CHAPTER 7

WATER TANK

7.1 INTRODUCTION

As per Greek philosopher Thales, “Water is the source of every creation.” In day to day life one cannot live without water. Therefore water needs to be stored for daily use. Over head water tank and underground water reservoir is the most effective storing facilities used for domestic or even industrial purpose.

Depending upon the location of the tank the tanks can be named as overhead, on ground or underground. The tanks can be made in different shapes usually circular and rectangular shapes are mostly used. The tanks can be made of RCC or even of steel. The overhead tanks are usually elevated from the roof top through column. In the other hand the underground tanks are rested on the foundation. Different types of tanks and their design procedure is discussed in subsequent portion if this chapter.

The water tanks in this chapter are designed on the basis of no crack theory. The concrete used are made impervious.

7.2 TYPES OF WATER TANK

Basing on the location of the tank in a building s tanks can be classified into three categories. Those are:

- Underground tanks
- Tank resting on grounds
- Overhead tanks

In most cases the underground and on ground tanks are circular or rectangular is shape but the shape of the overhead tanks are influenced by the aesthetical view of the surroundings and as well as the design of the construction.

Steel tanks are also used specially in railway yards. Basing on the shape the tanks can be circular, rectangular, square, polygonal, spherical and conical. A special type of tank named Intze tank is used for storing large amount of water for an area.

The overhead tanks are supported by the column which acts as stages. This column can be braced for increasing strength and as well as to improve the aesthetic views.

7.3 BASIS OF DESIGN

One of the vital considerations for design of tanks is that the structure has adequate resistance to cracking and has adequate strength. For achieving these following assumptions are made:

- Concrete is capable of resisting limited tensile stresses the full section of concrete including cover and reinforcement is taken into account in this assumption.
- To guard against structural failure in strength calculation the tensile strength of concrete is ignored.
- Reduced values of permissible stresses in steel are adopted in steel are adopted in design.

7.4 CIRCULAR TANK

The simplest from of water tank is circular tank for the same amount of storage the circular tank requires lesser amount of material. More over for its circular shape it has no corner and can be made water tight easily. It is very economical for smaller storage of water up to 20000000 liters and with diameter in the range of 5 to 8 m. The depth of the storage is between 3 to 4 m. The side walls are designed for hoop tension and bending moments.

7.4.1 PERMISSIBLE STRESSES IN CONCRETE

To ensure impervious concrete mixture linear than M 20 grade is not normally recommended to make the walls leak proof the concretes near the water face need to such that no crack occurs. To ensure this member thicknesses are so designed that stress in the concrete is lesser then the permissible as given in table 7.1.

7.4.2 THE PERMISSIBLE STRESS IN STEEL

The stress in steel must not be allowed to exceed the following values under different positions to prevent cracking of concrete.

- When steel is placed near the face of the members in contact with liquid 115 N/ sq mm for ms Bars and 150 N/ sq mm for HYSD bars.
- When steel is placed on face away from liquid for members less then 225 mm in thickness same as earlier.
- When steel is placed on the face away from the liquid for members 225 mm or more in thickness: 125 N/ sq mm for M.S. bars and 190 N/sq mm for HYSD bars.

Table 7.1 Permissible Stresses In Concrete (For calculations relating to resistance to concrete)

Grade of Concrete	Permissible Stresses		Shear = a/bd
	Direct Tension σ_{st} (N/mm^2)	Tension Due to bending σ_{cbt} (N/mm^2)	(N/mm^2)
M 15	1.1	1.5	1.5
M 20	1.2	1.7	1.7
M 25	1.3	1.8	1.9
M 30	1.5	2.0	2.2
M 35	1.6	2.2	2.5
M 40	1.7	2.4	2.7

7.4.3 BASE FOR FLOOR SLAB

The floor slab should be strong enough to transmit the load from the liquid and the structure itself to the ground without subsidence. The floor slab is usually 150 to 200 mm thick and is reinforced with nominal reinforcement, which may be provided in the form of mesh both at top and bottom face of the slab. Before laying the slab the bade has to be rammed and leveled then a75 mm thick layer of lean concrete of M 100 grade should be laid and cured. This layer should be covered with tar to enable the floor slab act independently on the bottom layer. I n water logged soils the bottom layer of concrete should preferably be of M 15 grade.

Minimum reinforcement required for 199mm thick sections is 0.3 % of the area of concrete section which reduced linearly to 0.2% for 450 mm thick sections. In case of floor slab for tank resting on ground the minimum reinforcement from practical consideration should not be less then 0.3% of the gross sectional area of the floor slab.

If the thickness of the section (wall, floor or roof slab of the tank) works out to be 225 mm and above two layers of reinforcing steel shall be placed, one near each of the section to make up the minimum reinforcement requirements.

7.4.4 DESIGN METHOD

The design of circular tanks can be carried out by one of the following three methods:

- Mr. H Carpenter's method
- Approximate method
- I.S. method

7.4.4.1 Mr. H Carpenter's method

For a tank of given dimensions the following expressions are used:

- Maximum cantilever B.M= FwH^3 (7-1)
- Position of maximum hoop tension = K H above base
- Maximum Hoop tension (T)= $\frac{1}{2}wHD(1-k)$ (7-2)

The value of coefficient k and f depend upon H/D and H/t ratio, which is tabulated in Table 7.2.

DESIGN PROCEDURE:

Step 1: Dimensions

- Dimension of the tank.

  Basing on the amount of water that needs to be stored the dimensions of the tanks are calculated.

  Total volume of water= $\frac{\prod D^2}{4} \times H$ (7-3)

  Where, D= Diameter of the tank

  H= Height of the liquid

- Thickness of the wall.

  Depending upon the depth of liquid (H) the thickness of the wall is assumed from the empirical formula

  $t = (30H + 50)$ mm (7-4)

or, t = 150 mm whichever is greater.

This thickness t is then converted in meter.

Table 7.2 Coefficient of f and k for bending moment and tension

Factor	**F**				**K**			
H/t	10	20	30	40	10	20	30	40
0.1	0.075	0.047	0.036	0.028	-	-	-	-
0.2	0.046	0.028	0.022	0.015	-	0.50	0.45	0.40
0.3	0.032	0.019	0.014	0.010	0.55	0.43	0.38	0.33
0.4	0.024	0.014	0.010	0.007	0.50	0.39	0.35	0.30
0.5	0.020	0.012	0.009	0.006	0.45	0.37	0.32	0.27
1.0	0.012	0.006	0.005	0.003	0.37	0.28	0.24	0.21
2.0	0.006	0.003	0.002	0.002	0.30	0.22	0.19	0.16
4.0	0.004	0.002	0.002	0.001	0.27	0.20	0.17	0.14

Step 2: Determination of the value of coefficient F and k

By knowing the values of H/D and H/t from table 7.2 we can obtain the value of F and k.

Step 3:

By using the values of coefficients F and k the following dimensions are calculated

- Maximum bending moment at the base = FwH^3
- Maximum circumferential or hoop tension T = $\frac{1}{2}wHD(1-k)$
- Position of maximum circumferential tension h = kH

Step 4:

- The thickness provided for the wall from maximum bending moment consideration should be checked.
- Sufficient area of steel must be provided at the height h to resist maximum tension.

- Above height h the area of reinforcement can be uniformly decreased and below this the area of steel is maintained constant.

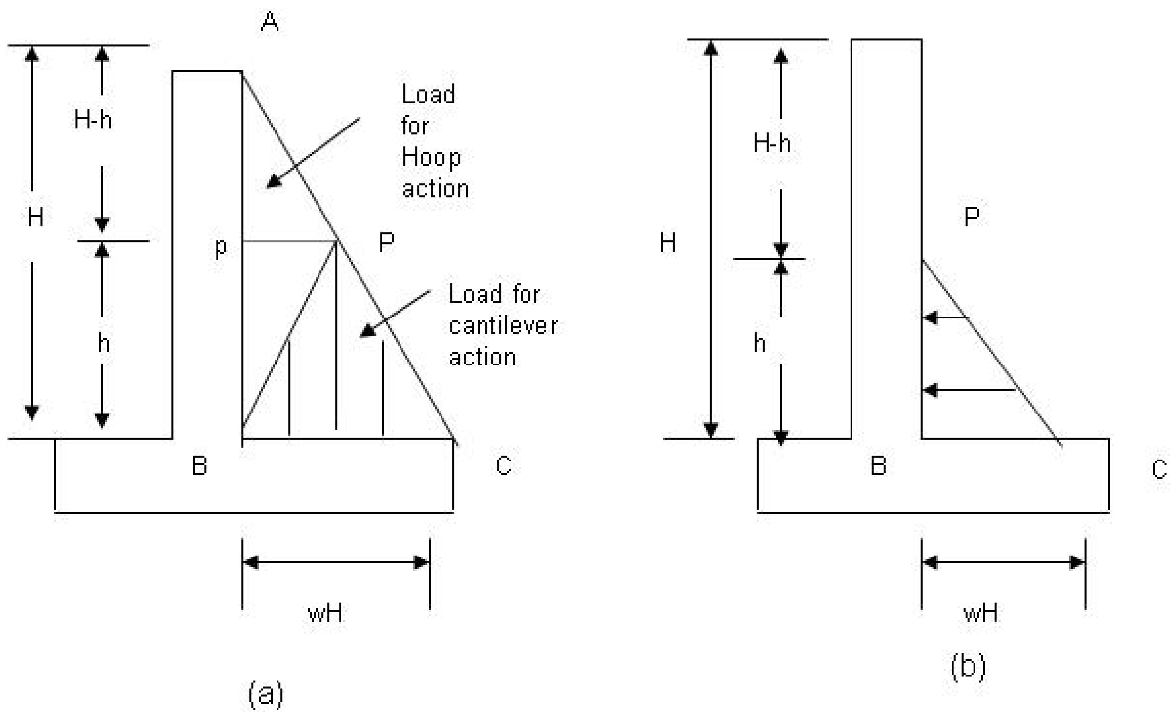


Figure 7.1: Hydrostatic Pressure Distribution

7.4.4.2 Approximate Method

- In this method it is assumed that the cantilever effect of the wall will be present for a height of approximately one fourth of the height of wall that is H/4 or 1 m whichever is more.

- The hydrostatic pressure distribution on the wall is shown in Figure 6.1 (a) the pressure varies from zero at A to maximum value at B. This is represented by ordinate BC of the pressure triangle ABC. Draw a horizontal line intersecting the pressure diagram at P at a height of H/4 or 1m whichever is more. Thus the cantilever action will be effective up to the height (h) =BP and hoop tension will be predominant from P to A having its maximum value at P.

- The bottom height of the wall i.e. h = BP will be designed as a cantilever fixed at B and subjected to a triangular load given by area PBC of pressure triangle. The load from cantilever action thus varies from zero at P to wH at B.

The maximum hoop tension per unit height at P

$$T = \frac{1}{2}w(H-h)D \qquad (7\text{-}5)$$

- Reinforcement for hoop tension may be provided near both faces. The spacing of hoop reinforcement (rings) is kept uniform from P to B. At heights above P, the spacing of rings can be increased.

6.4.4.3 I.S. Code Method

- From the capacity of the water tank the values of tank diameters (D) and depth of water (H) are determined.

- Approximate thickness of wall: The value t is determined by the following formula:

$t = (30H + 60)$ mm

or, t = 150 mm whichever is greater.

Then the value of t is converted into meters.

- Ratio $\frac{H^2}{D_t}$ is determined and respective co-efficient values for tension, bending moments and shears are found out from tables.

- Hoop tension

Hoop tension is determined from the following formula

T= $\frac{1}{2} w \times H \times D \times$ (coefficient determined from table 7.3) in kN/m

Where, w = wt of water in kN/ m^3

Table 7.3 Coefficient for bending moment in cylindrical tank wall (Fixed at base and free at top)

H^2/D_t	Coefficient at point									
	0.1H	0.2H	0.3H	0.4H	0.5H	0.6H	0.7H	0.8H	0.9H	1.0H
0.4	1.0005	0.0014	0.0021	0.0007	-0.0042	-0.0150	-0.0302	-0.0529	-0.0816	-0.1205
0.8	0.0011	0.0037	0.0063	0.0800	-0.0079	0.0023	-0.0068	-0.0024	-0.0465	-0.0795
1.2	0.0012	0.0042	0.0077	0.0103	0.0112	0.0090	0.0022	-0.0108	-0.0311	-0.0602
1.6	0.0011	0.0041	0.0075	0.0107	0.0121	0.0111	0.0058	-0.0051	-0.0232	-0.0505
2.0	0.0010	0.0035	0.0068	0.0099	0.0120	0.0115	0.0075	-0.0021	-0.0185	-0.0436
3.0	0.0006	0.0024	0.0047	0.0071	0.0090	0.0097	0.0077	0.0012	-0.0119	-0.0333
4.0	0.0003	0.0015	0.0028	0.0047	0.0066	0.0077	0.0069	0.0023	-0.0080	-0.0268
5.0	0.0002	0.0008	0.0016	0.0029	0.0046	0.0059	0.0059	0.0028	-0.0058	-0.0222
6.0	0.0001	0.0003	0.0008	0.0019	0.0032	0.0046	0.0051	0.0029	-0.0041	-0.0187
8.0	0.0000	0.0001	0.0002	0.0008	0.0016	0.0028	0.0038	0.0029	-0.0022	-0.0146
10.0	0.0000	0.0000	0.0001	0.0004	0.0007	0.0019	0.0029	0.0028	-0.0012	-0.0122
12.0	0.0000	-0.0001	0.0001	0.0002	0.0003	0.0013	0.0023	0.0026	-0.0005	-0.0104
14.0	0.0000	0.0000	0.0000	0.0000	0.0001	0.0008	0.0019	0.0023	-0.0001	-0.0090
16.0	0.0000	0.0000	-0.0001	-0.0001	-0.0001	0.0004	0.0013	0.0019	-0.0001	-0.0079

- Bending Moment

Maximum bending moment is determined from the following
Formula : M= (coefficient from table 7.4)$\times wH^3$ kN/m (7-6)

Table 7.4 Coefficient for tension in cylindrical tank wall (Fixed at base and free at top)

H^2/D_t	Coefficient at point									
	0.0H	0.1H	0.2H	0.3H	0.4H	0.5H	0.6H	0.7H	0.8H	0.9H
0.4	0.149	0.134	0.120	0.101	0.082	0.066	0.049	0.029	0.014	0.004
0.8	0.263	0.239	0.215	0.109	0.160	0.130	0.096	0.063	0.034	0.030
1.2	0.283	0.271	0.254	0.234	0.209	0.180	0.142	0.099	0.054	0.016
1.6	0.265	0.268	0.268	0.266	0.250	0.226	0.185	0.134	0.075	0.023
2.0	0.234	0.251	0.273	0.285	0.285	0.274	0.232	0.172	0.104	0.031
3.0	0.134	0.203	0.267	0.322	0.357	0.362	0.330	0.262	0.157	0.052
4.0	0.067	0.164	0.256	0.339	0.403	0.429	0.409	0.334	0.210	0.073
5.0	0.025	0.137	0.245	0.346	0.428	0.477	0.469	0.398	0.259	0.092
6.0	0.018	0.119	0.234	0.344	0.441	0.504	0.514	0.447	0.301	0.112
8.0	-0.011	0.104	0.218	0.335	0.443	0.534	0.575	0.530	0.381	0.151
10.0	-0.001	0.098	0.208	0.323	0.437	0.542	0.608	0.589	0.410	0.179
12.0	-0.005	0.097	0.202	0.312	0.429	0.543	0.628	0.633	0.494	0.211
14.0	-0.002	0.098	0.200	0.306	0.420	0.539	0.639	0.666	0.541	0.241
16.0	0.000	0.099	0.199	0.304	0.431	0.531	0.641	0.687	0.582	0.265

- Determination of shear force

Design shear force is found out from the following formula
T = (coefficient from table 7.5) $\times wH^3$ kN/m

Table 7.5 Coefficient for shear at the base

H^2/Dt	Coefficient	H^2/Dt	Coefficient
0.40	0.436	5.00	0.213
0.80	0.374	6.00	0.197
1.20	0.339	8.00	0.174
1.60	0.317	10.00	0.158
2.00	0.299	12.00	0.145
3.00	0.262	14.00	0.135
4.00	0.236	16.00	0.127

- Reinforcement is provided for hoop tension near both faces.

7.5 RECTANGULAR TANKS

In case of small amount of water storage rectangular tanks are more economical then circular because the construction of circular tanks requires complicated and costly formwork. Moreover compartmentation in a rectangular tank is much easier then the circular tanks. Moreover uses of rectangular tanks make the full use of the space available. The main components of a rectangular tank are side wall, base slab and roof slab.

6.5.1 DESIGN OF SIDE WALLS

Let, L = length of the tank
B = width of the tank
H = height of the tank

The design of the sidewalls is carried out by approximate method. The method is broadly categorizes as follows:

- Tank wall having ratio of L/B less then 2.
- Tank wall having ratio of L/B greater than 2.

Tank wall having ratio of L/B lesser than 2:

- The tank walls are designed as horizontal slabs continuous al along and subjected to a triangular load due to the water pressure varying from zero at the top to maximum height of h =H/4 of 1 m above the base whichever is greater.

- For the bottom portion the wall is considered as a vertical cantilever fixed at the base and subjected to triangular loading given by the area P.F.G of the diagram varying from zero at P and maximum wH at the base.

- Maximum pressure

Maximum pressure (p) for design of wall for horizontal bending per unit height at level of P = w (H-h) per m (7-7)

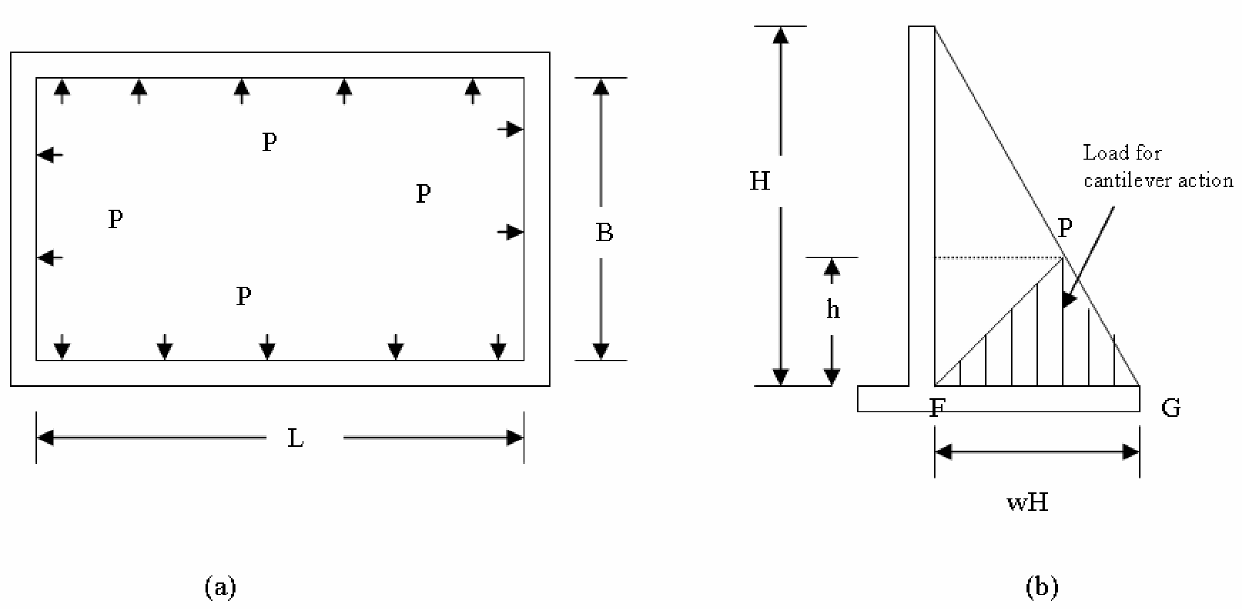


Figure 7.2: Pressure and Load distribution on Wall

- Determination of bending moments

B.M at the end of the span = $\frac{1}{12}pB^2$ (producing tension on water force)

B.M at the center of span = $\frac{1}{16}pB^2$ (producing tension on outer force)

- Direct tension or pull in long walls

The water pressures on short walls are transformed into tension to the long walls.

Pressure due to water

P = $w(H-h)\times 1\times B$ (7-8)

Direct tension or pull transformed to each long wall

T = $\frac{1}{2}w(H-h)B$ (7-9)

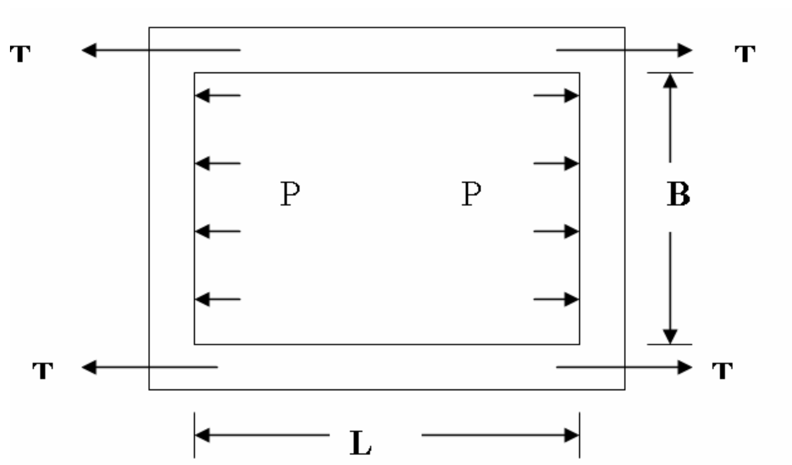


Figure 7.3: Plan showing pressure-causing pull in long walls

- Direct tension or pull on short walls

Direct tension or pull on short walls

$T_B = \frac{1}{2}w(H-h)L$ (7-10)

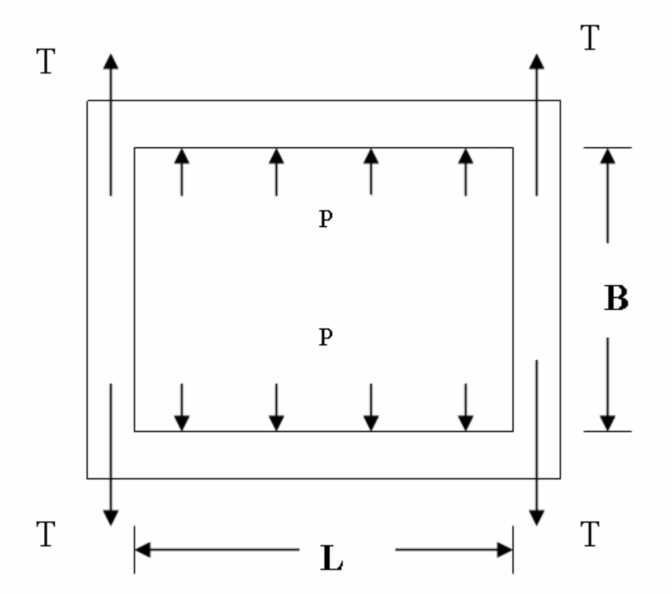


Figure 7.4 : Plan showing pressure- causing pull in short walls

- Cantilever moment in short walls.

Maximum cantilever B.M in short walls $= wH \times \frac{h}{2} \times \frac{h}{3} = \frac{1}{6} wHh^2$ (7-11)

Tank wall having ratio of L/B greater then 2:

- For rectangular tanks in which ratio of length to width is more than 2, the long walls are treated as vertical cantilever fixed art the base while the short walls are treated as horizontal slabs (bending horizontally) spanning between the long walls and fixed at ends. The lower portion of the short wall for a height of h = H/4 or 1 m whichever is greater is considered to act as vertical cantilever fixed at the base.

- Bending moments.

Maximum bending moment in long walls $= \frac{1}{2} w \times H \times H \times \frac{H}{3} = \frac{1}{6} wH^3$ (7.12)

For short walls the maximum bending moment at level P may be taken as follows:

B.M at ends of span

$\frac{1}{12} pB^2 = \frac{1}{12} w(H - h)B^2$ (7-13)

B.M at center of span

$$\frac{1}{16}pB^2 = \frac{1}{16}w(H-h)B^2 \qquad (7\text{-}14)$$

- Pull in long wall and short walls

Direct tension or pull transformed to each long wall

$$T_L = \frac{1}{2}w(H-h)B \qquad (7\text{-}15)$$

Direct tension or pull on short walls

$$T_B = w(H-h)\times 1 \qquad (7\text{-}16)$$

Since the short wall as well as long walls are subjected to bending moment and direct tension or pull (acting at center of wall) it will be necessary to design the wall section for combined effect of these two.

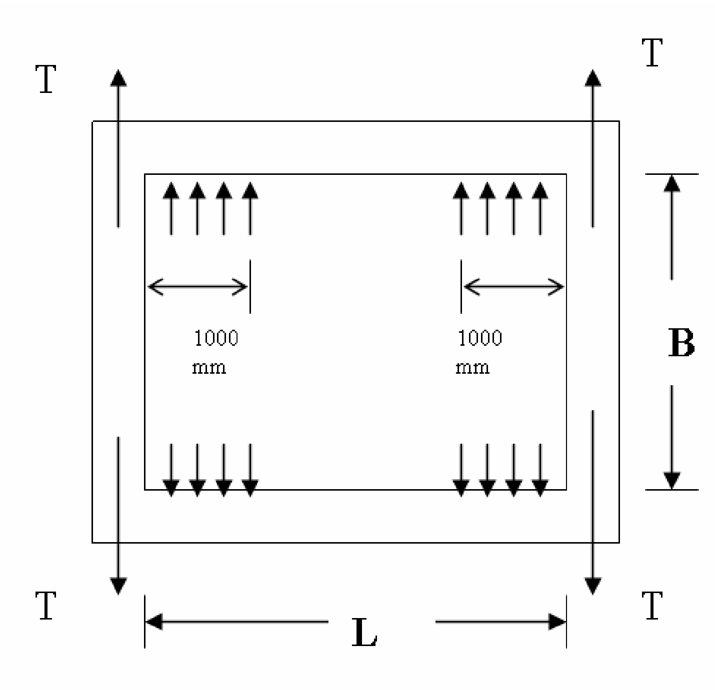


Figure 7.5 : Plan showing pressure causing pull in short walls

Reinforcement:

- Long wall

Long wall which act as cantilever fixed to the base reinforcement for moment is vertical and for the direct tension or pull it is horizontal.

- Short wall

In case of short wall above (h) from base the wall bends horizontally and hence the reinforcement for the B.M as well as tension are provided in horizontal directions.

For lower portion of the short walls for height (h) the main reinforcement is vertical whereas for the tension reinforcement is horizontal.

Analysis of Tank Wall Section Subjected To Combined Effect Of Bending And Direct Tension

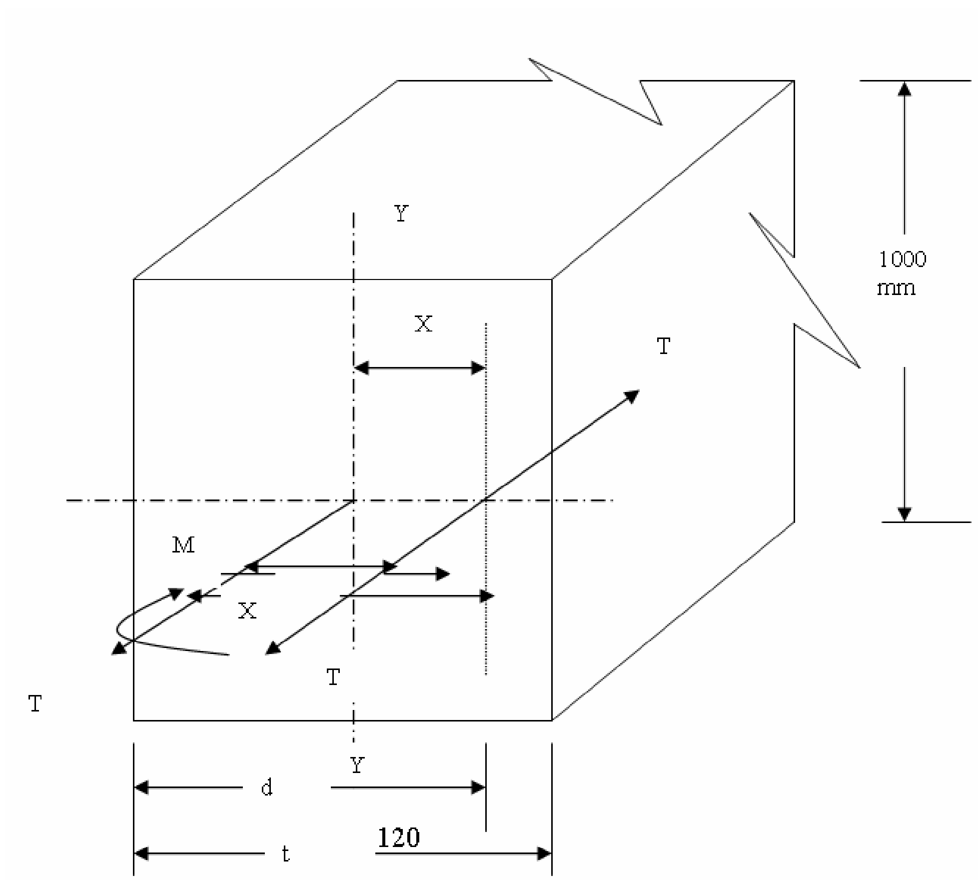


Figure 7.6 : Section subjected to bending moment

Let assume that two equal and opposite force of magnitude equal to T act on the main reinforcement the wall section can thus be considered to be subjected to a net
BM=M-Tx and a pull T.
Area of reinforcement is separately calculated for the bending moment and tension or pull and then added together to get the total reinforcement.

Step 1:

- Area of steel for net B.M

$$A_{st_1} = \frac{M - Tx}{leverarm \times stres\sin steel}$$

$$= \frac{M - Tx}{jd\sigma_{st}} \tag{7-17}$$

Notes:

Safe stress in steel in bending or σ_{st} is taken =115 N/ mm^2 if it is placed on the water face or within a distance of 225 m from the water face.

If steel is placed at a distance of 225 mm away from water face value of σ_{st} = 125 N/ mm^2

- Area of steel for direct tension

$$A_{st_2} = \frac{T}{safe \cdot stress \cdot in \cdot steel}$$

$$= \frac{T}{\sigma_{sc}} \tag{7-18}$$

Safe stress in steel for direction =115 N/ mm^2

- Total area of steel

$$A_{st} = A_{st_1} + A_{st_2} \tag{7-19}$$

6.5.2 DESIGN OF BASE SLAB

- For tank resting on ground the base slab should be so designed that it can transfer the load of the liquid as well as the self-weight of the structure to the ground. The floor slab is normally made 150 mm to 250 mm thick with 3% of the gross sectional area reinforced. The reinforcement provided as mesh at both top and bottom of the slab.

- For overhead tanks the floor slab is designed as a one way or a two way slab based on the length to width ratio of the tank. If L/B>2 the slab is designed as one-way slab and if L/B, 2, the floor slab is designed as two way slabs. The bending moment due to water load and self-weight need to be counted for slab design. The vertical wall is also to be considered.

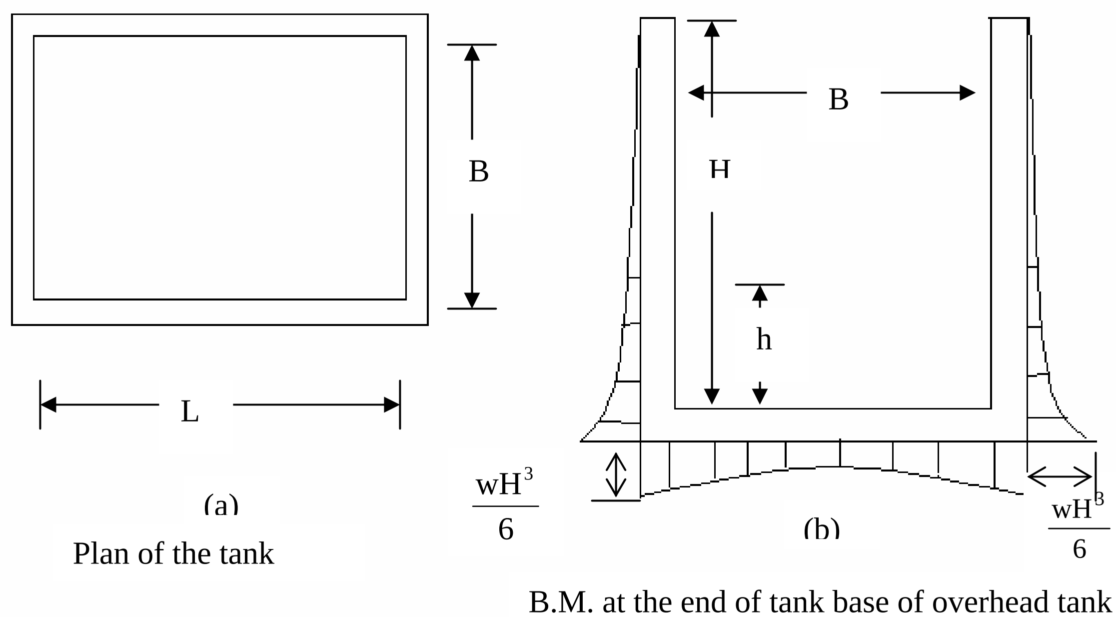


Figure 7.7: Plan and Bending Moment Diagram of Rectangular Tank

The bending moment at the mid span of base slab will comprise of the following:

- Sagging moment due to weight of water.
- Sagging moment due to weight of slab.
- Hogging moment due to water pressure on the long walls.

Let w_d =weight of base slab per sqm

And h =depth of water in the tank

$\therefore$ Net Moment at mid span

$$M_c = \frac{1}{8}whB^2 + \frac{1}{8}w_d B^2 - \frac{1}{6}wh^3 \qquad (7\text{-}20)$$

The value of M_c will be maximum when

$$\frac{d(M_c)}{d(h)} = 0$$

$$\therefore \frac{1}{8}wB^2 - \frac{1}{6}wh^2 = 0$$

$$\Rightarrow h^2 = \frac{1}{4}B^2$$

$$\Rightarrow h = \frac{B}{2}$$

Therefore the maximum positive B.M at mid span occurs when the depth of water in the tank =1/2*the width of the tank.

$$M_c = \frac{wB^2}{8} \times \frac{B}{2} + \frac{w_d B^2}{8} - \frac{1}{6}w\left(\frac{B}{2}\right)^3$$

$$= \frac{wB^3}{24} + \frac{w_d B^2}{8}$$

The direct tension on the slab = $\frac{1}{2}wh^2$ (7-21)

Here, h = $\frac{B}{2}$

Due to the pressure of water on long walls

$$T = \frac{1}{2}wh^2 = \frac{1}{8}wB^2 \qquad (7\text{-}22)$$

If height of tank itself is less then B/2 then the actual height of water in the tank shall be considered for finding out the values for B.M and tension. In case of large height of tank the B.M at mid span may be negative. In such condition tank mid span section is designed by considering the tank full of water.

6.5.3 DESIGN OF ROOF

Tank roof of small capacity tank are designed as one-way slab or two-way slab basing on the length and width ratio. For large capacity tank the roof may be supported by beam supported on column in regular interval. Flat slab type construction is found suitable and economical for tank roofs.

6.5.4 DESIGN OF UNDERGROUND RECTANGULAR TANK

While designing an underground tank the most crucial condition of the tank need to be kept under consideration. And that is when the empty and the soil surrounding the wall is wet. In this case the wall has to sustain the soil pressure.

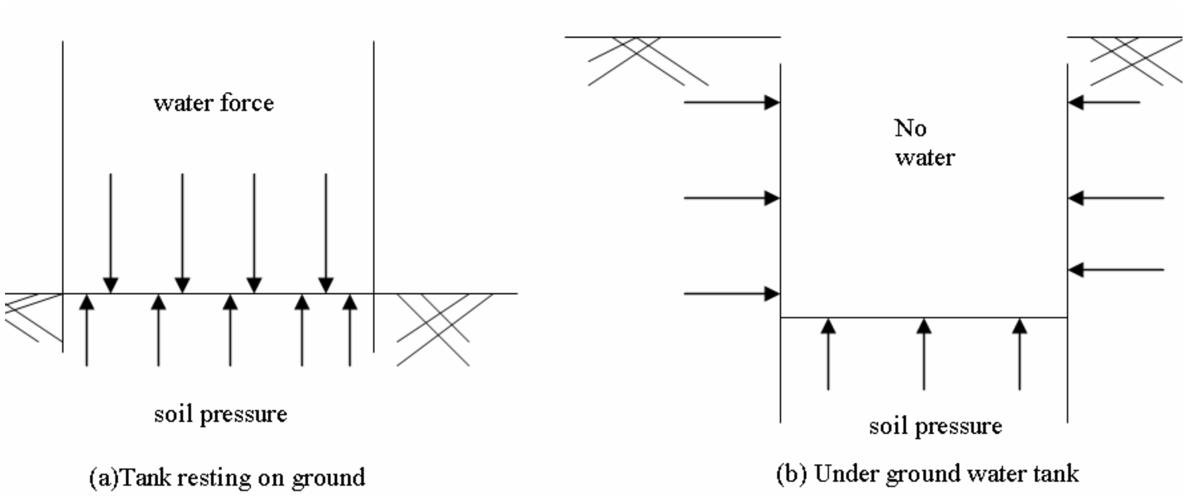


Figure 7.8 : Soil Pressure on Tank

Design of long walls

Maximum bending moment occurs for the case tank empty and surrounding soil is water logged. Long walls are designed as cantilever.

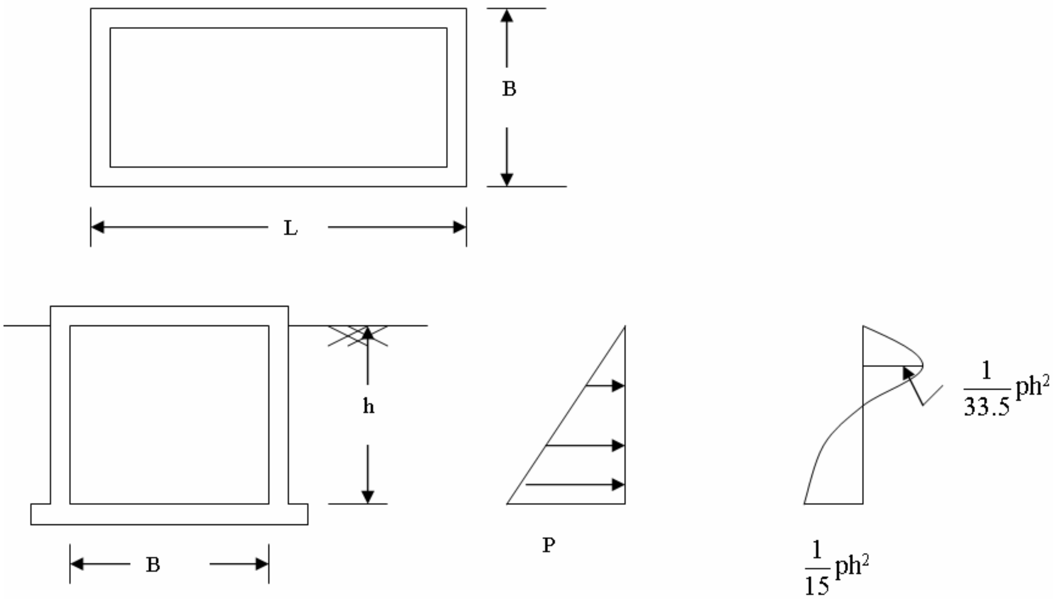


Figure7.9 : Moment diagram in tank walls

Pressure exerted by wet soil

$$P = \frac{wh(1-\sin\theta)}{1+\sin\theta} \tag{7-23}$$

Considering 1m run in the tank wall

$$M_{\max}\text{(Tension near water face)}=\frac{1}{33.5}ph^2 \tag{7-24}$$

$$M_{\max}\text{(Tension away from water face)} =\frac{1}{15}ph^2 \tag{7-25}$$

Thickness of wall is determined from the cracking consideration

$$D=\sqrt{\left(\frac{6M}{\sigma_{ct}b}\right)} \tag{7-26}$$

Steel area is calculated as follows

$$A_s = \frac{M}{\sigma_{st}\, jd} \tag{7-27}$$

Horizontal reinforcement are provided at 3% of gross area up to 100mm thick section. It can be reduced to 0.2% up to 450 mm thick section. For 225 mm thickness provide two layers of reinforcement.

Design of short wall

Short walls are designed as spanning between the long walls.
Intensity of earth pressure at bottom = P

Maximum moments at corners = $\frac{1}{12} pL^2$ (7-28)

Horizontal bars are determined as long wall. And vertical bars are provided with half spacing of horizontal bars.

Design of slab

The maximum moment at mid section = $\frac{1}{3} wL^2$ (7-29)

Distributing steel is provided usually 0.003 bt mm^2 /width.

Where, t = thickness of the slab
b = unit width

Minimum reinforcement

- The percentage of reinforcement in base or floor slab resting on ground must not be less then 0.15% of the gross section.
- Minimum cover to all reinforcement should be 25 mm or the diameter of the main bar which ever is greater.

7.6 DESIGN OF A ROOF TOP WATER TANK

Design Data:

Six storied building with 2 flat in each story.

Step 1:

Water requirement:

- Water consumption rate = 40 gpcd.
- Number of persons= no of flats X 6 =12 X 6 =72 persons (considering six persons per flat)
- Total water requirement=72 X 40=288 gal/day

$\therefore$ Daily water requirement $= \frac{2880}{6.24} cft \approx 462$ cft/day

Step 2:

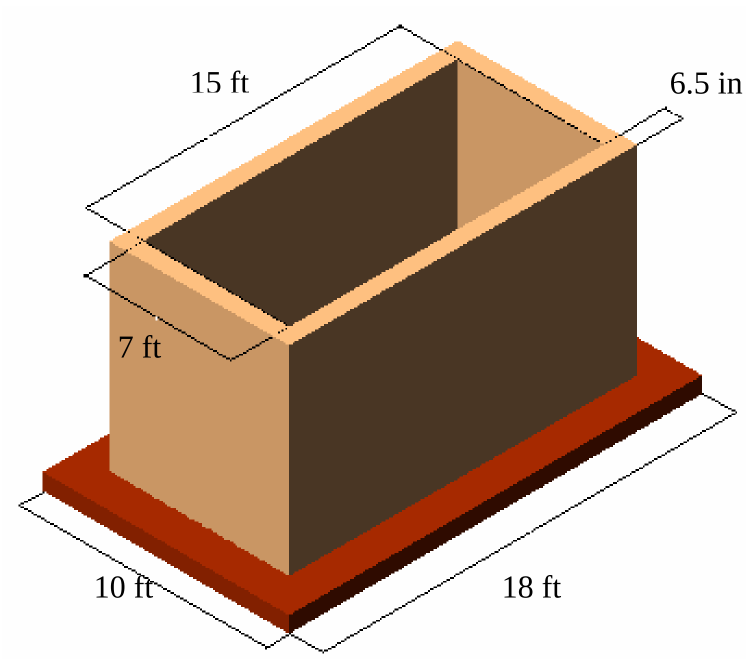
Tank dimension:

- Let inside Dimension

L=15 ft =4.572 m
B =7 ft =2.1336 m
So L/B=15/7>2

- Height of water level= $\frac{462}{15 \times 7} = 4.4$ ft
- Free board = 0.5 ft.

So, final height = 4.4+0.5=4.9 ft $\approx$ 5 ft



Step 3:

Maximum bending Moment:

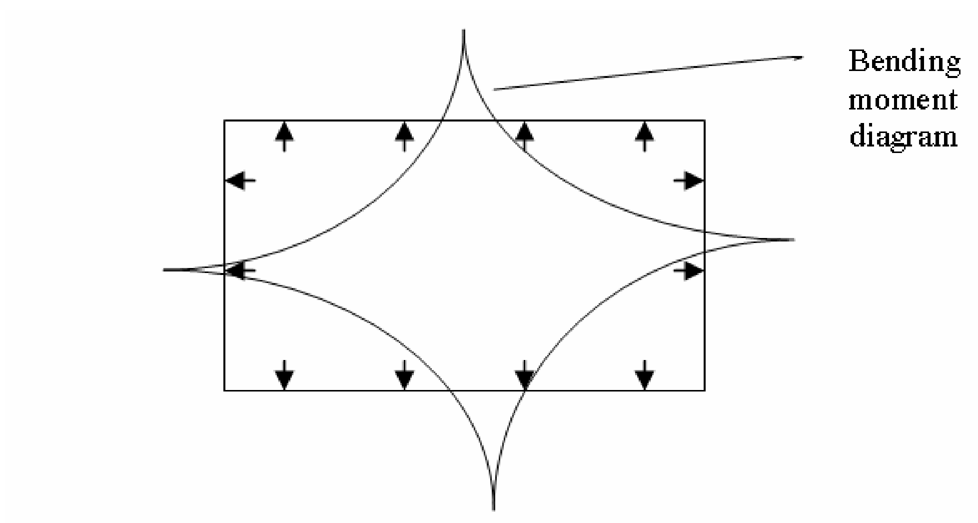


Figure 7.10 : Bending Moment Diagram on Tank Walls

Approximate Analysis:

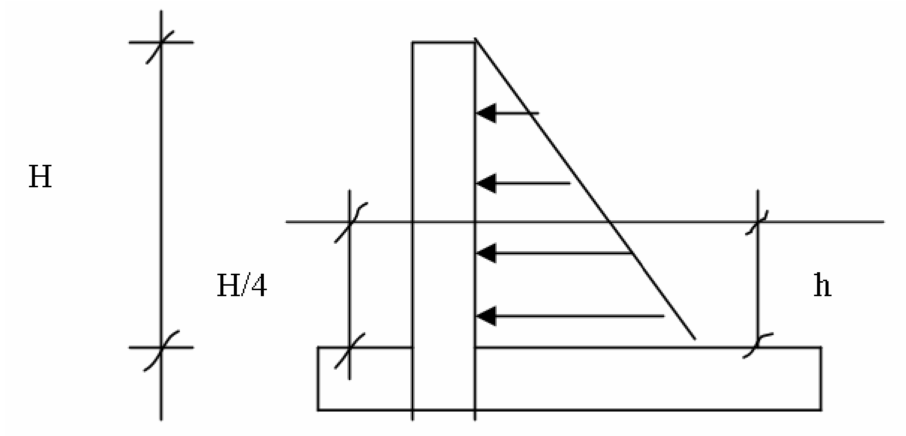


Figure 7.11 : Load diagram on tank wall

- Part 1

Here, h =H/4 or 1 m (larger height to be considered)

- Part 2

H-H/4) or (H-1) m to be considered.

For L/B>2

We have, h = H/4=5/4=1.25 ft $\approx$0.381 m <1m
$\therefore$ h =1 m =3.28 ft

Step 4:

Design for long wall:

Moment M = $\frac{wH^3}{6}$
Here, w= 9.81 kN/m^3 $\approx$10 kN/m^3
H=5ft=1.524 m

$$\therefore \text{M} = \frac{10\times1.524^3}{6} = 5.9 \text{ kN-M}$$
$$= \frac{5.9\times1000}{4.448\times0.3043} = 4351.35 \text{ lb-ft}$$
$$= 4.351 \text{ k-ft}$$
$$=52.22 \text{ k-in}$$

Check for

$$M_{\max} = \frac{1}{2} f_c kjbd^2$$
$$\Rightarrow d^2 = \frac{52.22\times1000}{0.5\times1350\times0.378\times0.874\times12}$$
$$\Rightarrow d = 4.41 inch$$

Overall depth=4.41+1+1.5X4/8=6.16 inch (considering # 4 bars)
Here,

$$f_c = 0.45 f_c' = 0.45\times3000 = 1350 psi$$
$$f_y = 40ksi$$
$$f_s = 0.5 f_y = 20ksi$$
$$n = \frac{E_s}{E_c} = \frac{29\times10^6}{57500\sqrt{3000}} \approx 9$$
$$r = \frac{f_s}{f_c} = \frac{20}{1.35} = 14.8$$
$$k = \frac{n}{n+r} = \frac{9}{9+14.81} = 0.378$$
$$j = 1 - \frac{k}{3} = 0.874$$

Let us take overall thickness of wall=6.5 inch
So effective depth =6.5-1-1.5 X4/8=4.75 inch

Then,

$$A_s = \frac{M}{f_s jd} = \frac{52.22\times1000}{20000\times0.874\times4.75} = 0.63 in^2/ft$$
$A_s(\min) = 0.3\%$ (of cross sectional area)
$$\Rightarrow \frac{0.3}{100}\times6.5\times12 = 0.234 in^2/ft$$

So, $A_s = 0.63 in^2 / ft$ (provide # 4 bar @ 4 inch c/c)

Direct tension in the wall, $T_L = w(H - h) \times \frac{B}{2}$

$= 10(1.524 - 1) \times \frac{2.1336}{2}$

$= 5.59 kN / m$

$= \frac{5.59 \times 1000 \times 0.3048}{4.448} = 383.06 lb / ft$

$\therefore A_s = \frac{T_L}{F_s} = \frac{383.06}{20000} = 0.019 in^2 / ft$

$A_s(\text{min}) = 0.234 in^2 / ft$

So # 3 bar @ 5.5 inch c/c to be provided

Since steel is provided on both faces therefore steel to be provided on both faces as # 3 bar @ 11 inch c/c.

Step 5:

Design for short wall:

- Force P=w (H-h)=10 x (1.524-1)= 5.24 kN/ m^2 =359.07 lb/ft (per m run)

- Effective span in horizontally spaced slab = 7+6.5/12=7.54ft =2.3 m
- Bending moment at end, M = $\frac{Pl^2}{12} = \frac{w(H-h)B^2}{12}$

  $\therefore M = \frac{5.24 \times 2.3^2}{12} = 2.31$ kN-m (per m run)
  =1703.83 lb-ft = 20.45 k in (per ft run)

- Reduction in moment due to tensile steel = Tx

  =383.06 x 1.5/12=47.88 lb-ft=0.575 k-in

- Design moment

  Design moment = M-Tx
  = 20.45-0.575
  = 19.875 k-in

- Steel requirement

$$A_s = \frac{M - Tx}{f_s jd} = \frac{19.875}{20 \times 0.874 \times 4.75} = 0.24 in^2 / ft$$

$$A_s(\min) = 0.234 in^2 / ft$$

$$\therefore A_s = 0.24 in^2 / ft$$

We will use # 3 bar @ 5.5 inch c/c.

- At mid section

$$M = \frac{PL^2}{24} = \frac{1}{2} \times \frac{PL^2}{12} = 10.23 kin$$

$$\therefore A_s = \frac{10.23}{20 \times 0.874 \times 4.75} = 0.123 in^2 / ft < A_s(\min)$$

So A_s will be provided as # 3 bar @ 5.5 c/c at mid section.

Step 6:

Cantilever effect on short column:

- Maximum moment

$$M_{\max} = \frac{wHh^2}{6} kN.m = \frac{10 \times 1.524 \times 1^2}{6} = 2.54 kN.m$$

= 1873.50 lb-ft

= 22.482 k-in

- Steel requirement

$$A_s = \frac{M}{f_s jd} = \frac{22.482}{20 \times 0.874 \times 4.75} = 0.271 in^2 / ft > A_s(\min) = 0.234 in^2 / ft$$

So, use # 3 bar @ 4.5 inch c/c.

Step 7:

Design of base slab

- L/B>2, so we will design for one way slab
- Minimum thickness of base slab

  For 60-grade steel,

  $$t = \frac{L}{20} = \frac{7 \times 12}{20} = 4.2 \text{ inch}$$

  For 40 grade steel,

  $$t = 4.2\left(0.4 + \frac{f_y}{100000}\right) = 4.2\left(0.4 + \frac{40000}{100000}\right) = 3.36 inch \approx 3.5 inch$$

- Let thickness = 6inch

  Total weight of base slab= $\frac{6}{12} \times 150 + \frac{4.5 \times 7 \times 15 \times 62.5}{7 \times 1.5 \times 1000} = 0.36 \text{ ksf}$

- Effective width, B= $7 + 2 \times \frac{6}{12 \times 2} = 7.5 \text{ ft}$
- Moments, $M_{\max} = 0.36 \times \frac{7.5^2}{8} = 2.53$ kft=30.375 k-in
- Depth $d = \sqrt{\frac{30.375}{0.9 \times 1.35 \times 0.874 \times 0.378 \times 12}}$ =3.37 inch (OK)

  $$\therefore A_s = \frac{30.373}{20 \times 0.874 \times 4.25} = 0.41 in^2 / ft$$

  $$\left[d = 6 - 1 - 1.5 \times \frac{4}{8} = 4.25 inch \right]$$

  Use # 4 bar @ 5inch c/c. So # 4 bar @ 10 inch c/c should be used at each face.

Step 8: Detailing

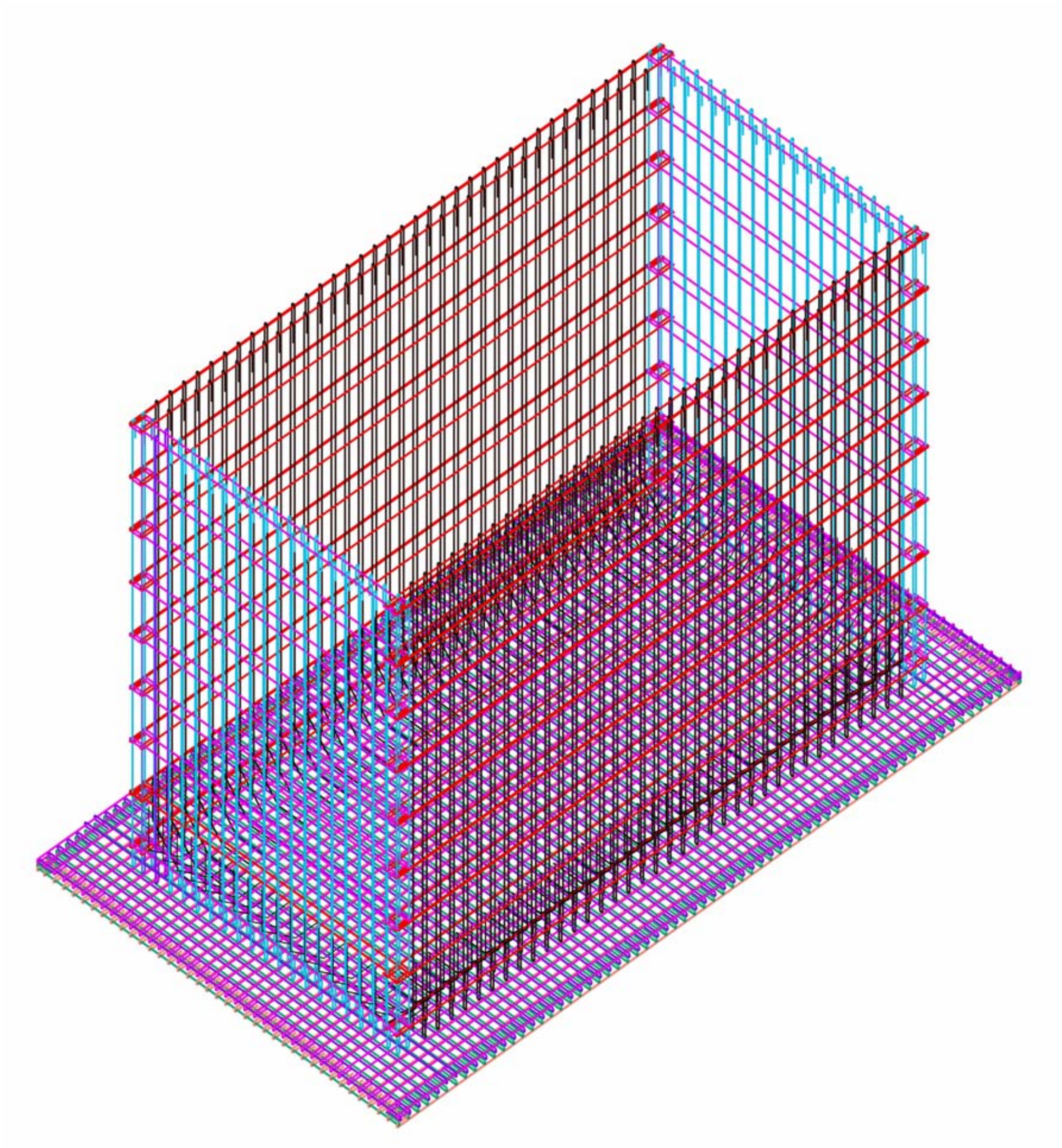


Figure 7.12: Detailing of example

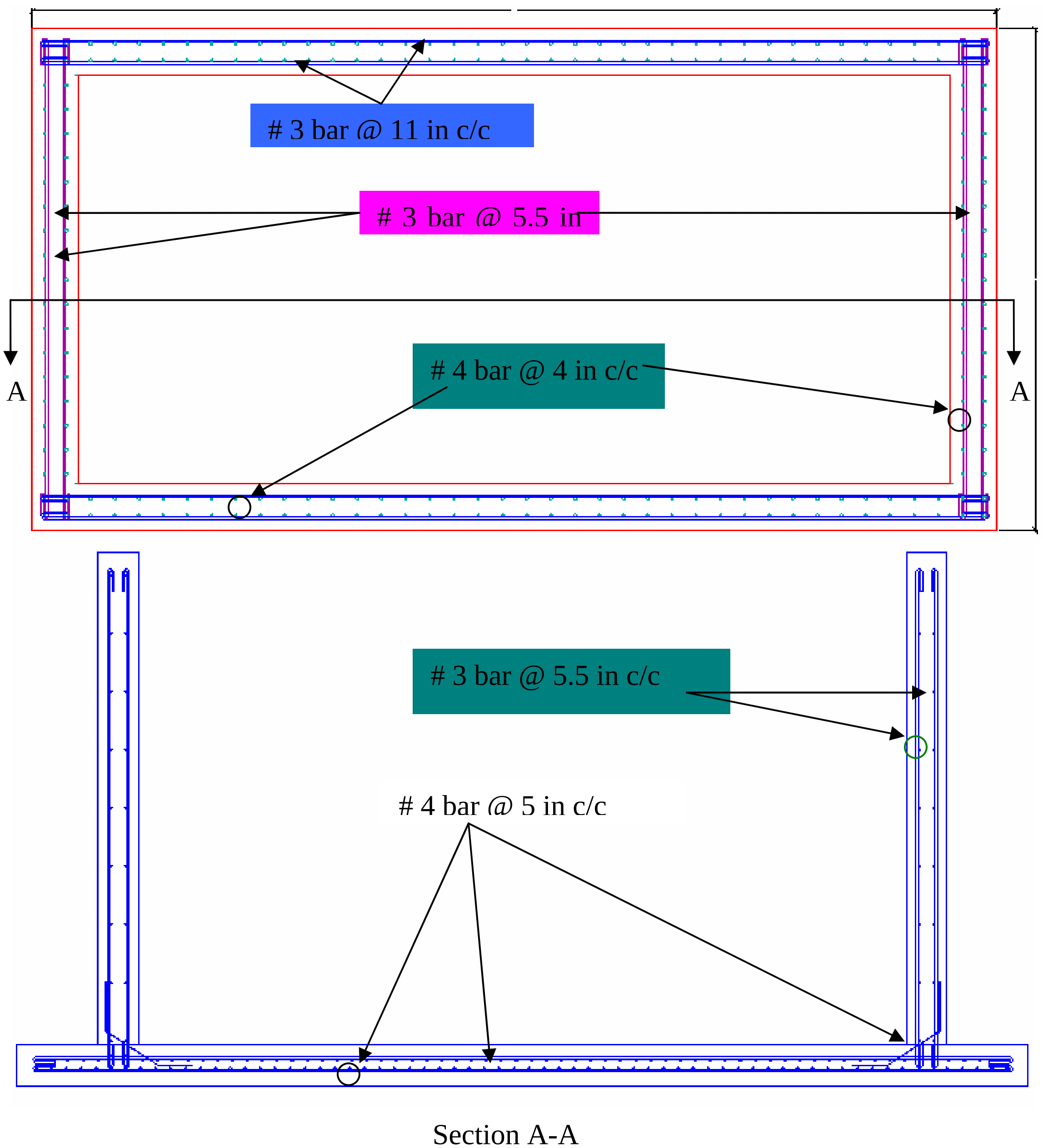


Figure 7.12: Detailing of example (continued)

7.7 DESIGN OF UNDERGROUND WATER TANK

General data:

- Volume to be stored= $2 \times 462 = 924$ cft
  (For two days store daily requirement 462 cft)
- Angle of repose $\phi_{dry} = 30^\circ, \phi_{wet} = 6^\circ$
- Unit weight of soil=w=125 pcf=20 kN/ m^2
- Most critical condition: Empty water tank and wet soil.

Step 1: Tank dimension

Let inside dimension, L=15 ft = 4.512 m.
B =7 ft = 2.1336 m.

So height of water level = $\frac{924}{15 \times 7} = 8.8\,ft$

Free board = 0.3 ft

Final height = 8.8+ 0.5 = 9.3ft $\approx$ 2.896 m.

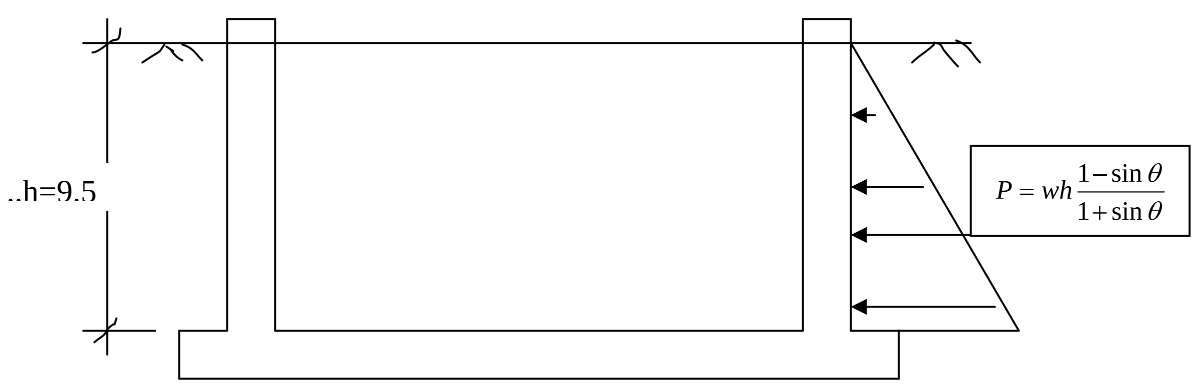


Figure 7.13: Cross section of ground water tank

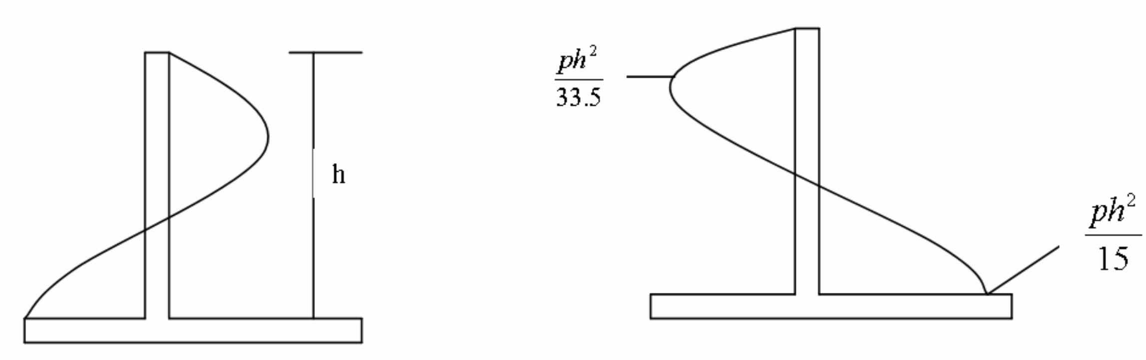


Figure 7.14: Moment diagram of tank wall

Step 2: Design of long walls

- Pressure exerted by wet soil $= wh\dfrac{1-\sin\theta}{1+\sin\theta}$ (7-30)

$$= 20 \times 2.896 \times \frac{1-\sin 6}{1+\sin 6} = 46.96 kN/m^2$$

$\therefore\ p = 46.96 kN/m^2$

- Tension near the water face$= \dfrac{ph^2}{33.5} = \dfrac{46.96 \times 2.896^2}{33.5} = 11.76$ kN-m

$$= \frac{11.76 \times 1000}{4.448 \times 0.3048} \times \frac{12}{1000}$$

=104.05 k-in (Per inch run)

So, tension near water face/ ft run=104.05 x 0.3048 = 31.72 kip inch

- Tension away from water face

$$M_{\max} = \frac{ph^2}{15} = \frac{46.96 \times 2.896^2}{15} = 26.26 \text{ kN/m}$$

=232.40 k-in (per inch run)

=70.84 kin (per ft run)

- From cracking consideration the thickness of wall is determined.

  Let, D = Total thickness

$$M = \frac{F_{ct} \times bD^2}{6}$$
$$\therefore D^2 = \frac{6M}{f_{et} \times b} = \frac{6 \times 70.80}{0.411 \times 12} = 86.18 in^2$$

D = 9.28 in $\approx$ 9.5 in

Here $f_{ct} = (6 \rightarrow 8)\sqrt{f_{c'}}$
Let, $f_{ct} = 7.5\sqrt{f_{c'}} = 7.5 \times \sqrt{3000} = 411 psi$
$M_{\max}$ = 70.84 k-in

$\therefore$ Effective depth =9.5-1.5 = 8 inch
$\therefore$ d = 8 inch

Step 3: Vertical reinforcement (long walls)

- Steel requirement, $A_s = \frac{M}{f_s jd} = \frac{70.84}{20 \times 0.874 \times 8} = 0.51 in^2 / ft$

  $A_s(\min) = .003bt = .003 \times 12 \times 9.5 = 0.342 in^2 / ft$
  $A_s = 0.51 in^2 / ft$

  So use# 4 bar @ 4.5 inch c/c (inner force)

- Steel requirements for M=31.72 kip in

$$A_s = \frac{31.72}{20 \times 0.874 \times 8} = 0.227 in^2 / ft < A_s(\min)$$
$$\therefore A_s = 0.342 in^2 / ft$$

So, use # 4 bar @ 7 inch c/c (Outer force)

Step 4: Horizontal reinforcement (long walls)

- Minimum steel requirements

$$A_s(\min) = .003bt = 0.342 in^2 / ft$$

Use # 4 bar @ 7 inch c/c

Step 5: Design of shot wall

- Earth pressure at the bottom P=46.96 kN/ m^2
- Maximum moment at the center, M = $\dfrac{PL^2}{12}$

$$\therefore M = \frac{46.96 \times 2.375^2}{12}$$

=22.07 k-in (per m length)
=195.35k-in (per in length)
=59.55 k-in (per ft length)

$$L = 7 + \frac{9.5}{12} = 7.79\, ft = 2.375\,\text{m}$$

In FPS system,

$$M = \frac{PL^2}{12} = \frac{0.963 \times 7.79^2}{12} \times 12 = 58.44 \text{ k-in (per ft length)}$$

- Now,

$$M_{\max} = \frac{f_c}{2} kjbd^2$$

$$\Rightarrow d = \frac{2 \times 195.36}{1.35 \times 0.37 \times 0.874 \times 3.28 \times 12} = 4.72 inch < 8 inch$$

Step 6: Vertical reinforcement (shot wall)

$$A_s = \frac{M}{f_s jd} = \frac{39.55}{20 \times 0.874 \times 8} = 0.48 in^2 / ft$$

Use # 4 bar @ 5 inch c/c.

Step 7: Horizontal reinforcement (shot wall)

$A_s\,(\text{min}) = 0.342 in^2\ /\ ft$

Use # 4 bar @ 7 inch c/c that is 14 inch c/c both side.

Step 8: Design of base slab

- Thickness provided = 9.5 inch
- Minimum reinforcement = 0.003bt = 0.342 $in^2\ /\ ft$

Use # 3 bar @ 3.5 inch c/c.

Step 9: Detailing

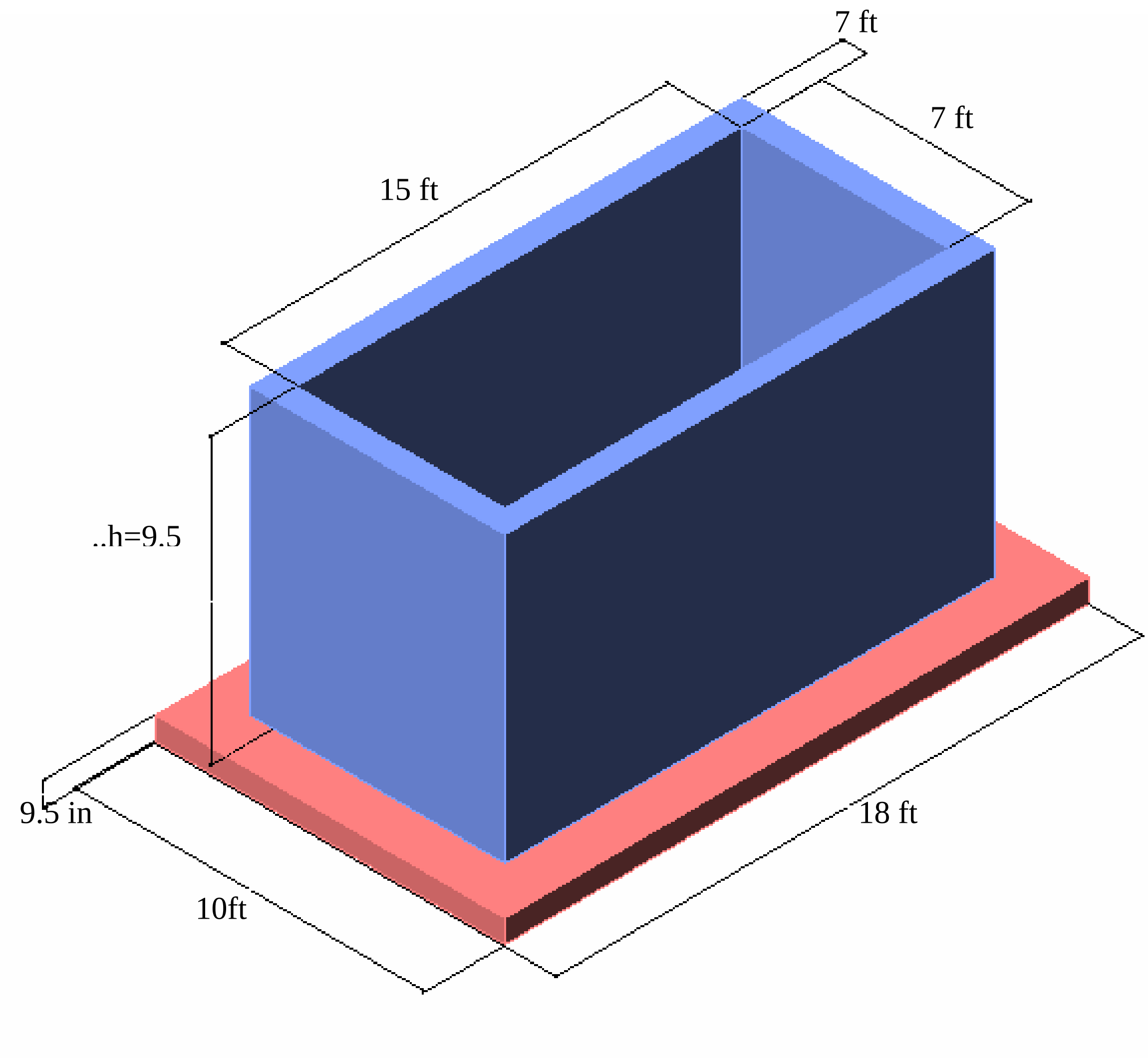
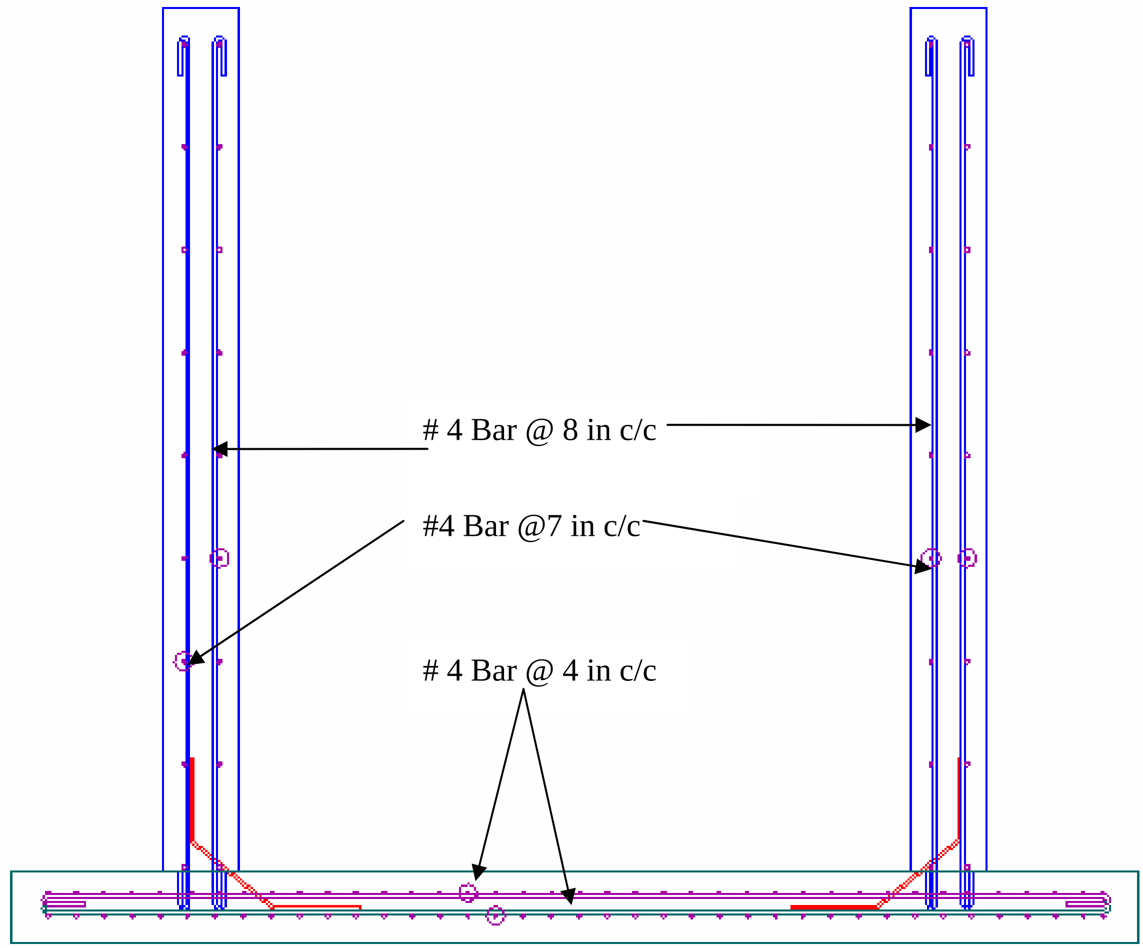
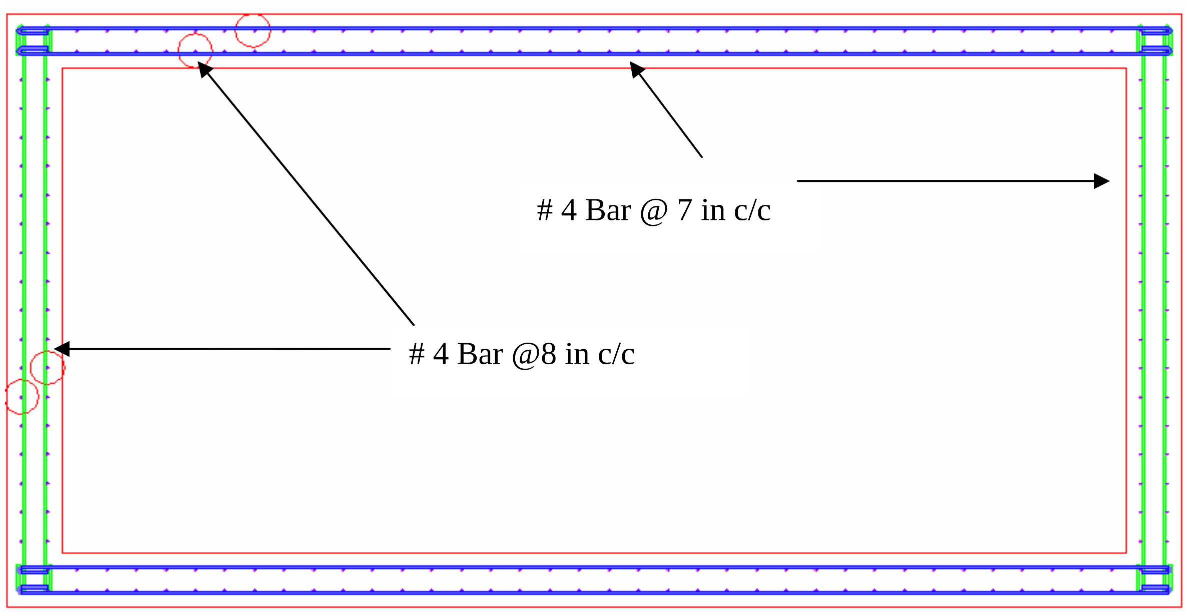


Figure 7.15: Tank dimension



Section A-A



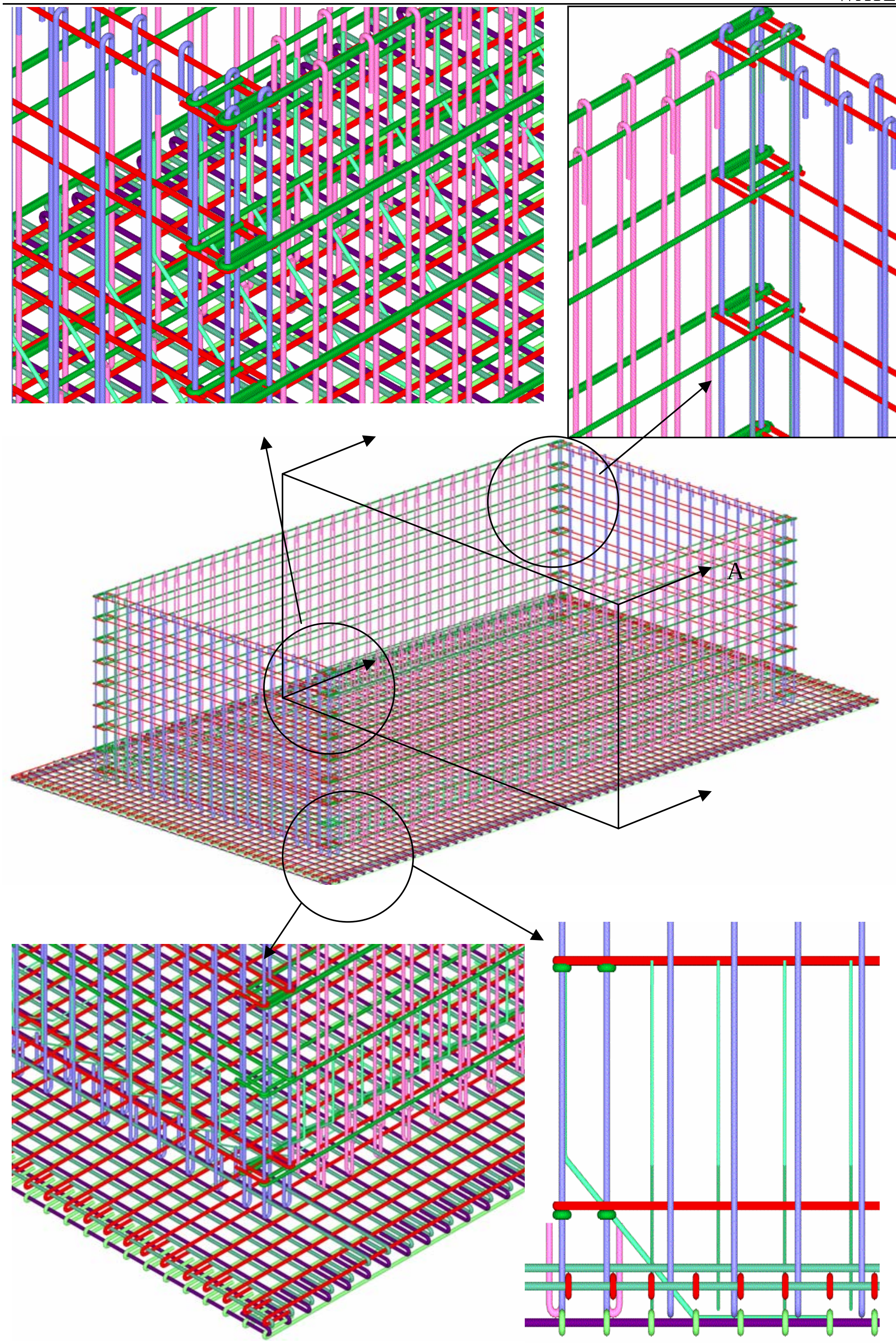


Figure 716: Detailing of example (continued)