (part IV)

- The coefficient for shear at base of the cylindrical wall are given in table 11 of IS 3370 part IV page 37.

- The coefficient for moment in cylindrical wall are given in table 10 of IS 3370 part IV page no: 36.

Case II – Wall with hinged base and free top subjected to triangular load.

- It is practically not possible to have a fixed joint between the walls and the base slab of the tank though they are cast monolithically.
- It is safe and reasonable to assume that the base is hinged and free at top.
- Table 12 and table 13 of IS code gives the values of ring tension and moments respectively at different height of the cylindrical wall.
- Coefficient of shear are given in table 11 of IS code.

Case III

Walls with hinged base and free top, subjected to trapezoidal loads.

- In this case, it is a combination of triangular and uniformly distributed loading.
- Table 12 and 14 of IS 3370 part IV gives the coefficient for hoop tension and table 13 and 11 gives the coefficient for moments and shear respectively.
- For this case, tables given in IS 3370 part IV gives the values for coefficients for hoop tension for various values of $\frac{H^2}{Dt}$ ratio.
- Hoop tension, T = coefficient $\times \gamma H \times \frac{D}{2}$ (kN/m height of the wall)
- Bending moment(M) is calculated as,

$$M = \text{coefficient} \times \gamma H^3 \text{ [kNm/m height of wall]}$$

- Similarly, the shear force at the base of the cylindrical wall is obtained as follows.

$$\text{Shear force} = \text{Coefficient} \times \gamma H^2 \text{ (kN)}$$

4 Design the wall of a circular tank 7m diameter and 4m height. The tank is fixed (→ rigid joint) at the base and resting on the ground. Sketch the details.

Solution.

Using M_{30} concrete and Fe415 steel

$\sigma_{cbc} = \frac{30}{3} = 10\ N/mm^2$

from IS 3370 (part II) page 7.

Direct tension for $M_{30} = 1.5\ N/mm^2$.

$\therefore \sigma_{ct} = 1.5\ N/mm^2$

From IS 3370 (part II) page 8,

$\sigma_{st} = 150\ N/mm^2$. (on face away from liquid. for members less than 225mm)

Design constants.

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

$k = \frac{1}{1 + \frac{\sigma_{st}}{m\sigma_{cbc}}} = \frac{1}{1 + \frac{150}{9.33 \times 10}} = 0.383$

$j = 1 - \frac{k}{3} = 1 - \frac{0.383}{3} = 0.872$

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

$= \frac{1}{2} \times 10 \times 0.872 \times 0.383 = 1.67\ Nmm$

Assuming the wall to be 200mm thick.

$t = 200mm$

$H = 4m$

$D = 7m.$

$\frac{H^2}{Dt} = \frac{(4 \times 10^3)^2}{(7 \times 10^3) \times 200} = 11.4$ ~~= 11.4~~

Using IS 3370 (part IV) table 10 (page 36) for moments in cylindrical wall fixed at base and free at top subjected to triangular load

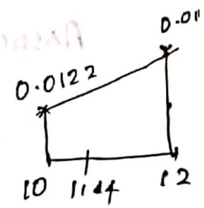
Maximum moment coefficient at the bottom of wall =

$= \left[0.0104 + \frac{(0.0122 - 0.0104) \times 0.6}{2}\right]$

$= -0.01094$ (maximum moment at bottom as it act like a cantilever i.e. at 1.0H on table)

$\frac{H^2}{Dt} = 4a,$

$\frac{H^2}{Dt}$	1.0 H.
10.0	-0.0122
12.0	-0.0104
11.4	?



$12 - 10 = -0.0104 - -0.0122$

$11.4 - 10 = x.$

coefficient = ~~0.0117~~ -0.01094

Maximum negative moment at the bottom of the wall = coefficient × γH^3

$= -0.01094 \times 4^3 \times \gamma$

(wt of water $(9.81\,kN/m^3 \approx 10\,kN/m^3)$; $1\,m^3$ of water = 1000 kg $= \frac{1000 \times 10}{1000} = 10\,kN/m^3$)

Taking $\gamma = 10\,kN/m^3$

Maximum negative moment $= -0.01094 \times 4^3 \times 10$

$= -7.0016\,kNm$ per m height of wall.

Thickness required $t = \sqrt{\frac{M}{R\,b}}$

$= \sqrt{\frac{7 \times 10^6}{1.67 \times 1000}} = 0.0647$

$= 64.74\,mm$

$\simeq 65\,mm$

Assuming an effective cover of 50mm

Total t required $= 65 + 50 = 115\,mm < 200\,mm$

Hence it is safe.

Maximum hoop tension (T)

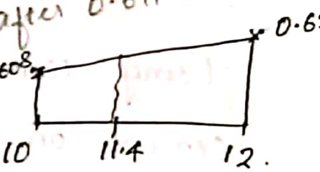
Using 3370 part(IV) table 9 (page 35)

Maximum hoop tension occurs at 0.6H

(0.6H is selected as value of hoop tension increases from 0H to 0.6H and after 0.6H it decreases)

Here $\frac{H^2}{Dt} = 11.4$.

$\frac{H^2}{Dt}$	0.6H
10.0	0.608
12.0	0.628
11.4	?



$\frac{12-10}{11.4-10} = \frac{0.628-0.608}{x}$

Hoop tension coefficient = 0.622.

Maximum hoop tension (T) = coefficient × $\gamma H R$ $\left\{ R = \frac{D}{2} \right\}$

$= 0.622 \times 10 \times 4 \times \frac{7}{2}$

$= 87.08\,kN$

Area of steel required $= \frac{T}{\sigma_{st}} = \frac{87.08 \times 10^3}{150}$

$= 580.533\,mm^2$

$Ast_{min} = 0.35\%$ of cross-sectional area

$= \frac{0.35}{100} \times 1000 \times 200 = 700 mm^2$

Here $Ast_{min} > Ast_{req}$

Hence, provide $Ast = Ast_{min} = 700 mm^2$

Using 10mm diameter hoops and providing reinforcement on both faces;

Spacing required $= \frac{\frac{\pi}{4} \times (10)^2 \times 1000}{700}$

$= 112.199$ mm.

∴ Providing 10mm diameter hoops at 110mm c/c upto a height of 0.3H from top (say 1.2m) and above this half of the bars can be curtailed as the hoop tension becomes almost half of the maximum value.

$\sigma'_{ct} = \frac{T}{1000t + (m-1) Ast}$.

$Ast_{prov} = \frac{\frac{\pi}{4} \times (10)^2 \times 1000}{110} = 713.99 mm^2 \approx 714 mm^2$

σ'_{ct} (Actual tensile stress in concrete due to hoop tension) $= \frac{T}{1000t + (m-1) Ast} = \frac{87.08 \times 10^3}{1000 \times 200 + (9.33-1) 714}$.

$= 0.422 N/mm^2 < 1.25 N/mm^2$

Hence it is safe.

Design for moments.

Maximum negative moment 7 kNm occurs at the base of the wall.

$Ast = \frac{M}{\sigma_{st} \cdot j \cdot d}$ [Assume 50mm effective cover. $D = t = 200mm$]

$= \frac{7 \times 10^6}{150 \times j \cdot d}$

$\therefore d = 200 - 50 = 150mm$

$Ast = \frac{7 \times 10^6}{150 \times 0.87 \times 150} = 357.59 mm^2$

$Ast_{min} = 0.35\%$ of cross-sectional area

$= 700 mm^2$

$Ast_{req} < Ast_{min}$

Hence provide $Ast = Ast_{min} = 700 mm^2$

Using 10mm diameter bars,

$$\text{Spacing} = \frac{\frac{\pi}{4} \times (10)^2 \times 1000}{700} = \underline{112.199 \text{ mm}}$$

Provide 10mm diameter bars @ 110mm c/c on the inner face as vertical steel at the bottom of the wall. These are required for a height of 1m above the bottom only. Half of the bars we can curtail at a height of 1m.

Development length (ld)

$$l_d = \frac{\phi \times \sigma_{st}}{4 \tau_{bd}} = \frac{150 \times 10}{4 \times 1.5 \times 1.6}$$

τ_{bd} value can be obtained from IS 456–2000 page 42

$$= \underline{156.25 \text{ mm}} < 1m.$$

Hence ok.

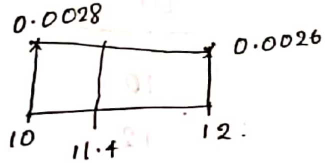
Reinforcement is provided on the inner face under −ve BM and for +ve BM reinforcement is provided on the outer face

Positive moment is, causing tension on the outer face is maximum at 0.7H

ie, 2.8m from the bottom of the wall.

Refer table 10 IS 3370 (part IV)

$\frac{H^2}{Dt}$	$0.8H$
10	0.0028
12	0.0026
11.4	?



$12 - 10 = 0.0026 - 0.0028$

$11.4 - 10 = x$.

moment coefficient $= \underline{0.00266}$

$$\text{Moment} = \text{coefficient} \times \gamma \times H^3$$
$$= 0.00266 \times 10 \times 4^3$$
$$= \underline{1.7024 \text{ KNm}}.$$

Hence provide minimum steel at 0.35% = $\underline{700 mm^2}$.

Assume 10mm diameter bars.

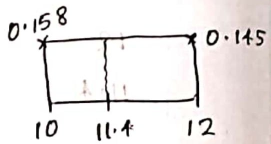
Spacing $= \underline{112.199 \text{ mm}}$

Provide 10mm diameter bars @ 110mm c/c on the outer face as vertical steel

Check for shear. [Page 37, IS 3370 (part IV) table 1]

Design shear force =

$\frac{H^2}{Dt}$	Triangular load fixed base
10	0.158
12	0.145
11.4	?



12-10 = 0.145 - 0.158

11.4-10 = x

Coefficient = 0.1489

Shear force = coefficient × γH^2 for triangular load

= 0.1489 × 10 × 4^2

= 23.824 KN.

Nominal shear stress $\tau_v = \frac{V_u}{bd}$

$= \frac{23.824 \times 10^3}{1000 \times 150}$

= 0.1588 N/mm²

(Page 84, table 23, IS-456-2000, working stress method)

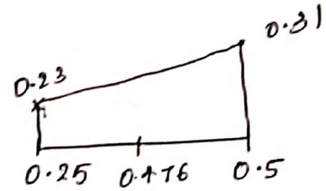
τ_v $\%$ $\frac{}{}$ $P_t = \frac{100 A_{st}}{bd} = \frac{100 \times 709.9}{1000 \times 150} = 0.476$

τ_c =

0.25 - 0.23

0.5 - 0.31

0.476 - ?



0.5 - 0.25 = 0.31 - 0.23

0.476 - 0.25 = x

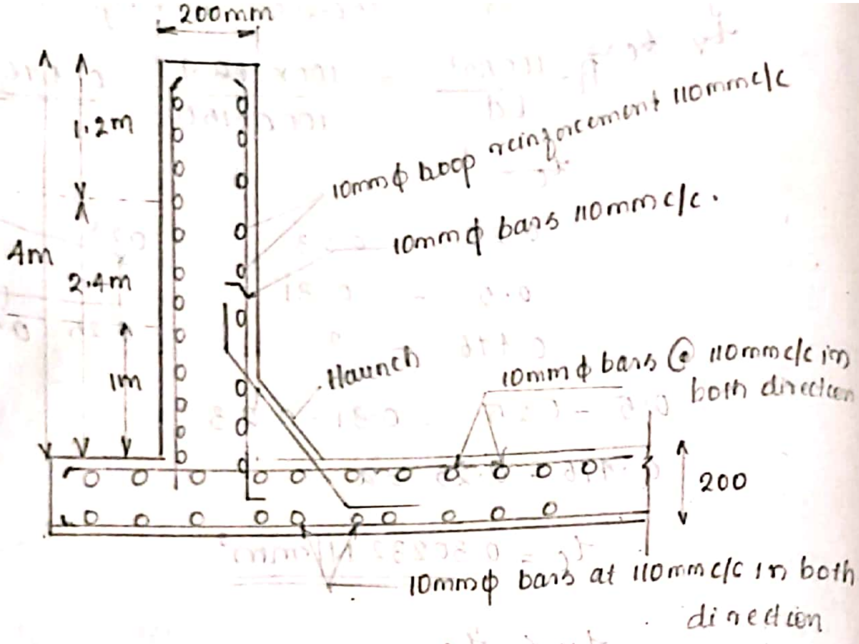
τ_c = 0.30232 N/mm²

$\tau_v < \tau_c$.

∴ Shear of design is not necessary

Base slab.

Base slab is provided as 200mm thick with minimum steel as 700mm² in each direction. Hence providing 10mm ϕ bars @ 110mm c/c in both directions at top and bottom face.



5 Design a circular water tank with fixed base resting on the ground with a capacity of 500 kl. The depth of water in tank is 5 m and a free board of 200mm is to be provided. Use M_{30} concrete and Fe 415 steel. Use IS code method.

Given.

Capacity of tank = $500 \times 10^3 l = 500 m^3$

Depth of water = 5m

Free board = 200mm

For M_{30} concrete, $\sigma_{cbc} = \frac{30}{3} = 10 N/mm^2$

$\sigma_{ct} = 1.5 N/mm^2$

$\sigma_{st} = 150 N/mm^2$

$H = 5 + 0.2$ (free board) $= 5.2m$.

Design constants

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

$k = \frac{1}{1 + \frac{\sigma_{st}}{m\sigma_{cbc}}} = \frac{1}{1 + \frac{150}{9.33 \times 10}} = 0.383$

$j = 1 - \frac{k}{3} = 1 - \frac{0.383}{3} = 0.872$.

$R = \frac{1}{2} \times \sigma_{cbc} \times k \times j = \frac{1}{2} \times 10 \times 0.383 \times 0.872$

$= 1.669 \simeq 1.67$ Nmm

Diameter.

$\frac{\pi}{4} D^2 \times 5 = 500$

$D = 11.283 m$

$D = 11.28 m$.

Hence taking $D = 11.3m$.

Assuming thickness of wall as 150mm

$\frac{H^2}{Dt} = \frac{(5.2 \times 10^3)^2}{11.3 \times 10^3 \times 150} = 15.95 \simeq 16.$

Referring IS 3370 (Part IV) table 9, 10 and 11

Design values.

i) Maximum BM coefficient value from table 10

For $\frac{H^2}{Dt} = 16$ and 1.0H

Coefficient = -0.0079 at bottom of wall

[at 1.0H, triangular load]

ii) Maximum shear force coefficient from table 11

For $\frac{H^2}{Dt} = 16$

Coefficient $= 0.127$

iii) Maximum hoop tension coefficient

Coefficient $= 0.687$ (at 0.7H)

Design Bending moment M

$M = \text{coefficient} \times \gamma H^3$ → ht of water tank

$= -0.0079 \times 10 \times 5^3$

$=$ ~~11.108 KNm~~ 9.875 KNm

Design shear force.

$F = \text{coefficient} \times \gamma H^2$

$= 0.127 \times 10 \times 5^2 = 31.75$ KN

Design hoop tension.

$T = \text{coefficient} \times \gamma H \times \frac{D}{2}$

$= 0.687 \times 10 \times 5 \times \frac{11.3}{2} = 194.07$ KN.

At 0.3H ie,

$0.3 \times 5 = 1.5m$, hoop tension

Coefficient $= 0.304$ (for 0.3H, $\frac{H^2}{Dt}$).

$T =$ ~~65.8~~ $0.304 \times 10 \times 5 \times \frac{11.3}{2} = 85.88$ KN

which is less than half of the maximum hoop tension value.

Depth or thickness required.

$d_{req} = \sqrt{\frac{M}{Rb}} = \sqrt{\frac{9.875 \times 10^6}{1000 \times 1.67}}$

$= 76.89$ mm

Total thickness provided $= 150$ mm

Assume 30mm effective cover

$d_{provide} = 150 - 30$

$= 120mm > 76.89\ mm$

Hence OK.

Area of steel for BM.

$$A_{st} = \frac{M}{\sigma_{st}\, j \times d}$$

$$= \frac{9.875 \times 10^6}{150 \times 0.872 \times 120} = 629.14\ mm^2$$

$$A_{st\,min} = \frac{0.35}{100} \times \text{Cross sectional area}$$

$$= \frac{0.35}{100} \times 150 \times 1000$$

$$= 525mm^2$$

$A_{st\,req} > A_{st\,min}$.

$\therefore A_{st\,prov} = 629.14\ mm^2$

Using 12mm diameter bars,

$$\text{Spacing required} = \frac{\frac{\pi}{4} \times (12)^2 \times 1000}{629.14} = 179.76\ mm$$

Hence provide 12mm diameter bars at 175mm c/c at inner face in vertical direction curtailing half of the bars at 1m from ground and continuing the rest.

i.e,

12mm diameter @ 350mm (175×2) c/c till top.

Area of steel for hoop tension.

$T = 194.07\ kN.$

$$A_{st} = \frac{T}{\sigma_{st}} = \frac{194.07 \times 10^3}{150} = 1293.8\ mm^2$$

Using 16mm (~~40mm~~) diameter bars

$$\text{Spacing} = \frac{\frac{\pi}{4} \times (16)^2 \times 1000}{1293.8} = 155.4\ mm$$

Hence using 16mm diameter bars at 155mm c/c from base upto a height of 2.5m $\left(\frac{5m}{2}\right)$ from base and providing 16mm diameter hoops at 310mm (155×2) c/c.

Check for permissible direct tensile stress in concrete.

$$\sigma'_{ct} = \frac{T}{1000t + (m-1)A_{st}}$$

$$A_{st\,prov} = \frac{\frac{\pi}{4} \times (16)^2 \times 1000}{155} = 1297.173\ mm^2$$

$$\sigma_{ct}' = \frac{194.07\times10^3}{1000\times150+(9.33-1)\,1297.173}$$

$= 1.2 < 1.5$

Hence OK.

Maximum positive moment.

For $\frac{H^2}{Dt} = 16$, maximum +ve coefficient at 0.8H

Coefficient = 0.0019

Positive Moment $= 0.0019\times5^3\times10$.

$= 2.375$ kNm.

$A_{st} = \sqrt{\;\;}$

$$A_{st} = \frac{M}{\sigma_{st}\times j\times d}$$

$$= \frac{2.375\times10^6}{150\times0.872\times120}$$

$= 151.312\ mm^2$

$A_{st\,req} < A_{st\,min}$

$A_{st\,provided} = A_{st\,min} = 525\ mm^2$

Assume 12mm diameter bars,

$$\text{Spacing} = \frac{\frac{\pi}{4}\times(12)^2\times1000}{525} = 215.423\ mm$$

Hence provide 12mm diameter bars @ 215mm c/c in vertical direction at outer faces.

Check for shear.

Nominal shear stress $= \frac{V}{bd}$

$$\tau_v = \frac{31.75\times10^3}{1000\times120}$$

$= 0.26\ N/mm^2$

Permissible shear stress in concrete τ_c,

$$\frac{100A_{st}}{bd} = \frac{100\times525}{1000\times120}$$

$= 0.4375$

Refer table 23, page 84 IS456 – 2000

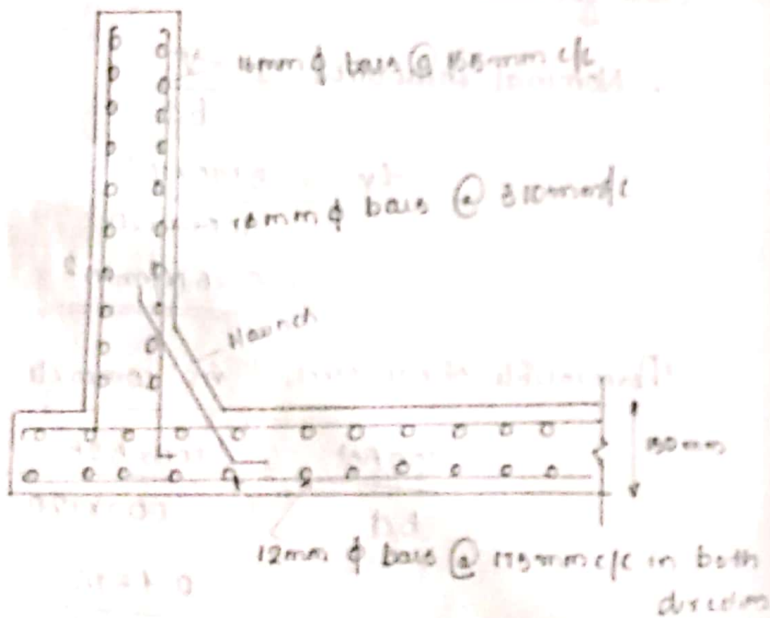
$\tau_c = 0.287\ N/mm^2$

$\tau_v < \tau_c$

∴ Shear design is not necessary.

Base slab

Base slab is provided as 150mm thick with minimum steel as 525mm² in each direction. Hence providing 12mm diameter bars @ 175mm c/c in both direction at the top



Design of elevated circular water tank

6. Refer the above problem

Depth of water = 5m.

Diameter of tank = 11.3m

All design same as that of question 5 except base slab

Design of base slab

- The base slab is cast monolithic with the tank wall and hence it is assumed to be fixed at the edges.
- The base slab can be designed as a circular slab fixed along the edges and subjected to udl on its entire surface.
- Assume the thickness of slab = 500mm

Pressure due to weight of water caused by base slab = $5 \times 1 \times 10 = 50\ kN/m^2$

Pressure due to self weight of base slab = $0.5 \times 1 \times 25$
$= 12.5\ kN/m^2$

Total pressure exerted on the base slab $= 62.5\ kN/m^2$

i) Circumferential moment in the circular slab

a) At centre,

$M = +\frac{Wr^2}{16}$

~~= 62.5×~~

W = Total weight , r = radius.

$M = +\frac{Wr^2}{16}$ $r = \frac{11.3}{2} = 5.65\ m$

$= \frac{62.5 \times 5.65^2}{16} = 124.69\ kNm$

b) At edge, M = 0

ii) Radial moment in the circular slab.

a) At centre,

$M = \frac{Wr^2}{16}$

$= \frac{62.5 \times 5.65^2}{16} = 124.69\ kNm$

b) At edge,

$M = -\frac{2}{16} Wr^2$

$= -\frac{2}{16} \times 62.5 \times 5.65^2 = -249.39\ kNm$

iii) Radial shear force in the circular slab.

Radial shear force $= 0.5\,Wr = 0.5 \times 62.5 \times 5.65$

$= 176.56\ kN$

Here the maximum BM = 249.39 kNm.

Check for depth.

$d_{req} = \sqrt{\frac{M}{Rb}}$

$= \sqrt{\frac{249.39 \times 10^6}{1.67 \times 1000}} = 386.439\ mm$

Hence,

Providing a base slab of 450mm depth with an effective cover of 50mm. 386.439 < 450mm , hence OK.

Steel for negative BM.

$M = -249.39\ kNm \approx 25$

$A_{st} = \frac{M}{\sigma_{st} \times j \times d}$

$= \frac{250 \times 10^6}{150 \times 0.872 \times 450} = 4247.366\ mm^2$.

Providing 30mm diameter bars

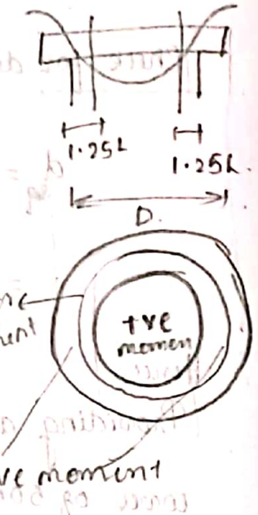
Spacing required $= \frac{\frac{\pi}{4} \times (30)^2 \times 1000}{4247.366}$

$= 166.422\ mm$

Hence providing 30mm ϕ bars radially @ 165 mm c/c at the edge ~~at~~ upto a distance of diameter

$0.25L = 0.25 \times 11.3 = \underline{2.825m} \simeq 3m$

Three rings of 30mm ϕ are provided to support and the



Steel for positive BM.

$M = 125\ kNm$.

$$A_{st} = \frac{M}{\sigma_{st}\, j \times d}$$

$$= \frac{125 \times 10^6}{150 \times 450 \times 0.872} = \underline{2123.683\ mm^2}$$

Use 20mm ϕ bars

$$\text{Spacing} = \frac{\frac{\pi}{4} \times (20)^2 \times 1000}{2123.683} = \underline{147.93\ mm}$$

$$\simeq \underline{145mm}$$

Hence providing 20mm ϕ bars @ 145mm c/c in both direction as a mesh at the bottom face of the slab.

Check for shear.

$F = V = 176.56\ kN$.

$$\tau_v = \frac{V}{bd} = \frac{176.56 \times 10^3}{1000 \times 450} = \underline{0.3923\ N/mm^2}$$

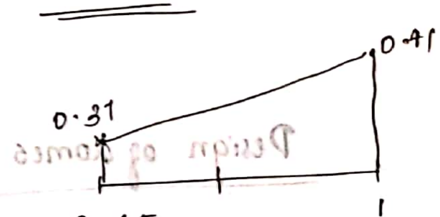
$$P_t = \frac{A_{st} \times 100}{bd} \qquad A_{st\,prov} = \frac{\frac{\pi}{4} \times (30)^2 \times 1000}{165}$$

$$= \underline{4283.989\ mm^2}$$

Consider Ast at support as maximum shear occurs at support (Ast corresponding to -ve BM)

$$P_t = \frac{4283.989 \times 100}{450 \times 1000} = \underline{0.95199}$$

0.75	0.37
1.00	0.41
0.95199	?



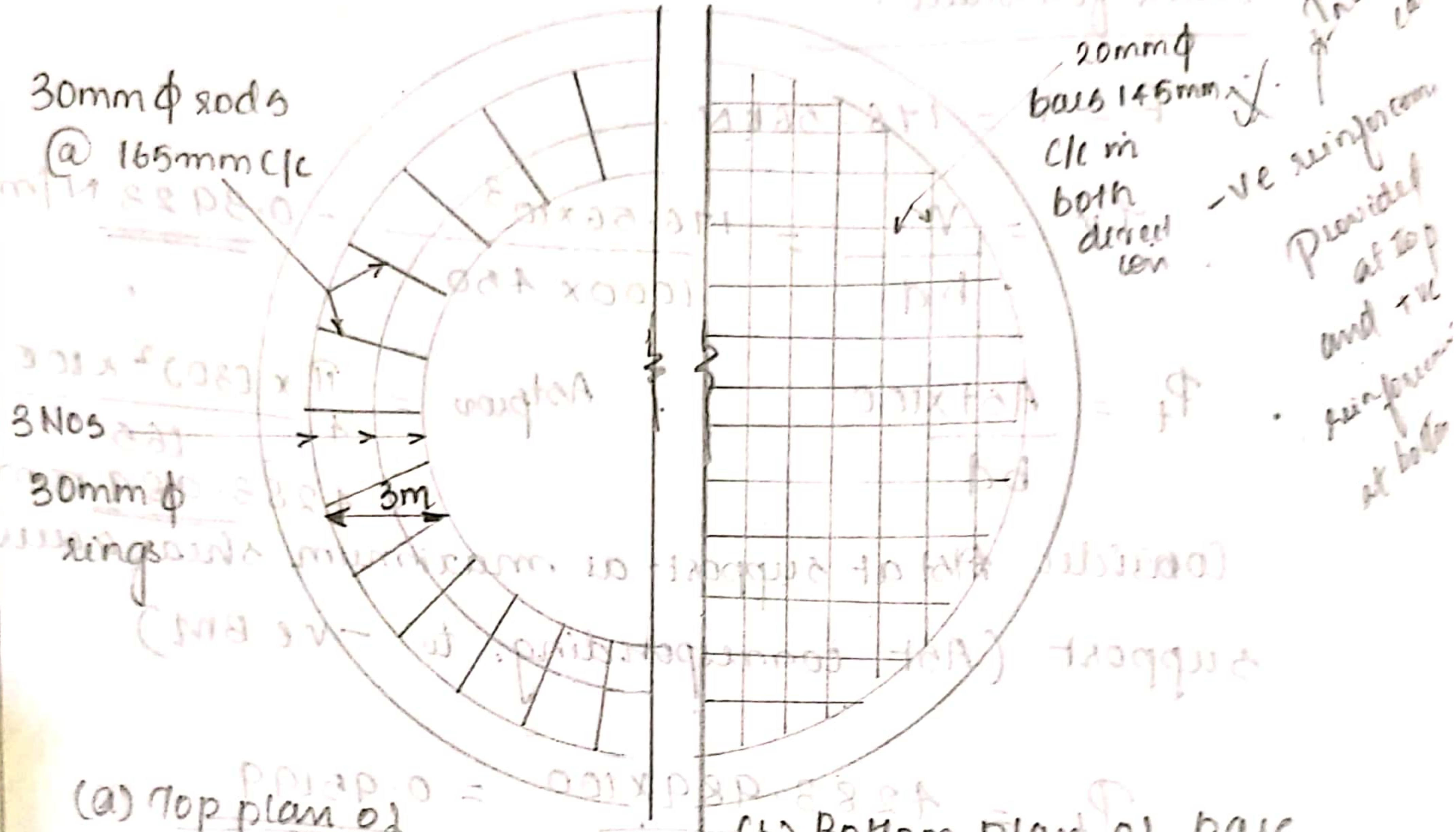
$1 - 0.75 = 0.41 - 0.37$

$0.95199 - 0.75 = x$

$$\tau_c = \underline{0.4023\ N/mm^2}$$

$\tau_v < \tau_c$.

$\therefore$ Shear design is not required.



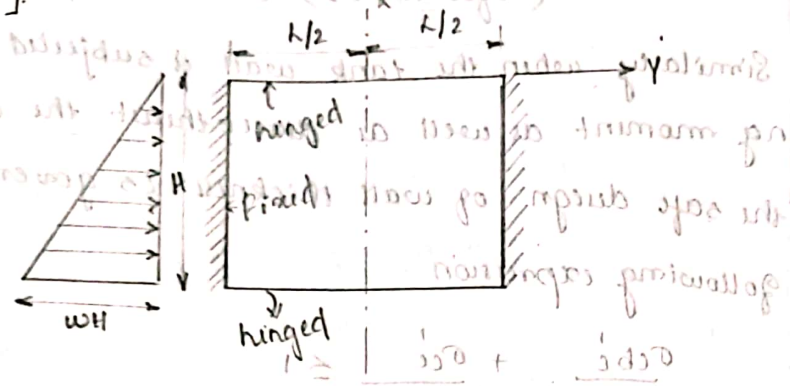
(a) Top plan of base section

(b) Bottom plan of base section

Design of rectangular water tank (IS 3370 (part IV))

- The exact analysis is based on elastic theory.
- The resulting differential equation are very difficult to be solved directly.
- IS 3370 (part IV) gives the tables for moments and shear forces in walls for certain edge conditions.
- Moment coefficients for individual panels considered fixed along vertical edges, but having different

edge conditions at top and bottom are given in table 1, table 1, table 2 and table 3 in IS 3370 part IV [page no 14, 15 and 16].



Horizontal moment $M_H = M_y \times w \times H^3$

Vertical moment $M_V = M_x \times w \times H^3$

Shear force coefficients given in table 7 and 8. Pg 33 and 34. IS 3370 - Part IV

Shear force = coefficient $\times wH^2$

When the tank wall is subjected to both bending moments as well as direct tension, the criterion for the safe design of wall thickness is governed by following expression

$$\frac{\sigma_{cbt}'}{\sigma_{cbt}} + \frac{\sigma_{ct}'}{\sigma_{ct}} \leq 1$$

IS 3370 Part II page 11

where σ_{cbt}' = calculated direct tensile stress in concrete

σ_{cbt} = Permissible direct tensile stress in concrete (Refer table I) (IS 3370 - part II page 7)

Similarly when the tank wall is subjected to both bending moment as well as direct thrust the criterion for the safe design of wall thickness is governed by following expression.

$$\frac{\sigma_{cbc}'}{\sigma_{cbc}} + \frac{\sigma_{cc}'}{\sigma_{cc}} \leq 1$$

where, σ_{cbc}' = calculated bending compressive stress in concrete

σ_{cbc} = permissible bending compressive stress in concrete.

σ_{cc}' = calculated direct compressive stress in concrete.

σ_{cc} = permissible direct compressive stress in concrete.

10 A rectangular water tank 4.5m long, 2.25 wide and 2.25m height has its walls rigidly jointed at the verticals edges and pin jointed at their horizontal edges. Design a tank if it is supported on all sides under the wall. Use M_{20} concrete and mild steel reinforcement.

Given data.

Length of the tank = 4.5m.

Width of the tank = 2.25 m

Height of the tank = 2.25 m

Grade of concrete = 20N/mm²

Grade of steel = Fe 250

Design constants $\sigma_{cbc} = \frac{20}{3} = 7N/mm^2$

$$m = \frac{280}{3\sigma_{cbc}} = 13.33 N/mm^2$$

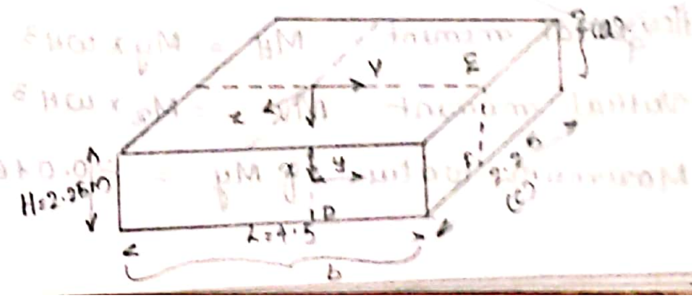
Taking σ_{st} = 115N/mm² (given in table 2 IS3370-part2)

We have $K = \frac{1}{1+\frac{\sigma_{st}}{m\sigma_{cbc}}} = \frac{1}{1+\frac{115}{13.33\times7}}$

$K = 0.447$

$j = 1 - \frac{K}{3} = 0.8506$

$R = \frac{1}{2} \times \sigma_{cbc} \times K \times j = 1.33$



Moment and shear.

The length of the tank (b) = 4.5 m

Height of the tank (a) = 2.25 m

Width of the tank (c) = 2.25 m

[Page no: 14, IS 3370 Part IV table 1.]

Moment coefficient for individual wall panel top and bottom hinged, vertical edges fixed.

Page 30, table 6

$\frac{b}{a} = \frac{4.5}{2.25} = 2m$

$\frac{c}{a} = \frac{2.25}{2.25} = 1$

x/a	y = 0 Line CD		y = b/2 Line AB		z = 0 Line EF	
	Mx	My	Mx	My	Mx	My
1/4	+0.026	+0.013	-0.006	-0.028	+0.002	0.008
1/2	+0.044	0.020	-0.009	-0.046	0.004	+0.014
3/4	+0.041	+0.016	-0.009	~~+0.013~~ -0.044	+0.013	+0.013

Horizontal moment $M_H = M_y \times wH^3$

Vertical moment $M_V = M_x \times wH^3$

Maximum value of My = -0.046.

Hence maximum moment in horizontal direction occur in the mid point of edge AB.

Maximum value of Mx = 0.044

Hence ~~value of Mx~~ maximum moment in vertical direction occurs in the mid point of edge CD.

Specific weight of water $w = 9800 N/m^3$.

Maximum moment M_H at edge AB $= -0.046 \times 9800 \times (2.25)^3$

$= -5135$ Nm

i.e, hogging.

Maximum moment M_H at EF $= 0.014 \times 9800 \times 2.25^3$

$= 1562.79$ Nm

i.e, sagging.

Maximum moment M_H at CD at mid point

$= 0.020 \times 9800 \times 2.25^3$

$= 2232.56$ Nm (sagging)

Maximum moment M_V at CD $= 0.044 \times 9800 \times 2.25^3$

$= 4911.63$ Nm (sagging)

Maximum ~~mont~~ moment M_V at EF (at lower corner)

$= 0.013 \times 9800 \times (2.25)^3$

$= 1451.16$ Nm (sagging)

- The horizontal moment M_H in the wall will be combined with the direct tension due to shear force on adjacent wall.
- Similarly, vertical moment M_V in the wall will be combined with direct thrust due to weight of roof slab and wall itself, this effect will be of minor importance.

[From table 7, IS-3370 part IV Page 33]

(Shear at edges of wall panel hinged at top and bottom)

The shear force at mid span of fixed side edge AB of long wall ($b/a = 2.00$)

$= 0.3604\, wa^2$

$= 0.3604 \times 9800 \times 2.25^2$

$= 17880.345$ N.

Similarly shear force at ~~mid span~~ mid point of fixed side edge AB of short wall ($c/a = 1$, or $b/a = 1$)

$= + 0.2582\, wa^2$

$= 0.2582 \times 9800 \times 2.25^2$

$= 12809.94$ N.

Design of thickness of tank walls.

The thickness of wall is governed by moment M_H and SF at mid point of AB.

M_H at AB = 5135 Nm

Shear force = 17880.345 N (long wall)

Thickness of wall be 150 mm

The criterions for the safe design is

$$\frac{\sigma'_{cbt}}{\sigma_{cbt}} + \frac{\sigma'_{ct}}{\sigma_{ct}} \leq 1$$

where,

σ'_{cbt} = calculated bending tensile stress in concrete

$= M/Z$

$Z = \frac{bd^2}{6}$, ~~$\frac{5135 \times 1000 \times 6}{1000 \times (150)^2} = \sigma'_{cbt}$~~

$\sigma'_{cbt} = \frac{5135 \times 1000 \times 6}{1000 \times (150)^2} = 1.37$ N/mm²

σ_{cbt} = Permissible bending tensile stress in concrete

$= 1.7$ N/mm² (table 1, IS 3370 Part 2).

[Page no: 7 - Tension due to bending]

σ_{ct}' = calculated direct tensile stress in concrete

$$= \frac{\text{Load}}{\text{area}} = \frac{17880}{1000 \times 150} = 0.119\,N/mm^2$$

σ_{ct} = Permissible direct tensile stress in concrete

$= 1.2\,N/mm^2$ (Table 1, page 7, IS 3370 part 2)

$$\frac{\sigma_{cbt}'}{\sigma_{cbt}} + \frac{\sigma_{ct}'}{\sigma_{ct}} \leq 1$$

$$\frac{1.37}{1.7} + \frac{0.19}{1.2} = 0.905 < 1$$, Hence safe.

- Thus keep total thickness T = 150mm and an effective thickness of 120mm.

Assume effective cover = 30mm

Depth of neutral axis $= k \times d$

$= 0.447 \times 120 = 53.64\,mm$

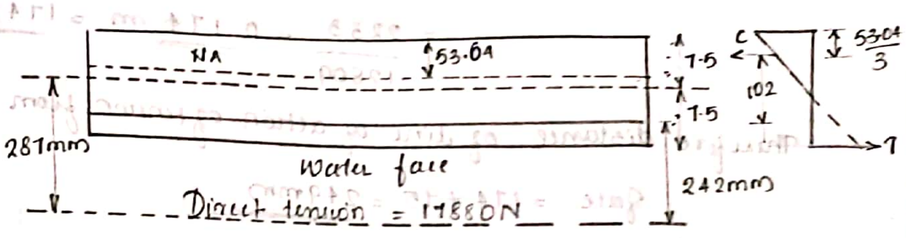
Reinforcement in horizontal direction.

Eccentricity of tensile force $= \frac{\text{Moment}}{\text{load}} = \frac{5135}{17880.34}$

$= 0.287m = 287mm$

This eccentricity is from the centre of the thickness of the section

Eccentricity of the tensile force measured from the centre of the steel will be $= 287 - 75 + 30 = 242\,mm$



Let the area of tensile steel = Ast

To find its value, take moment about the C.G of the compression zone.

Distance of the reinforcement from the C.G of the compression zone $= 120 - \frac{53.04}{3} = 102.32\,mm$

Therefore $17880\,(242 + 102.32) = Ast \times 115 \times 102$
(Compressive force x distance) (stress x area)

$Ast = 524\,mm^2$

Assume 10mm diameter bars 145mm c/c on water face.

Maximum sagging moment in horizontal direction occurs at mid point of CD and its value is 2233Nm

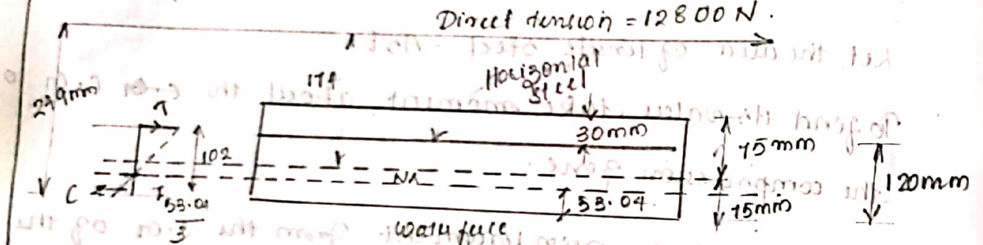
The direct tension at this point = Shear force at mid point of vertical edge AB of short wall

= 12809 N.

Eccentricity of tension = $\frac{\text{Moment}}{\text{load}}$

$= \frac{2233}{12809} = 0.174\ m = 174\ mm$

Therefore distance of line of action of tension from water face $= 174 + 75 = 249\ mm$



Taking moment about the centre of compression zone.

$A_{st} \times 115 \times 102 = 12809.9\left(249 - \frac{53.04}{3}\right) = 252.39\ mm^2$

Minimum area (A_{st} min) = 0.3% cross sectional area

$= \frac{0.3}{100} \times 1000 \times 150 = 450\ mm^2$

Provide A_{st}min $= 450\ mm^2$

Assume 8mm diameter bars,

Spacing $= \frac{\frac{\pi}{4} \times 8^2 \times 1000}{450} = 111.70\ mm$

So provide 8mm diameter bars @ 110mm c/c.

The horizontal BM (sagging) at the line EF of the short wall is 1562 Nm but the direct tension is 17880.345 N.

Hence provide the same reinforcement i.e, 8mm diameter bars @ 110mm c/c at the outer face.

Shear check.

Maximum shear stress = $\frac{\text{Shear force}}{\text{Area}} = \frac{17880.345}{1000 \times 120}$

$= 0.149\ N/mm^2$

Permissible shear stress in concrete τ_c.

Reinforcement in vertical direction.

- The BM, M_v in vertical direction comprise with the weight direct compression due to weight of wall and weight of roof.
- Let thickness of roof slab be 10cm = 0.1m.
- Assuming unit weight of concrete as $25000\ N/m^2$
- Dead load transferred to wall $= \left(\frac{2.25}{2} + 0.15\right) \times 0.1 \times 1 \times 25000$

$= 3188\ N/m$

- Dead weight of wall upto its mid height

$= \frac{2.25}{2} \times 0.15 \times 1 \times 25000 = 4219\ N/m$

Vertical thrust in wall @ its mid height = 3188 + 4219

= 7407 N/m

Bending moment in vertical direction at mid point

of CD = 4912 Nm (sagging)

Therefore, eccentricity of thrust in vertical direction

in long wall $= \frac{Moment}{force} = \frac{4912}{7409} = 0.663 = 663mm$

Its distance from water face = 663 − 75 = 588mm

Let the cover to the centre of steel be 20mm

Effective depth = 150 − 20 = 130mm

Depth of neutral axis = 130 × k = 130 × 0.4402

= 57.5 mm

Taking moment about the C.G of compression area

$= Ast \times 115 \times 111 = 7409\left(615 + \frac{57.5}{3}\right)$

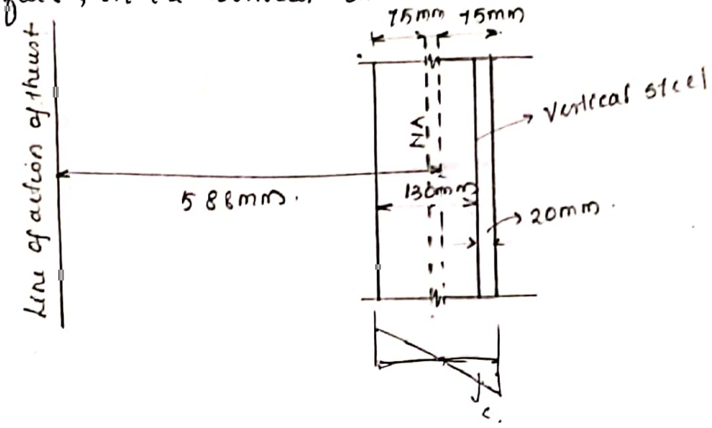
Ast = 368 mm²

Minimum area of steel @ 0.3%

$= \frac{0.3}{100} \times (1000 \times 150)$

= 450mm²

Hence provide 8mm diameter bars. 110mm c/c at the outer face, in the vertical direction.



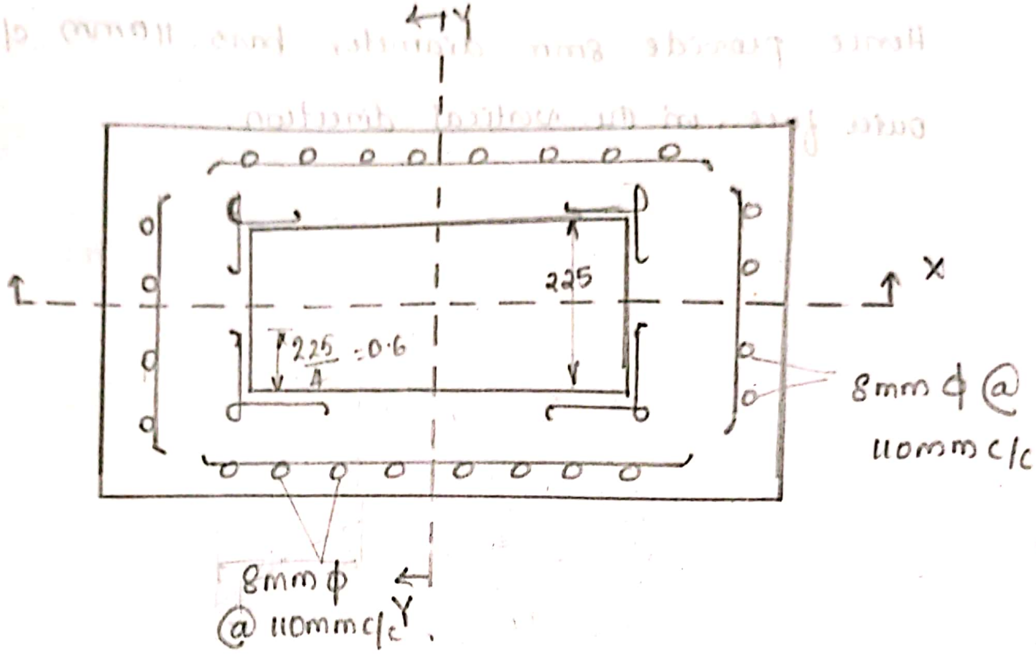
The bending moment Mv in the vertical direction in short wall is 1452 Nm (sagging) against 4912 Nm in the long wall.

Hence provide minimum area of steel @ 0.3% = 450mm²

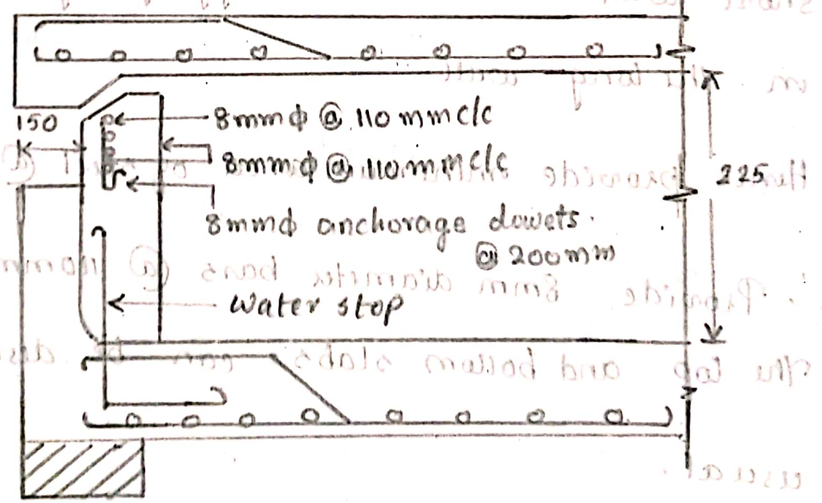
∴ Provide 8mm diameter bars @ 110mm c/c.

The top and bottom slabs can be designed as usual.

Provide Astmin = 450mm²



Horizontal section at mid height



Vertical section @ XX & YY