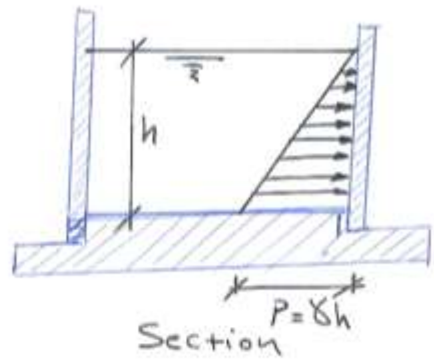
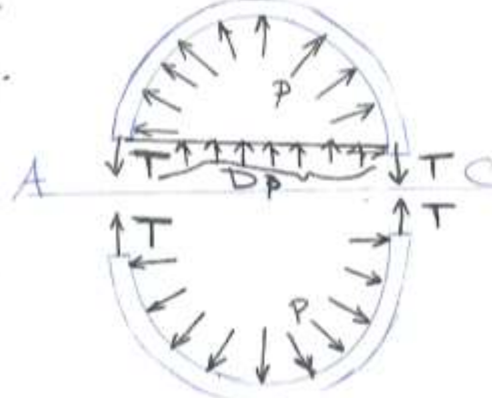
Design Circular Concrete Tanks:

Case one: Wall not monolithic with the base:

* In Designing water tanks, Working Design Method is used.
* Analysis & design of Sections Consider that the concrete is uncracked concrete, i.e. the tensile stresses in concrete is smaller than (f_r) to prevent lekage.





a- Main Reinforcement:-

Total Pressure on Diameter

$$Ac = DP$$

$$2T = DP$$

$$\therefore T = \frac{DP}{2} = \frac{\gamma h D}{2} \text{ per meter of wall height}$$

γ = density of water = 10 kN/m³

T = hoop tension in wall (circumferential tension)

Steel is required to resist this hoop tension

$$A_{st} = \frac{T}{\text{allowable steel stresses in tension}} = \frac{T}{f_{st}} \ (mm^2)$$

$$f_{st} \leq 80 \text{ MPa} \quad \text{(in order to prevent lekage)}$$

A_{st} = Steel per 1m height

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b:- Wall thickness

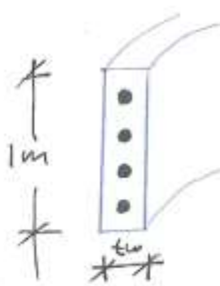
t_w = thickness of the wall

equivalant area = (area of 1m of wall)

$$A_{eq} = 1000\, t_w + (n-1) A_{st} \quad (mm^2)$$

This area must resist tensile stresses without cracking.

$$T = \{1000\, t_w + (n-1) A_{st}\} f_{ct}$$



f_{ct} = Tensile Stress in Concrete

n = modular ratio = $\frac{E_s}{E_c}$

$$\therefore\ t_{min}\ \text{required} = \frac{1}{1000}\left[\frac{T}{f_{ct}} - (n-1) A_{st}\right] \ (mm)$$

Usually good quality concrete is used

[for example concrete mix (1:1.5:3) (Cement: Sand: gravel) is used to produce concrete use in tanks. This concrete give a Tensile strength ≥ 1.38 MPa

n = 15] but use $f_{ct} = 1.38$ MPa

min t = 100 mm but t_{min} = 125 mm is preferd

or use t = 125 mm for h = 0 to 6 m

t = 150 mm for h = 6 m to 9 m etc.

or t_{min} from above equation (choose whichever is greater)

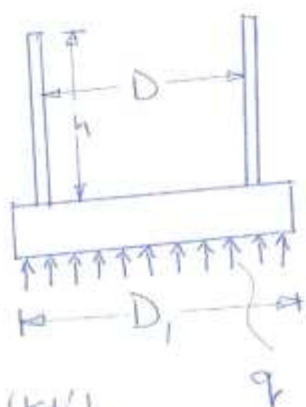
C: Secondary Reinforcement :-

Provide Secondary Reinf. (vertical) = 0.2 → 0.3% of wall area.

$$A_{s\,secondary} = \frac{0.25}{100} \times 1000 \times t_w \qquad \text{(for one meter)}$$

d: Base Slab:-

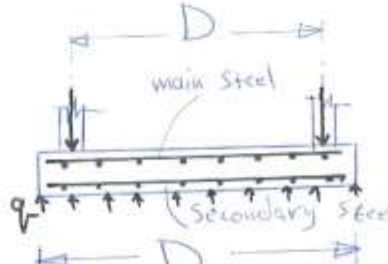
When the tank is empty the Earth Pressure due to dead loads of the walls cause Negative moments (Tension on the top & compressive at the bottom of the slab). This pressure can calculate as follows:-



$$W_t \text{ of side walls} = \pi (D+t) \times t \times h \times 24 \quad (kN)$$

$$q = \text{upward pressure} = \frac{\text{weight}(W)}{\frac{\pi}{4} D^2}$$

$$\text{Max. B.M. at Center} = \frac{qD^2}{16}$$



The slab is consider is simply supported.

∵ In both sides the parts of tank is symetrical, the half of load is transmitted in all directions.

Min depth of base slab is 150 mm ⟶ 200 mm

Provide main Reinforcement for this B.M. at top in both directions & provide (0.2-0.3)% secondary Reinf. in both directions at bottom of slab.

e- Bearing Capacity:-

Check the allowable bearing capacity of soil when tank is full of water.

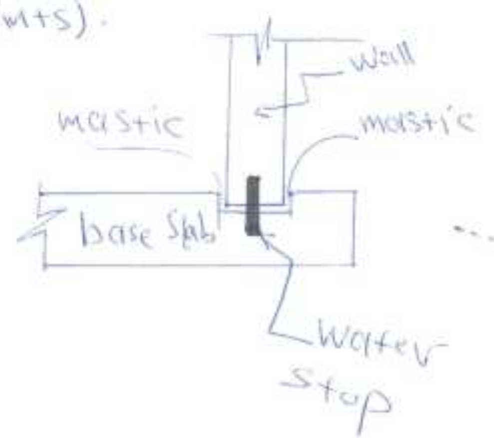
$$W_{water} + W_{walls} + W_{slab} = W$$

$$q_{net} = \frac{W}{\frac{\pi}{4} D_1^2} \leq q_{allowable}$$

If more increase the area of the base slab.

f- Other Requirements:-

Water stop (Rubber) must be provide at the joint between the base slab & the walls in all types of tanks. (and at the construction joints).



Example:- Design a cylindrical water tank for 300,000 liter Capacity, assume the wall is not monolithic with the base. Given $f_{st} = 80 MPa$, $f_{ct} = 1.38 MPa$, $n=15$, $f_c = 8$.

Solution:-

1000 litre = $1 m^3$

∴ Required Capacity = $300 m^3$

* take height of the tank = 4.5 m

* Capacity = Volume of water = $\frac{\pi D^2}{4} * h = 300 m^3$

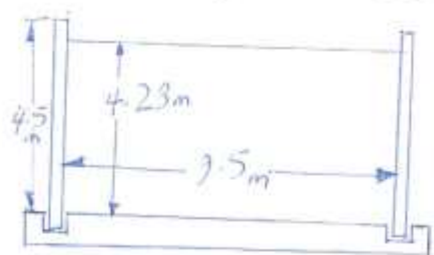
$\therefore D = \sqrt{\frac{4*300}{\pi * 4.5}} = 9.2 m$

∴ Take the diameter of tank (inside) = 9.5 m

Then capacity = $\frac{\pi}{4} D^2 * h = \frac{\pi (9.5)^2 * (4.5)}{4} = 318.97 m^3 > 300 m^3$ o.k.

$D = 9.5 m$, $h = 4.5 m$

$h_{water} = \frac{4*300}{\pi (9.5)^2} = 4.23 m$



a. Reinforcement (Main):-

$T = \frac{1}{2} \gamma * D * h = \frac{1}{2} * 10 * 4.5 * 9.5 = 213.75 kN/m'$

$A_{st} = \frac{T}{f_{st}} = \frac{213.75 \times 1000}{80} = 2671.88 mm^2/m' \simeq 2672 mm^2/m'$

b. Thickness of Wall (t):-

$\min t = \frac{1}{1000}\left[\frac{T}{f_{ct}} - (n-1)A_{st}\right] = \frac{1}{1000}\left[\frac{213.75 \times 10^3}{1.38} - (15-1) * 2672\right]$

$= 117.48 mm \Rightarrow$ use $t = 125 mm$

A_{st} = Steel per 1m height

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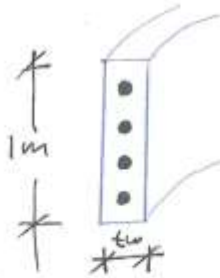

f_{ct} = Tensile Stress in concrete

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$$\therefore\ t_{min\ required} = \frac{1}{1000}\left[\frac{T}{f_{ct}} - (n-1)A_{st}\right] \ (mm)$$

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$n = 15$] but use $f_{ct} = 1.38$ MPa

min $t = 100$ mm but $t_{min} = 125$ mm is preferd

or use $t = 125$ mm for $h = 0$ to 6m

$t = 150$ mm for $h = 6$m to 9m etc.

or t_{min} from above equation (choose whichever is greater)

Use main reinforcement at different heights.

$T = \frac{1}{2}\gamma D h = \frac{1}{2} * 10 * 9.5 * h = 47.5h\ (kN) = 47500\ h\ (N/m)$

$A_{st} = \frac{T}{80}$

Devide the height in two strips (Rings), 1m each

depth h(m)	T=47500h(N)	$A_{st}=\frac{T}{80}$ (mm²)	ø	Vertical spacing	if on two faces
4.5 - 3.5	213 750	2672	ø16	75mm	150mm
3.5 - 2.5	166 250	2078	ø16	90mm	180mm
2.5 - 1.5	118 750	1484	ø16	130mm	260mm
1.5 - 0	71 250	891	ø16	225mm	450mm

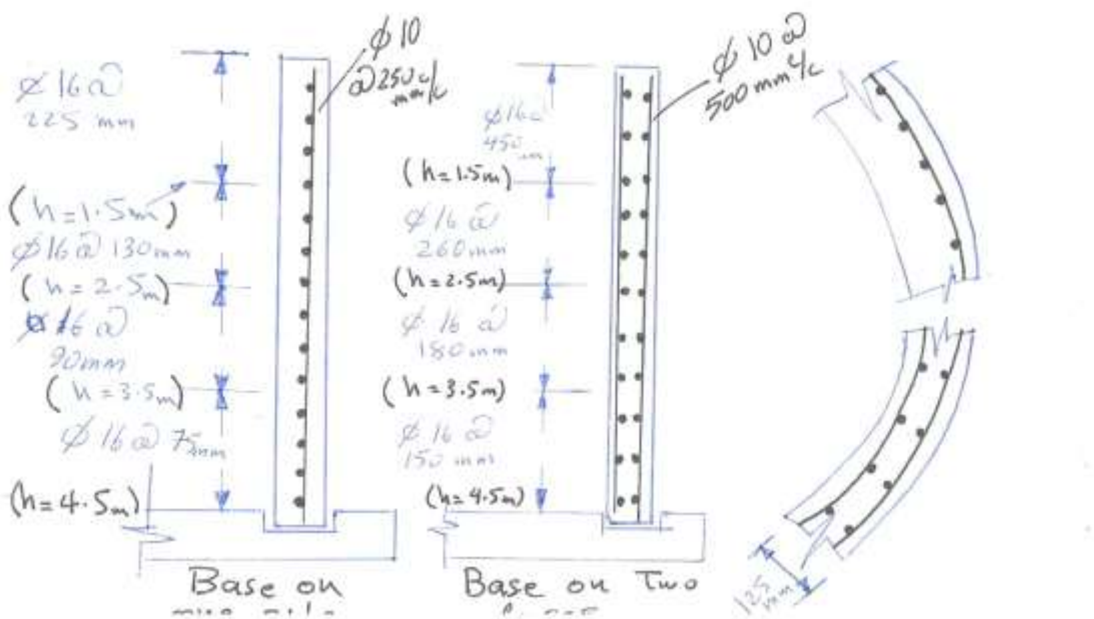
$A_b = 201\ mm^2$, $N = \frac{A_{st}}{201}$, $S = \frac{1000}{N} = \frac{201 * 10^3}{A_{st}}$

C:- Secondary Reinforcement :-

Provide $0.25\% = \frac{0.25}{100} * 1000 * 125 = 312\ mm^2/m$

Use ø10mm $A_b = 79\ mm$ $N = \frac{312}{79}$, $S = \frac{1000}{312/79} = 253\ mm$

Use ø10mm @ 250mm c.c.



d- Base Slab :-

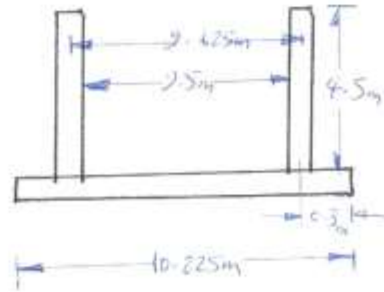
When the tank is empty :-

W_w = load or weight of the walls $= \pi (9.5 + 0.125) \times 0.125 \times 4.5 \times 24$

$= 408.2$ kN

q = Intensity of soil pressure below the base slab

$$q = \frac{W_w}{\frac{\pi}{4}(10.225)^2} = \frac{408.2}{\frac{\pi}{4}(10.225)^2} = 4.97\ kN/m^2$$

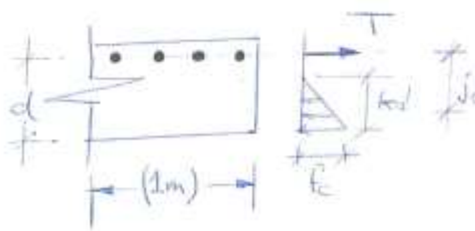


Max B.M. at the center of slab $= \frac{qD^2}{16}$ (simply supported)

أن البعد الباقي من البلاطة قليل ضا العزم السالب لأن
هنا لا يؤخذ بنظر الاعتبار وذلك في الحالات الآمنة
عليه تأخذ الفضاء الصافي

S = 9.5m

$$B.M. = \frac{4.97(9.5)^2}{16} = 28\ kN.m/m$$



$$k = \frac{n}{n+r} = \frac{15}{15 + \frac{80}{8}} = 0.6$$

$$J = 1 - \frac{k}{3} = 0.8$$

$$M = 0.5 f_c\, kd\, b\, jd = 0.5\, f_c\, k\, j\, b d^2$$

$$d = \sqrt{\frac{28 \times 10^6}{0.5 \times 8 \times 0.6 \times 0.8 \times 1000}} = 120\ mm$$

Thickness of the slab = 120 + 40 + 30 = 190 mm (cover / 1.5 × φ)

Slab reinforcement :-

$f_{st} = 80$ MPa , J = 0.8 , $A_s = \frac{M}{f_s J d} = \frac{28 \times 10^6}{80 \times 0.8 \times 120} = 2500\ mm^2/m$

Use φ 20mm $A_b = 314\ mm^2$ $N = \frac{2500}{314}$

$S = \frac{1000}{2500/314} = 125.6\,mm$

Use ϕ 20mm @ 125 mm c/c in both directions.

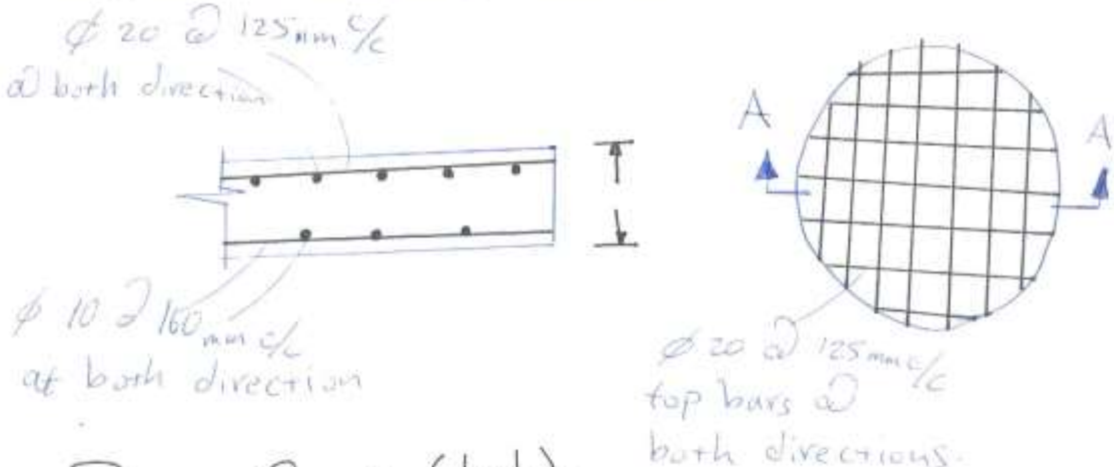
This Steel must be provided at top face of slab.

Provide secondary bars @ bottom 0.25%

$A_s = \frac{0.25}{100} * 1000 * 190 = 475\ mm^2/m$

$S = \frac{1000}{475/79} = 166\,mm$

Use ϕ 10mm @ 160mm c/c bars @ bottom in both direction



e:- Bearing Capacity (check):-

assume $q_{all} = 100\ kN/m^2$

when tank is full

W_T = wt of wall + wt of slab + wt of water

$= 408.2 + 0.190 \times 24 \times \frac{\pi}{4}(10.225)^2 + 10 \times 4.5 \times \frac{\pi}{4}(9.5)^2 = 3972.34\ kN$

Max Pressure on soil $= \frac{3972.34}{Area} = \frac{3972.34}{\frac{\pi}{4}(10.225)^2} = 48.38\ kN/m^2 < 100\ kN/m^2$

∴ o.k

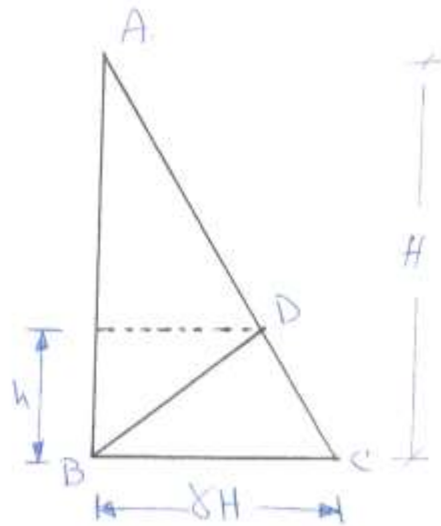
Case Two: Wall monolithic with the base:

In this method some portion of the tank at the base acts as a cantilever & some load at the bottom is taken by the cantilever effect.

The cantilever effect depends on the dimensions of tank & the thickness of wall.

i- for $\frac{H^2}{D.t}$ is between 6 to 12 the value of $h = \frac{H}{3}$ or (1m) which ever is more.

ii- for $\frac{H^2}{D.t}$ is between (12 to 30) the value $h = \frac{H}{4}$ or (1m) whichever is more.



Portion ABD is taken as Pressure causing hoop tension & DBC is taken as cantilever load.

The max. hoop tension occurs at D.

Example :- $H = 3.65m$, $D = 11.3m$, $t = 0.16m$

$$\frac{H^2}{D.t} = \frac{3.65^2}{11.3 \times 0.16} = 7.369 > 6$$

$$\therefore h = \frac{H}{3} = \frac{3.65}{3} = 1.22 > 1m$$

hence $h = 1.22m$

Calculation for Reinforcement where the Hoop Force is Max:-

$T = \frac{PD}{2} = \frac{10\ (3.65 - 1.22)}{3\ \ 2} * 11.3 = 137.3\ kN$

$A_s = \frac{T}{f_s} = \frac{137.3 * 10^3}{800} = 171.6.25\ mm^2$ use ϕ 12 mm

$S = \frac{1000}{(1716.25 / \frac{\pi}{4} * 12^2)} = 65.89\ mm\ c/c$

Use $S = 130\ mm\ c/c$ on both faces

Calculation of Max. B.M.:-

$B.M._{max} = \frac{1}{2}\ \gamma H \cdot h \cdot \frac{h}{3} = 9\ kN.m$

$M = A_s f_s \cdot jd \Longrightarrow d_{eff} = t - (cover + \frac{\phi}{2})$

$d = 160 - (40 + \frac{12}{2}) = 114\ mm$ 1160.1 $\simeq$ 1160 mm²

$A_s = \frac{M}{f_s j d} = \frac{9 * 10^6}{80 * 0.85 * 114} =$

Provide 12 ϕ @ 97 mm c/c USE ϕ12 @ 90 mm c/c

Nominal vertical reinforcement:

$\frac{0.25}{100} * 160 * 1000 = 400\ mm^2$

Provide $\frac{1000}{(400 / \frac{\pi}{4} * 12^2)} = 282.74\ mm\ c/c$

Use 560 mm c/c in each face.

E.X.:- Design a circular tank with fixed base, for a capacity of 400 m^3. The depth of water is to be 4.5m, including a free-board of 25cm. $f_c = 9 N/mm^2$, $f_{ct} = 1.2 N/mm^2$, $n = 9$, $f_s = 80 N/mm^2$. Bearing Capacity of soil = 70 kN/m^2.

Solution:- effective depth = 4.5 − 0.25 = 4.25m

$V = \frac{\pi}{4} D^2 * 4.25 = 400 m^3$

$D = 10.95$ Use $D = 11.0m$

$t_{min} = ?$ $T = \frac{1}{2} \gamma h D = \frac{1}{2} \times 10 * 4.5 * 11 = 247 \; kN/m$

$A_{st} = \frac{T}{f_{st}} = \frac{247 \times 1000}{80} = 3094 mm^2$

$t_{min} = \frac{1}{1000} \left[\frac{T}{f_{ct}} - (n-1) A_{st} \right]$, $n = \frac{E_s}{E_c} = \frac{200 \times 10^3}{4700\sqrt{f_c}}$

$= \frac{1}{1000} \left[\frac{247 \times 1000}{1.2} - (9-1) * 3094 \right]$

$= 181 mm$ use $t = 185 mm$

$\frac{H^2}{Dt} = \frac{(4.25)^2}{11 * 0.185} = 8.876$ (between 6-12)

$\therefore \frac{4.250}{3} = 1.4166 > 1m$

$\therefore h = 1.416m$

Design of Walls for hoop tension:-

Max. hoop tension $= \frac{\gamma (H-h) D}{2} = \frac{10(4.25 - 1.42) * 11}{2} = 155.65 \; kN$

Area of steel

$$A_s = \frac{T}{f_s} = \frac{155.65 \times 10^3}{80} = 1945.625\ mm^2$$

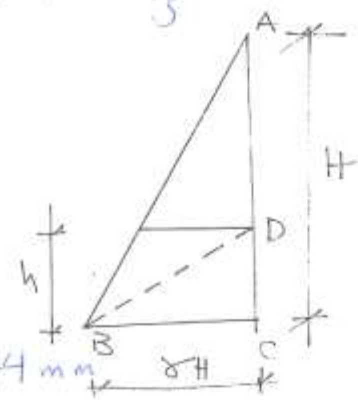
Use ϕ 12mm $A_b = 113\ mm^2$

$$S = \frac{1000}{1946/113} = 58 \simeq 60\ mm\ c/c$$

for both faces use $S = 120\ mm\ c/c$

Design for Cantilever Action:-

$$M_{max} = \frac{1}{2}\gamma H \cdot h \cdot \frac{h}{3} = \frac{1}{2} \times 10 \times 4.25 \times 1.42 \times \frac{1.42}{3} = 14.28\ kN.m/m$$



$$M = \frac{1}{2} f_c\, k d\, b j d$$

$$k = \frac{n}{n+r} = \frac{9}{9+\frac{80}{9}} = 0.5$$

$$j = 1 - \frac{k}{3} = 1 - \frac{0.5}{3} = 0.83$$

$$d = \left(\frac{2 \times 14.28 \times 10^6}{9 \times 0.5 \times 1000 \times 0.83}\right)^{\frac{1}{2}} = 87.44\ mm$$

Thickness of the wall $t = 87.44 + 40 + \frac{12}{2} = 133.44\ mm < 185\ mm$ ∴ ok

$$M = A_s f_s j d \Longrightarrow A_s = \frac{M}{f_s j d} = \frac{14.28 \times 10^6}{80 \times 0.83 \times (185 - (40+6))} = 1547\ mm^2/m$$

$$S = \frac{1000}{1547/113} = 73\ mm\ c/c$$ ∴ use ϕ12mm @ 70mm c/c

nominal Vertical Reinforcement = (0.2 - 0.3)% of gross concrete area:-

Use 0.3% $\Rightarrow A_{s\,secondary} = \frac{0.3}{100} * 185 * 1000 = 555\ mm^2/m'$

for two faces $A_s = \frac{555}{2} = 277.5\ mm^2/m'$

$S = \frac{1000}{277.5/113} = 407.2 \Rightarrow$ use $S = 400\ mm\ c/c$ for both faces.

Design of Base Slab :-

Critical case when tank is empty

Load from wall $= \pi (11 + 0.185) * 4.5 * 0.185 * 24$
$= 644.28\ kN$

Intensity of soil Pressure $= \frac{644.28}{\frac{\pi}{4} * (12.34)^2} = 5.39\ kN/m^2$

Max B.M. $= \frac{3}{16} q$