6. Design of Water Tanks

(For class held on 23rd, 24th, 30th April 7th and 8th May 07)

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6.1 Introduction:

Storage tanks are built for storing water, liquid petroleum, petroleum products and similar liquids. Analysis and design of such tanks are independent of chemical nature of product. They are designed as crack free structures to eliminate any leakage. Adequate cover to reinforcement is necessary to prevent corrosion. In order to avoid leakage and to provide higher strength concrete of grade M20 and above is recommended for liquid retaining structures.

To achieve imperviousness of concrete, higher density of concrete should be achieved. Permeability of concrete is directly proportional to water cement ratio. Proper compaction using vibrators should be done to achieve imperviousness. Cement content ranging from 330 Kg/m^3 to 530 Kg/m^3 is recommended in order to keep shrinkage low.

The leakage is more with higher liquid head and it has been observed that water head up to 15 m does not cause leakage problem. Use of high strength deformed bars of grade Fe415 are recommended for the construction of liquid retaining structures. However mild steel bars are also used. Correct placing of reinforcement, use of small sized and use of deformed bars lead to a diffused distribution of cracks. A crack width of 0.1mm has been accepted as permissible value in liquid retaining structures.

While designing liquid retaining structures recommendation of "Code of Practice for the storage of Liquids- IS3370 (Part I to IV)" should be considered. Fractured strength of concrete is computed using the formula given in clause 6.2.2 of IS 456 - 2000 ie., $f_{cr}=0.7\sqrt{f_{ck}}$ MPa. This code does not specify the permissible stresses in concrete for resistance to cracking. However earlier version of this code published in 1964 recommends permissible value as $\sigma_{cat}= 0.27\sqrt{f_{ck}}$ for direct tension and $\sigma_{cbt}= 0.37\sqrt{f_{ck}}$ for bending tensile strength.

Allowable stresses in reinforcing steel as per IS 3370 are

σ_{st}= 115 MPa for Mild steel (Fe250) and σ_{st}= 150 MPa for HYSD bars(Fe415)

In order to minimize cracking due to shrinkage and temperature, minimum reinforcement is recommended as:

i) For thickness ≤ 100 mm = 0.3 %

ii) For thickness ≥ 450 mm = 0.2%

iii) For thickness between 100 mm to 450 mm = varies linearly from 0.3% to 0.2%

For concrete thickness ≥ 225 mm, two layers of reinforcement be placed, one near water face and other away from water face.

Cover to reinforcement is greater of i) 25 mm, ii) Diameter of main bar.

In case of concrete cross section where the tension occurs on fibers away from the water face, then permissible stresses for steel to be used are same as in the analysis of other sections, ie., σ_{st}=140 MPa for Mild steel and σ_{st}=230 MPa for HYSD bars.

6.2 Introduction to Working Stress method:

In this method the concrete and steel are assumed to be elastic. At the worst combination of working loads, the stresses in materials are not exceeded beyond permissible stresses. The permissible stresses are found by using suitable factors of safety to material strengths. Permissible stresses for different grades of concrete and steel are given in Tables 21 and 22 respectively of IS456-2000.

The modular ratio 'm' of composite material ie., RCC is defined as the ratio of modulus of elasticity of steel to modulus of elasticity of concrete. But the code stipulate the value of 'm as $m = \dfrac{280}{3\sigma_{bc}}$, where σ_{bc} is the permissible stress in concrete in bending compression.

To develop equation for moment of resistance of singly reinforced beams, the linear strain and stress diagram are shown in Fig. 6.1

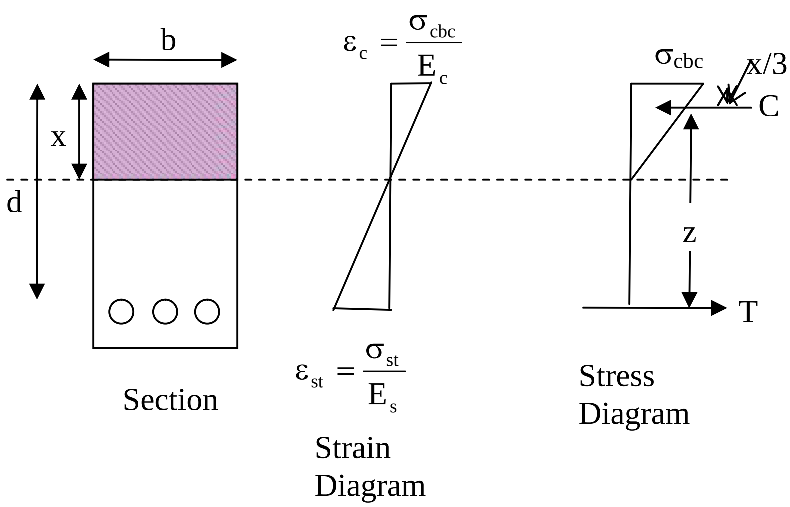


Fig. 6.1 Singly Reinforced Section

The neutral axis depth is obtained from strain diagram as

$$\frac{x}{d-x} = \frac{\sigma_{cbc}/E_c}{\sigma_{st}/E_s} = \frac{m\sigma_{cbc}}{\sigma_{st}} \text{ solving for x; } x = \left[\frac{m\sigma_{cbc}}{m\sigma_{cbc} + \sigma_{st}}\right] d = kd$$

where, $k = \left[\dfrac{m\sigma_{cbc}}{m\sigma_{cbc} + \sigma_{st}}\right]$, k is known as neutral axis constant

The lever arm z=d-x/3 = d-(kd/3)= d(1-k/3) = jd, where, j=1-k/3; j is known as lever arm constant

C= ½ σ_{cbc}bx; T= σ_{st} A_{st}

Moment of resistance M= C z = T z

Consider, M=C z = (½ σ_{cbc}bx) jd = (½ σ_{cbc}bkd) jd = (½ σ_{cbc}kj) bd^2 = Q_{bal} bd^2

Where, Q_{bal} is known as moment of resistance factor for balanced section.

Now consider M= T z = σ_{st} A_{st} jd;

$\therefore A_{st} = \dfrac{M}{\sigma_{st} jd}$; Let p_t be the percentage of steel expressed as

$$p_{tbal} = \frac{100A_{st}}{bd} = 100\frac{M}{\sigma_{st} jd}\frac{1}{bd} = \frac{50k\sigma_{cbc}}{\sigma_{st}}$$

Design constants for balanced section is given in table 6.1

Table 6.1 **Design constants**

Concrete Grade	Steel Grade	σ_{cbc}	σ_{st}	k	j	Q_{bal}	p_{tbal}
M20	Fe250	7	140	0.4	0.87	1.21	1.00
	Fe415	7	230	0.29	0.9	0.91	0.44
M25	Fe250	8.5	140	0.4	0.87	1.48	0.68
	Fe415	8.5	230	0.29	0.9	1.1	0.533

6.3 Liquid Retaining Members subjected to axial tension only:

When the member of a liquid retaining structure is subjected to axial tension only, the member is assumed to have sufficient reinforcement to resist all the tensile force and the concrete is assumed to be uncracked.

For analysis purpose 1m length of wall and thickness 't' is considered. The tension in the member is resisted only by steel and hence

$A_{st} = \dfrac{T}{\sigma_{st}}$ and $T \leq 1000\, t\, \sigma_{ct} + (m-1)A_{st}\, \sigma_{st}$ or $t \geq \dfrac{T}{1000\sigma_{ct}}\left[1-(m-1)\dfrac{\sigma_{ct}}{\sigma_{st}}\right]$

Minimum thickness of the member required is tabulate in table 6.2

Table 6.2 **Minimum thickness of members under direct tension (Uncracked condition)**

Grade of concrete	Thickness of members in mm for force T in N	
	Mild steel	HYSD
M20	T/1377	T/1331
M25	T/1465	T/1423
M30	T/1682	T/1636

6.4 Liquid Retaining Members subjected to Bending Moment only:

For the members subjected to BM only with the tension face in contact with water or for the members of thickness less than 225 mm, the compressive stress and tensile stresses should not exceed the value given in IS 3370. For the member of thickness more than 225 mm and for the face away from the liquid, this condition need not be satisfied and higher stress in steel may be allowed. The bending analysis is done for cracked and uncracked condition.

Cracked condition: The procedure of designing is same as in working stress method except that the stresses in steel are reduced. The design coefficients for these reduced stresses in steel is given in Table 6.3

Table 6.3 **Design constants for members in bending (Cracked condition)**

Concrete Grade	Steel Grade	σ_{cbc}	σ_{st}	k	j	Q_{bal}	p_{tbal}
For members less than 225 mm thickness and tension on liquid face							
M20	Fe250	7	115	0.445	0.851	1.33	1.36
	Fe415	7	150	0.384	0.872	1.17	0.98
For members more than 225 mm thickness and tension away from liquid face							
M20	Fe250	7	125	0.427	0.858	1.28	1.2
	Fe415	7	190	0.329	0.89	1.03	0.61

Uncracked condition: In this case, the whole section is assumed to resist the moment. Hence the maximum tensile stress in concrete should not be more than permissible value. The section is designed as a homogenous section.

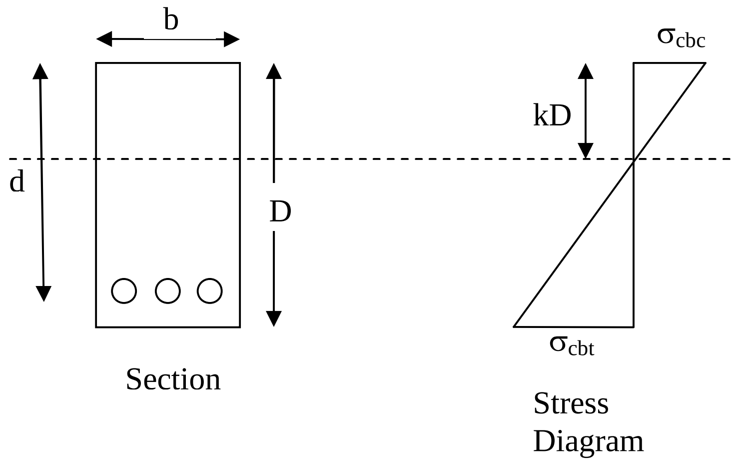


Fig. 6.1 Singly Reinforced Section

Taking moments of transformed areas about NA

b kD kD/2 = b (D-kD) (D-kD)/2 + (m-1) A_{st} (d-kD)

Substituting $A_{st} = p_t$ bD /100 and simplifying

$$k = \frac{100 + 2p_t \frac{d}{D}(m-1)}{200 + 2p_t(m-1)}$$

Moment of inertia $I_{xx}=bD^3/12 + bD\,(kD-D/2)^2 + (m-1)\,A_{st}\,(d-kD)^2$

substituting $A_{st} = p_t$ bD /100 and simplifying

$I_{xx}=(1/3 - k(1-k)+(d/D-k)^2\,(m-1)\,p_t/100)bD^3$

The moment of resistance may be expressed using Bernouli's equation

$$\frac{M}{I_{xx}} = \frac{\sigma_{cb}}{D - kD} = \frac{\sigma_{cbc}}{D(1-k)} \text{ and } M = \frac{\sigma_{cbt}\, I_{xx}}{D(1-k)}$$

6.5 Liquid Retaining Members subjected to Combined axial tension and Bending Moment :

For the members subjected to combined axial tension and bending moment, two cases are considered:

i) Tension on liquid face and ii) Tension on remote face

Tension on liquid face

IS 3370 requires that the stresses due to combination of direct tension and bending moment shall satisfy the following condition

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

where, f_{ct} = calculated direct tensile stress in concrete

σ_{ct}= permissible direct tensile stress in concrete

f_{cbt}=calculated stress in concrete in bending tension

σ_{cbt}= permissible stress in concrete in bending tension.

Tension on remote face

For the sections less than 225 mm thick, the procedure explained above for tension on liquid face should be used. For the sections more than 225 mm thick, concrete strain need not be checked. This has two cases:

i) Tensile force is large ie., the line of action of resultant force lies within the effective depth

ii) Tensile force is small ie., the line of action of resultant force lies outside the section

i) *Tensile force is large*: Steel is provided on both faces. T_1 and T_2 are tensile forces in steel on remote and water face face respectively. Total tensile force $T=T_1+T_2$. Referring to Fig. 6.2 and taking moment about cg of steel on water face

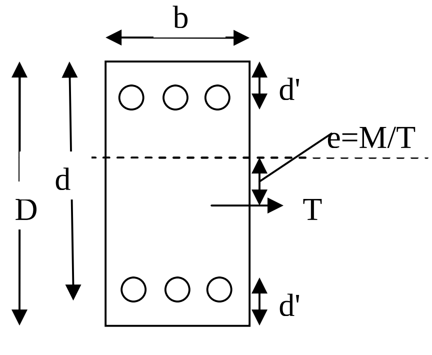


Fig. 6.2

$T_1(d-d') = T(D/2+e-d')$ but $d' = D-d$

$$T_1 = \frac{d - \frac{D}{2} + e}{2d - D} T$$

$T_2=T-T_1$

$$T_2 = \frac{d - \frac{D}{2} - e}{2d - D} T$$

ii) *Tensile force is small*: If steel is provided on both faces then the equation derived in case 1 is valid. When steel is provided only on tension face and referring to Fig.6.3 , an approximate method may be used as given below

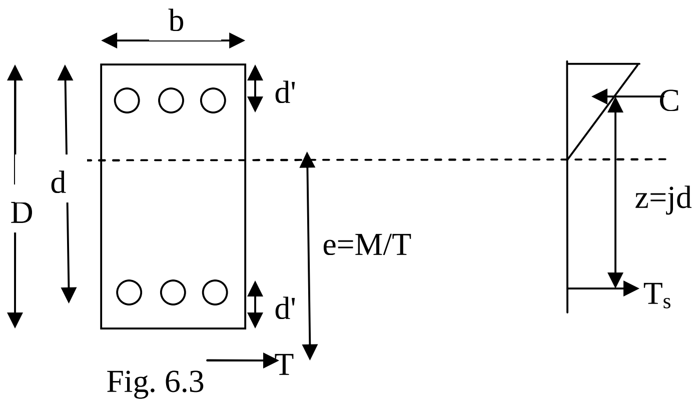


Fig. 6.3

Equilibrium of forces give T_s-C=T
Taking moment about centroid of tensile reinforcement
Cjd=T (e-D/2+d')
Let E= e-D/2+d' = e-D/2+(D-d)=e+D/2-d

$C = \frac{TE}{jd}$ Substituting in equilibrium equation

$$\sigma_{st} A_{st} - \frac{TE}{jd} = T$$

$$A_{st} = \frac{T}{\sigma_{st}} + \frac{TE}{\sigma_{st} jd}$$

6.6 WATER TANKS :

A water tank is used to store water to facilitate the daily requirements of habitats. Types of water tank based on placing and shape is given in Fig. 6.4. Circular tanks have minimum surface area when compared to other shapes for a particular capacity of storage required. Hence the quantity of material required for circular water tank is less than required for other shapes. But the form work for a circular tank is very complex and expensive when compared to other shapes. Square and Rectangular water tanks are generally used under ground or on the ground. Circular tanks are preferred for elevated tanks.

Fig. 6.4

WATER TANK

BASED ON PLACEMENT OF TANK

1. RESTING ON GROUND
2. UNDER GROUND
3. ELEVATED

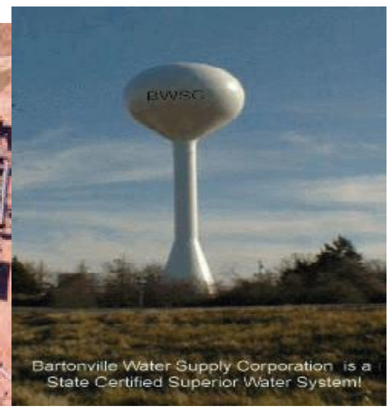
BASED ON SHAPE OF TANK

1. CIRCULAR
2. RECTANGULAR
3. SPHERICAL
4. INTZ
5. CONICAL BOTTOM

Resting on ground

Under Ground


Elevated Circular

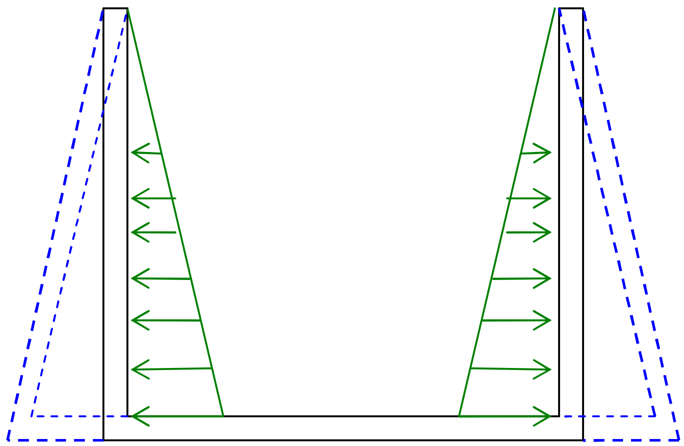



Rectangular Spherical

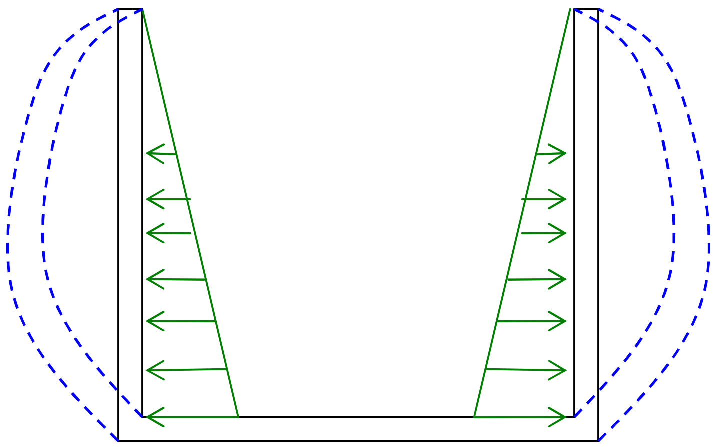

Intz Conical Bottom

6.6.1 Circular Tanks resting on ground :

Due to hydrostatic pressure, the tank has tendency to increase in diameter. This increase in diameter all along the height of the tank depends on the nature of joint at the junction of slab and wall as shown in Fig 6.5



Tank with flexible base



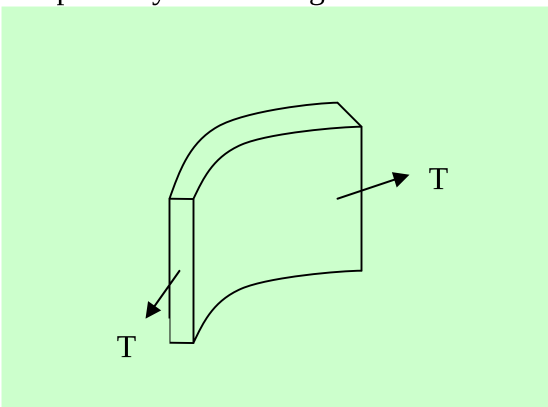
Tank with rigid base

Fig. 6.5

When the joints at base are flexible, hydrostatic pressure induces maximum increase in diameter at base and no increase in diameter at top. This is due to fact that hydrostatic pressure varies linearly from zero at top and maximum at base. Deflected shape of the tank is shown in Fig. 6.5. When the joint at base is rigid, the base does not move. The vertical wall deflects as shown in Fig. 6.5.

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 $A_{st} = \frac{T}{\sigma_{st}} = \frac{\gamma HD/2}{\sigma_{st}}$ 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 to be less than permissible stress, the stress in concrete is computed using equation

$\sigma_c = \frac{T}{A_c + (m-1)A_{st}} = \frac{\gamma HD/2}{1000t + (m-1)A_{st}}$ If $\sigma_c \le \sigma_{cat}$, where $\sigma_{cat}=0.27\sqrt{f_{ck}}$, 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:

i) Plan at base
ii) 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 m^3

Area of tank A = 400/3.3 = 121.2 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≈ 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

$A_{st\ min}$=0.24%of area of concrete = 0.24x 1000x160/100 = 384 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=1430x 1000/201= 140.6 mm c/c

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

Step 3: Check for tensile stress

Area of steel provided $A_{st\ provided}$=201x1000/140 = 1436.16 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 σ_{cat}=0.27$\sqrt{f_{ck}}$= 1.2 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 an 3 x 160 = 480 mm

Height from top	Hoop tension T =γHD/2 (kN)	A_{st}= T/σ_{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

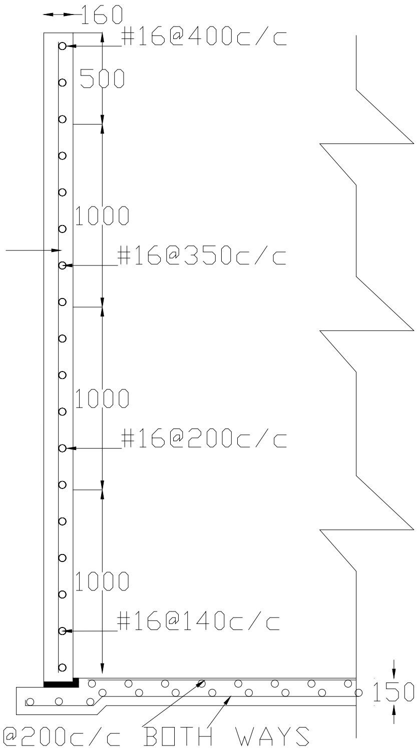
Step 5: Vertical reinforcement:

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

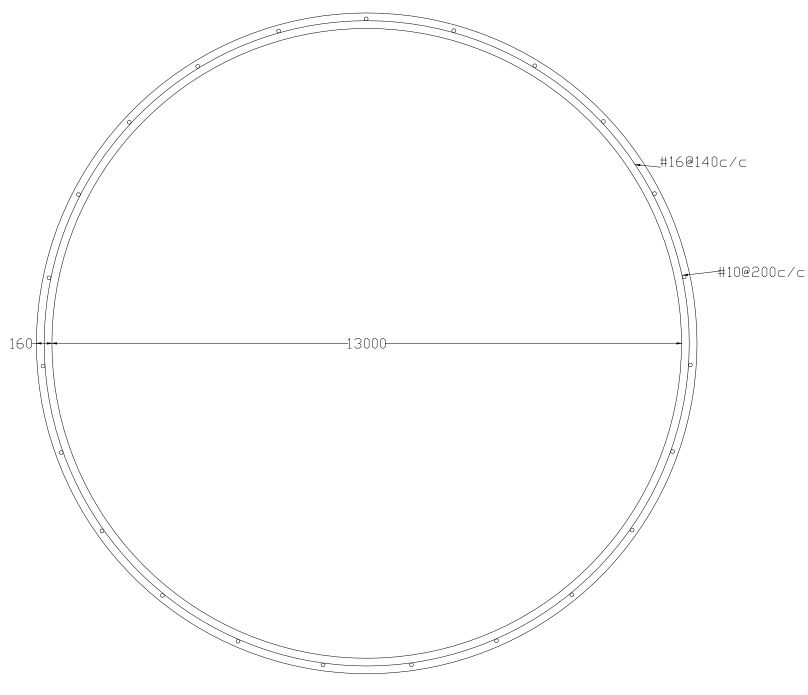
Spacing of 10 mm diameter bar = 78.54x1000/384=204 mm c/c ≈ 200 mm c/c

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.



SECTIONAL ELEVATION



PLAN AT BASE

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= coefficient ($\gamma_w HD/2$)

M= coefficient ($\gamma_w H^3$)

V= coefficient ($\gamma_w H^2$)

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

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

where,

$Q = \frac{1}{2} \sigma_{cbc} jk$

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

$j = 1-(k/3)$

$b = 1000\text{mm}$

Providing suitable cover, the over all thickness is then computed as t = d+cover.

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

$\therefore A_{st} = \frac{M}{\sigma_{st}\, jd}$. 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

$\sigma_c = \frac{T}{1000t + (m-1)A_{st}}$ 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 and volume V = 700 m^3

A=700/4.7 = 148.94 m^2

D= $\sqrt{}(4 \text{ x } 148.94/\pi) = 13.77 \approx 14$ 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 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 x 10 x 4.7 x 7 =189.175 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 x 10 x 4.7^3=15.15 kN-m

Step 3: Design of section:

For M20 concrete σ_{cbc}=7, For Fe415 steel σ_{st}=150 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= ½ σ_{cbc}jk = 1.19

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

For M20 concrete σ_{cbc}=7, For Fe415 steel σ_{st}=150 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= ½ σ_{cbc}jk = 1.19

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

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

$$A_{st} = \frac{M}{\sigma_{st} jd} = \frac{15.15x10^6}{150x0.87x167} = 695.16mm^2$$

Spacing of 16 mm diameter bar = $\frac{201x1000}{695.16} = 289.23mmc/c$ (Max spacing 3d=501mm)

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

Hoop steel: $A_{st1} = \frac{T}{\sigma_{st}} = \frac{189.275x10^3}{150} = 1261mm^2$

Spacing of 12 mm diameter bar = $\frac{113x1000}{1261} = 89.mmc/c$

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

Actual area of steel provided $A_{st} = \frac{113x1000}{80} = 1412.5mm^2$

Step 4: Check for tensile stress:

$$\sigma_c = \frac{T}{1000t + (m-1)A_{st}} = \frac{189.275x10^3}{1000x200 + (13.33-1)x1412.5} = 0.87N/mm^2$$

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

Step 5: Distribution Steel:

Minimum area of steel is 0.24% of concrete area

A_{st}=(0.24/100) x1000 x 200 = 480 mm^2

Spacing of 8 mm diameter bar = $\frac{50.24x1000}{480} = 104.7.mmc/c$

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

Step 5: Base slab:

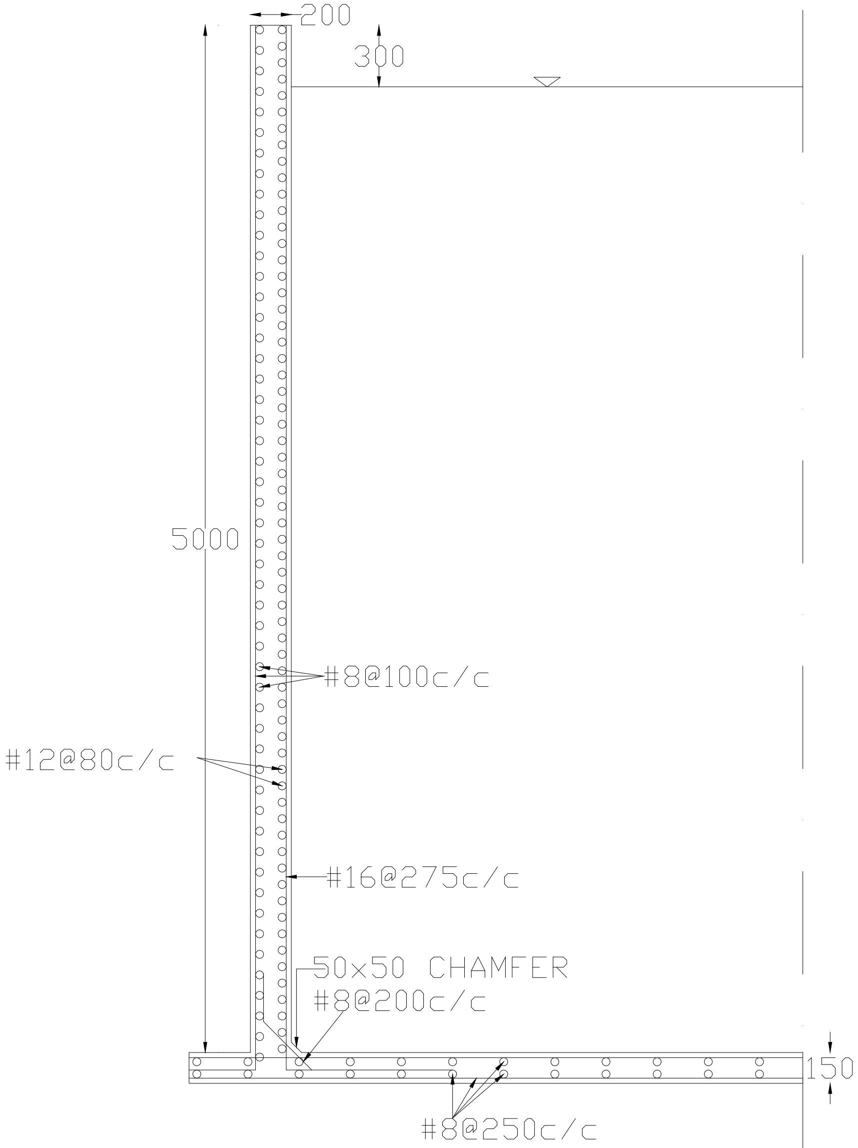
The thickness of base slab shall be 150 mm. The base slab rests on firm ground, hence only minimum reinforcement is provided.

A_{st}=(0.24/100) x1000 x 150 = 360 mm^2

Reinforcement for each face = 180 mm^2

Spacing of 8 mm diameter bar = $\frac{50.24x1000}{180} = 279.mmc/c$

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



SECTIONAL ELEVATION

Design Problem No.2:

Design a circular water tank to hold 5,50,000 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 m^3

Assume H= 4.5

A=550/4.5 = 122.22 m^2

D= $\sqrt{(4 \times 122.22/\pi)}$ = 12.47 ≈12.5 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 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 x 10 x 4.5 x 6.25 =161.72 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 x 10 x 4.5^3=13.3 kN-m

Step 3: Design of section:

For M20 concrete σ_{cbc}=7, For Fe415 steel σ_{st}=150 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= ½ σ_{cbc}jk = 1.19

Effective depth is calculated as $d = \sqrt{\frac{M}{Qb}} = \sqrt{\frac{13.3x10^6}{1.19x1000}} = 105.7mm$

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

$$A_{st} = \frac{M}{\sigma_{st} jd} = \frac{13.3x10^6}{150x0.87x167} = 610.27mm^2$$

Spacing of 16 mm diameter bar = $\frac{201x1000}{610.27} = 329.36mm c/c$ (Max spacing 3d=501mm)

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

Hoop steel: $A_{st1} = \frac{T}{\sigma_{st}} = \frac{161.72x10^3}{150} = 1078.13mm^2$

Spacing of 12 mm diameter bar = $\frac{113x1000}{1078.13} = 104mmc/c$

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

Actual area of steel provided $A_{st} = \frac{113x1000}{100} = 1130mm^2$

Step 4: Check for tensile stress:

$$\sigma_c = \frac{T}{1000t + (m-1)A_{st}} = \frac{161.72x10^3}{1000x200 + (13.33-1)x1130} = 0.76N/mm^2$$

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

Step 5: Distribution Steel:

Minimum area of steel is 0.24% of concrete area

A_{st}=(0.24/100) x1000 x 200 = 480 mm^2

Spacing of 8 mm diameter bar = $\frac{50.24x1000}{480} = 104.7.mmc/c$

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

Step 5: Base slab:

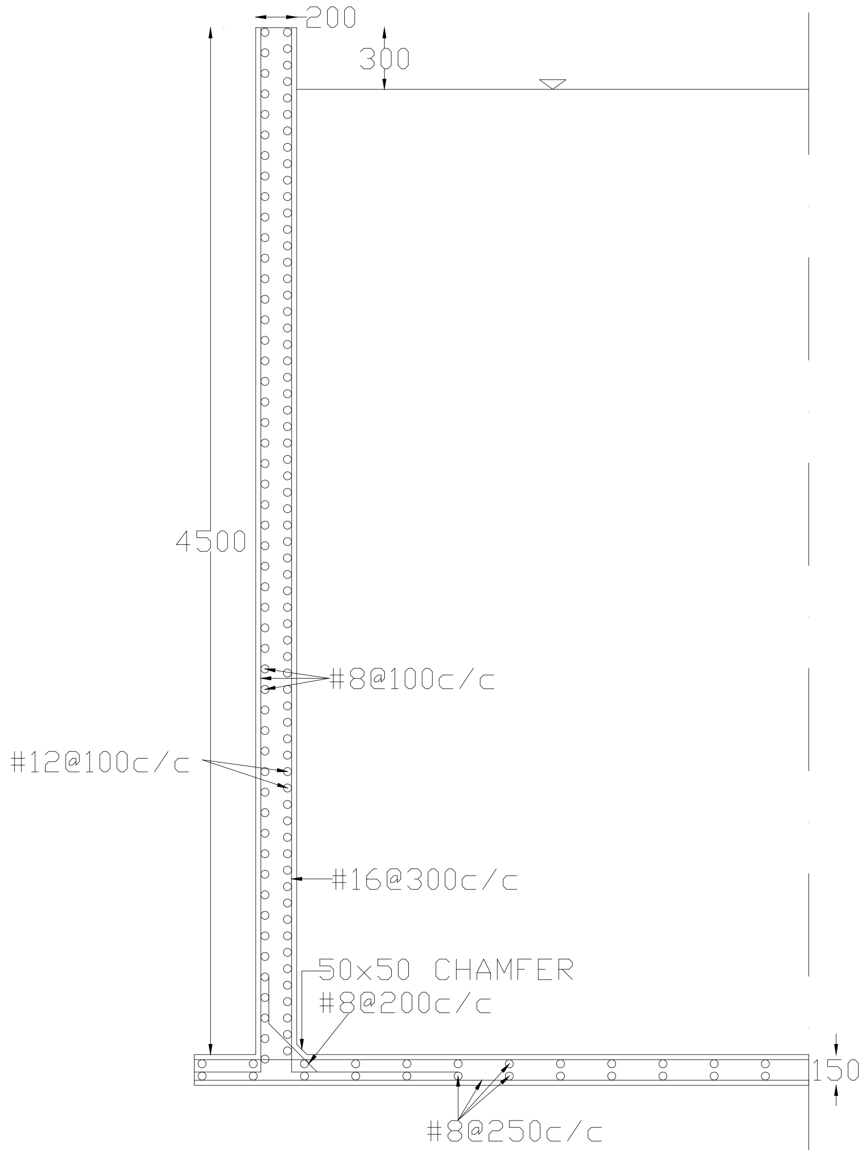
The thickness of base slab shall be 150 mm. The base slab rests on firm ground, hence only minimum reinforcement is provided.

A_{st}=(0.24/100) x1000 x 150 = 360 mm^2

Reinforcement for each face = 180 mm^2

Spacing of 8 mm diameter bar = $\frac{50.24x1000}{180} = 279.mmc/c$

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



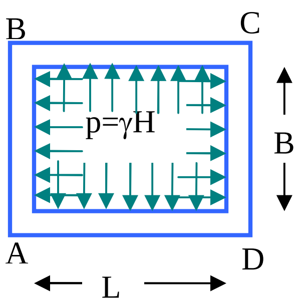
SECTIONAL ELEVATION

6.6.2 Rectangular tank with fixed base resting on ground :

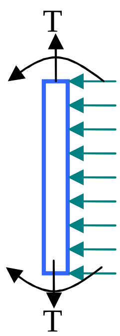
Rectangular tanks are used when the storage capacity is small and circular tanks prove uneconomical for small capacity. Rectangular tanks should be preferably square in plan from point of view of economy. It is also desirable that longer side should not be greater than twice the smaller side.

Moments are caused in two directions of the wall ie., 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, ie., 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.

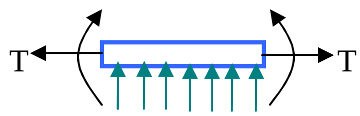
In addition to the moments, the walls are also subjected to direct pull exerted by water pressure on some portion of walls. The walls are designed both for direct tension and bending moment.



PLAN @ BASE



FBD OF AB
IN PLAN



FBD OF AD
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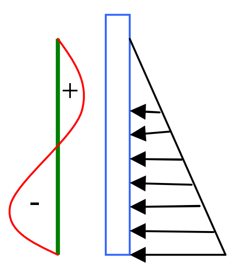
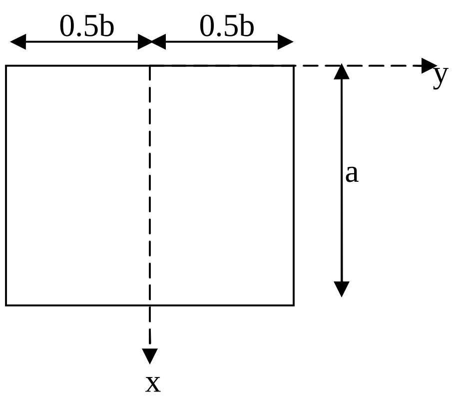


Bending moment diagram



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)

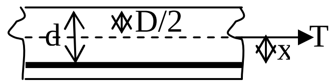
Tension in short wall is computed as T_s=pL/2

Tension in long wall T_L=pB/2

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

$A_{st}=A_{st1}+A_{st2}$; $A_{st1}=\dfrac{M'}{\sigma_{st}\,jd}$; M'=Maximum horizontal bending moment – T x; x= d-D/2

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

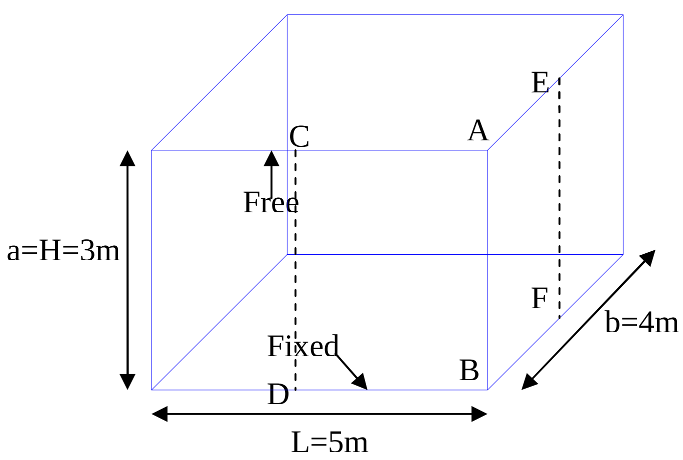


Design problem No.1

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≈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; $T_{long}=\gamma_w ab/2$=60 kN

ii) Short wall:

B/a=1.33≈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; $T_{short}=\gamma_w aL/2$=75 kN

Step2: Design constants

σ_{cbc}=7 MPa, σ_{st}=150 MPa, m=13.33

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

j=1-(k/3)=0.87

Q= ½ σ_{cbc}jk = 1.15

Step3: Design for vertical moment

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

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

$$d = \sqrt{\frac{M}{Qb}} = \sqrt{\frac{19.98x10^6}{1.15x1000}} = 131.8mm$$

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

t=131.88+33=164.8 mm≈170 mm

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

$$A_{st} = \frac{M}{\sigma_{st} jd} = \frac{19.98x10^6}{150x0.87x137} = 1117.54mm^2$$

Spacing of 12 mm diameter bar = $\frac{113x1000}{1117.54} = 101.2\,mmc/c$ (Max spacing 3d=411mm)

Provide #12 @ 100 mm c/c

Distribution steel

Minimum area of steel is 0.24% of concrete area

A_{st}=(0.24/100) x1000 x 170 = 408 mm^2

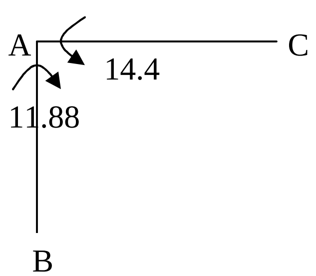
Spacing of 8 mm diameter bar = $\frac{50.24x1000}{408} = 123.19mmc/c$

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.



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

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

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

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; $\therefore H_1$= 1m
Depth of water $h=H-H_1=3-1-2m$; $p=\gamma_w h=10 \times 2= 20\ kN/m^2$
Tension in short wall $T_s=pL/2=50$ kN
Tension in long wall $T_L=pB/2= 40$ kN
Net bending moment M'=M-Tx, where, x= d-D/2=137-(170/2)=52mm
M'=13.0672-50 x 0.052=10.4672 kN-m

$$A_{st1} = \frac{10.4672x10^6}{150x0.87x137} = 585.46mm^2$$

$$A_{st2} = \frac{50x10^3}{150} = 333.33mm^2$$

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

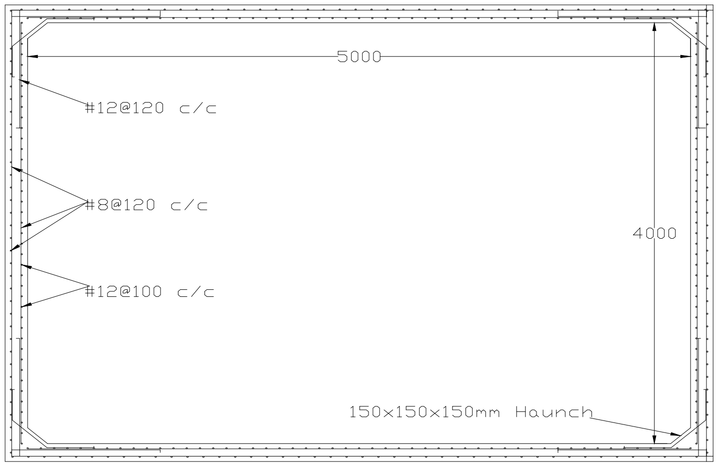
Spacing of 12 mm diameter bar = $\frac{113x1000}{918.74} = 123\,mmc/c$ (Max spacing 3d=411mm)

Provide #12@120 mm c/c at corners

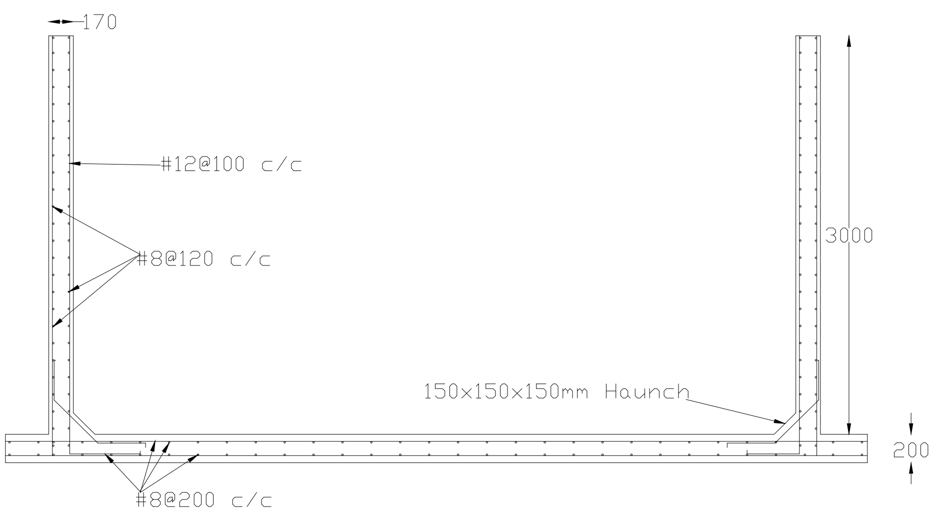
Step5: Base Slab:

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