Concrete and **W**ater **T**ank **D**esign

Introduction

Reinforced Concrete Water Tanks

Type of Water Tanks based on shape:

1. Cylindrical tank
2. Rectangular tank

Type of Water Tanks based on location:

1. on grounds Tanks
2. Underground tanks
3. Elevated (Overhead) tanks

Water Tank Components:

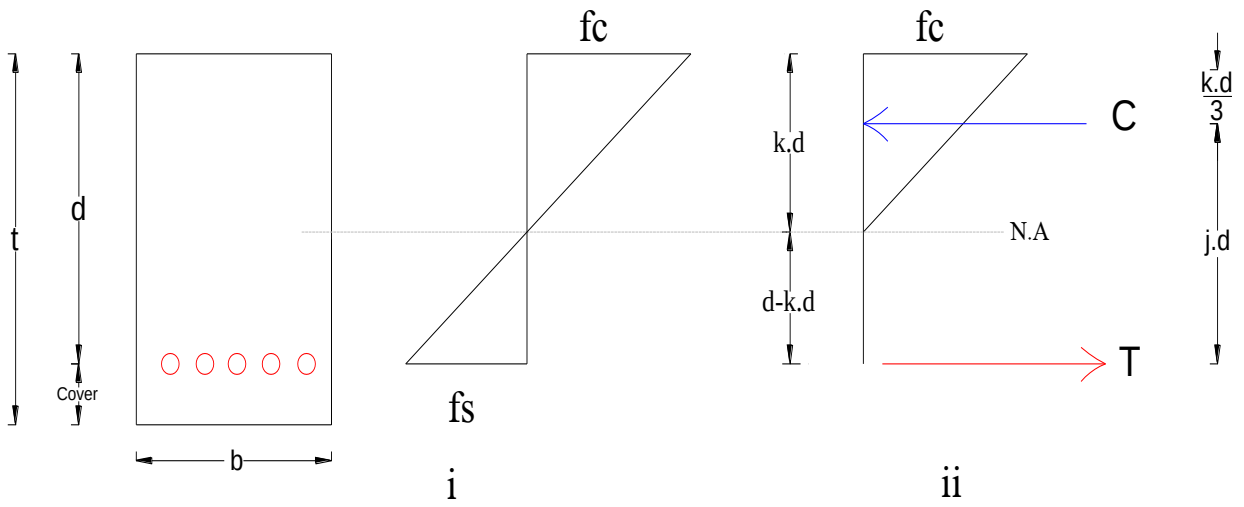
1. Side Walls [Rectangular or cylindrical]
2. Base slab
3. Cover slab or dome
4. Columns, Beams, Bracings for (Elevated tanks).

Types of Joints:

1. Flexible base.
2. Fixed base
3. Hinged base.

Working Stress Method for Beams

Working Stress Method



Stress Diagrams

f_c = The allowable compressive stress of the concrete

f_s = Allowable tensile stress in steel

f_t = The allowable tensile stress of the concrete

$$M = T * j * d = C * j * d$$

1. Determine the Total Applied Load, Wt

   Wt = D.L + L.L

2. Determine the Bending Moment, M

3. Determine the effective depth {d}

   $$M = C * j * d$$

$$M = \frac{1}{2} * fc * k \,.\, d * b * j * d$$

$$M = \frac{1}{2} * fc * k * b * j * d^2$$

$$d = \sqrt{\frac{2 * M\,max}{fc * k * J * b}}$$

4. Determine the area of Steel Reinforcement , As = mm^2

$$M = T * j * d = C * j * d$$

$$M = T * j * d$$

$$\because \; f_s = \frac{T}{As}$$

$$\therefore \; As = \frac{T}{fs}$$

$$\therefore \; M = As * fs * j * d$$

$$As = \frac{M}{fs * j * d}$$

$$j \,.\, d = d - \frac{k \,.\, d}{3}$$

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

$$K = \frac{n}{n+r}$$

$$n = \frac{Es}{Ec}$$

$$r = \frac{fs}{fc}$$

$$fc = 0.35\, \bar{fc}$$

5. Determine the number of bars, no. bars

   Choose ∅ Diameter and Area from Rebar Table

   No. bars = $\frac{As}{Ab}$

   Use No. bars ∅ for Top or Bottom (End or mid) of beam

6. Assume the Stirrups Steel bars ∅ @ mm

7. Determine Beam thickness

   t_{beam} = d + cover

8. Determine Reinforcement Ratio

   $\% \rho min$ = 0.3 – 0.1* ($\frac{t-100}{350}$)

Rebar Table

Rebar Diameter (mm) (∅)	Area of Rebar (A_b) (mm^2)
8	50
10	79
12	113
16	201
20	314
25	490
28	615
32	804
36	1017
40	1257

9. Determine Minimum Area of Steel Reinforcement

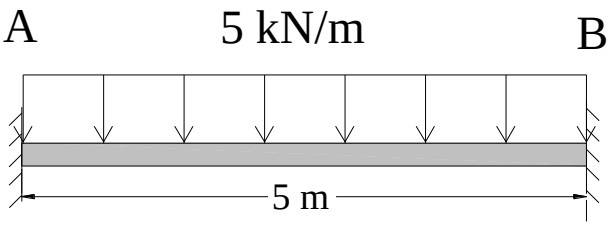
$A_{s\,min} = \%\,\rho\,min * t * b$

$As = \dfrac{M}{fs * j * d}$, Check

- If $As = \dfrac{M}{fs * j * d} > \dfrac{As\,min}{2}$, $\therefore$ o.k.
- If $As = \dfrac{M}{fs * j * d} < \dfrac{As\,min}{2}$, use $As = \dfrac{As\,min}{2}$

10. Beam Reinforcement Details

Example: Design the Beam AB Below by using Working Stress Method ;



Dead Load, D.L = 10 kN/m

Live Load, L.L = 5 kN/m

The allowable compressive stress of the concrete, fc = 10 N/mm^2

Allowable tensile stress in steel, fs = 150 N/mm^2

Modulus of elasticity of steel, Es = 200000 Mpa

Modulus of elasticity of Concrete, Ec = 20000 Mpa

Beam Width, b = 250 mm

Solution:

1. Determine the Total Load Applied , Wt

   Wt = D.L + L.L

   Wt = 10 + 5

   Wt = 15 kN/m

- $M_{MAX} = M_{END}$

2. Determine the Bending Moment at end, M_{END}

   $M_{END} = \frac{W L^2}{12}$

   $M_{END} = \frac{15 * 5^2}{12}$

   M_{END} = 31.25 kN.m

3. Determine the effective depth {d}

- $n = \frac{Es}{Ec}$ (Modular Ratio)

  $n = \frac{200000}{20000}$

  $n = 10$

- $r = \frac{fs}{fc}$ (Stress Ratio)

  $r = \frac{150}{10}$

  $r = 15$

- $K = \frac{n}{n+r}$

  $K = \frac{10}{10+15}$

  $K = 0.4$

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

  $j = 1 - \frac{0.4}{3}$

  $j = 0.866$

  $d = \sqrt{\frac{2 * M\ max}{fc * k * j * b}}$

  $d = \sqrt{\frac{2 * 31.25 * 10^6}{10 * 0.4 * 0.866 * 250}}$

  $d = 268.646 \cong 270\ mm$

4. Determine the area of Steel Reinforcement , As = mm^2

$$As = \frac{M\,end}{fs * j * d}$$

$$As = \frac{31.25 * 10^6}{150 * 0.866 * 270}$$

$$As = 890.998\ mm^2$$

5. Determine the number of bars, no. bars

Choose ∅ 16 from rebar table

$$\text{No. bars} = \frac{As}{Ab}$$

$$\text{No. bars} = \frac{890.998}{201}$$

$$\text{No. bars} = 4.432 \cong 5$$

∴ Use 5 ∅ 16 @ Top of End Beam

- M_{Mid}

2. Determine the Bending Moment at end, M_{Mid}

$$M_{Mid} = \frac{W\,L^2}{24}$$

$$M_{Mid} = \frac{15 * 5^2}{24}$$

$$M_{Mid} = 15.625\ kN.m$$

3. Determine the effective depth {d}

d =270 mm

4. Determine the area of Steel Reinforcement , As = mm^2

$$As = \frac{M\ mid}{fs * j * d}$$

$$As = \frac{15.625 * 10^6}{150 * 0.866 * 270}$$

$$As = 445.499\ mm^2$$

5. Determine the number of bars, no. bars

Choose ∅ 16 from rebar table

$$\text{No. bars} = \frac{As}{Ab}$$

$$\text{No. bars} = \frac{445.499}{201}$$

$$\text{No. bars} = 2.216 \cong 3$$

∴ Use 3 ∅ 16 @ Bottom of Mid Beam

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6. Assume the Stirrups Steel bars ∅ 10 @ 250 mm

7. Determine Beam thickness

$t_{beam} = d + cover$

$t_{beam} = 270 + 30$

$t_{beam} = 300\ mm$

8. Determine Reinforcement Ratio

$$\% \rho\ min = 0.3 - 0.1 * \left(\frac{t-100}{350} \right)$$

$$\% \rho\ min = 0.3 - 0.1 * \left(\frac{300-100}{350} \right)$$

$$\rho\ min = 0.242\ \%$$

9. Determine Minimum Area of Steel Reinforcement

$$A_{s\ min} = \% \rho\ min * t * b$$

$$A_{s\ min} = \frac{0.242}{100} * 300 * 250$$

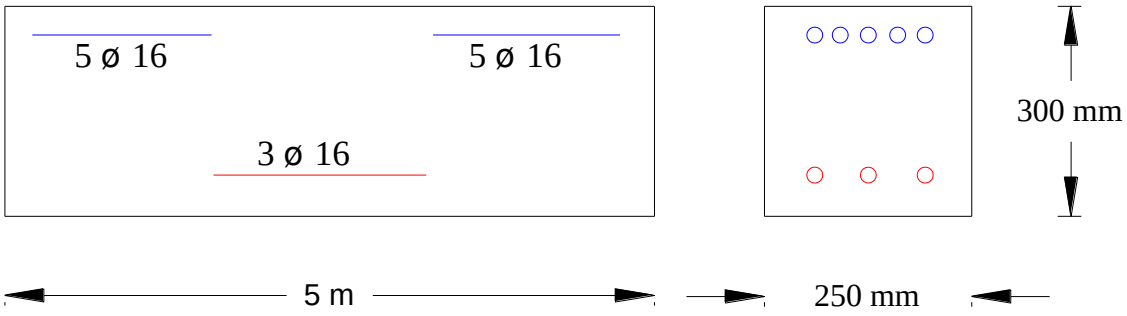
$$A_{s\ min} = 181.5$$

$$\frac{As\ min}{2} = 90.75\ mm^2$$

$$\because As_{End} = 890.998\ mm^2 > \frac{As\ min}{2} = 90.75\ mm^2\ ,\ \therefore \text{O.K.}$$

$$\because As_{mid} = 445.499\ mm^2 > \frac{As\ min}{2} = 90.75\ mm^2\ ,\ \therefore \text{O.K.}$$

10.Beam Reinforcement Details



Beam Reinforcement Details

Design of Reinforced Concrete Cylindrical Tank

(Flexible base, on ground)

Design of Reinforced Concrete Cylindrical Tank (Flexible base, on ground)

Design Steps

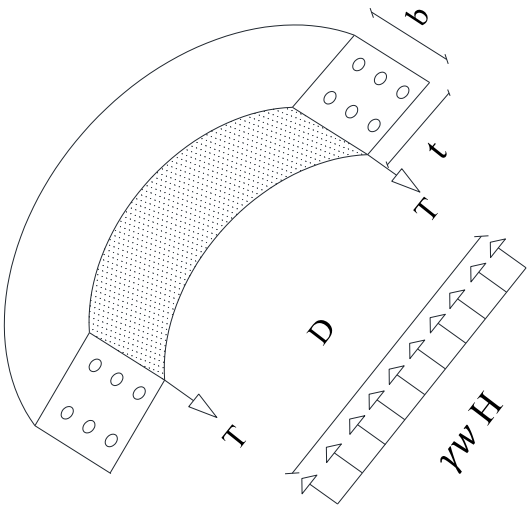
1. Determine the diameter of the cylindrical tank:

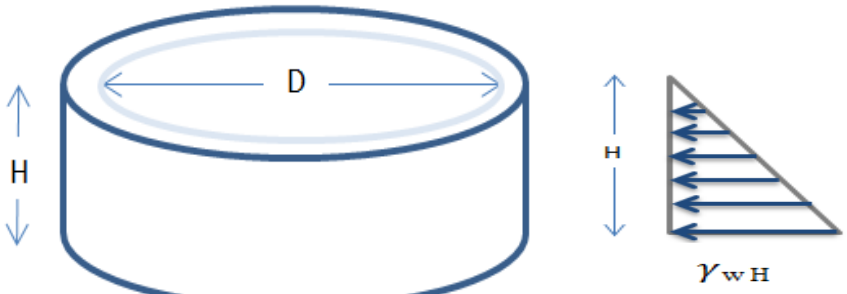
   $V = \frac{\pi}{4} * D^2 * H$

2. Horizontal Steel Reinforcement Design for Tank Walls

3. Determine The Hoop Tension force which applied to Tank Walls:

   $T = \gamma w * H * \frac{D}{2}$ (per meter height)





4. Determine The Area of Steel Reinforcement

   $A_s = \frac{T}{fs}$

5. Choose Ø and A_b from Rebar Table

Rebar Table

Rebar Diameter (mm) (Ø)	Area of Rebar (A_b) (mm^2)
8	50
10	79
12	113
16	201
20	314
25	490

6. Determine the spacing between the horizontal steel reinforcement A_b (mm^2)

$$S_{req} = \frac{2000 * Ab}{As}$$

Then Determine S_{act} should maximum don't exceed 300 mm

$$S_{act} =$$

7. Determine the Actual area of Steel Reinforcement

$$A_{S\ act} = \frac{2000 * Ab}{S\ act}$$

8. Use Ø @ S_{act} c/c in two layers

9. Determine Wall Thickness (**t**) (mm)

$$n = \frac{ES}{EC} \text{ (Modular Ratio)}$$

$$n = \frac{ES}{5000 * \sqrt{fc}\times}$$

$$T = f_t \{ (n-1) * A_{s\ act} + A_c \}$$

$$T = (n-1) * A_{s\ act} * f_t + f_t * (1000 * t)$$

$$\mathbf{t = \frac{T - (n-1) * As_{act} * ft}{ft * 1000}}$$

10.Vertical Steel Reinforcement Design for tank walls

11.Determine Reinforcement Ratio

$$\% \rho min = 0.3 - 0.1 \left(\frac{t-100}{350} \right)$$

12.Determine Minimum Area of Steel Reinforcement

$$A_{s\,min} = \% \rho min * t * 1000$$

13.Choose ∅ and A_b from Rebar Table

$$S_{req} = \frac{2000 * Ab}{As\ min}$$

Then Determine S_{act} should maximum don't exceed 300 mm

S_{act} =

14.Use ∅ @ S_{act} c/c in two layers.

15.Check the Horizontal Steel Reinforcement Area

- If As_{act} for (Horizontal Steel Reinforcement) > As_{min} , ∴ O.K.
- If As_{act} for (Horizontal Steel Reinforcement) < As_{min} , use $As_{act} = As_{min}$.

16. Horizontal Steel Reinforcement Design at Various Depths (repeat the steps from 3 to 7)

Horizontal Steel Reinforcement Table for Tank Walls					
	Formula	*H=1 m	*H=2 m	*H=3 m	*H=….
T (kN)	$= \gamma_w * H * \frac{D}{2}$				
A_s (mm2)	$= \frac{T}{fs}$				
S_{req} (mm)	$= \frac{2000 * Ab}{As}$				
S_{act} (mm)					
$A_{S\ act}$ (mm^2)	$= \frac{2000 * Ab}{S\ act}$				
		Use Ø @ S_{act}	Use Ø @ S_{act}	Use Ø @ S_{act}	Use Ø @ S_{act}

*H= The Distance is Calculated from the Top to the bottom of the Tank.

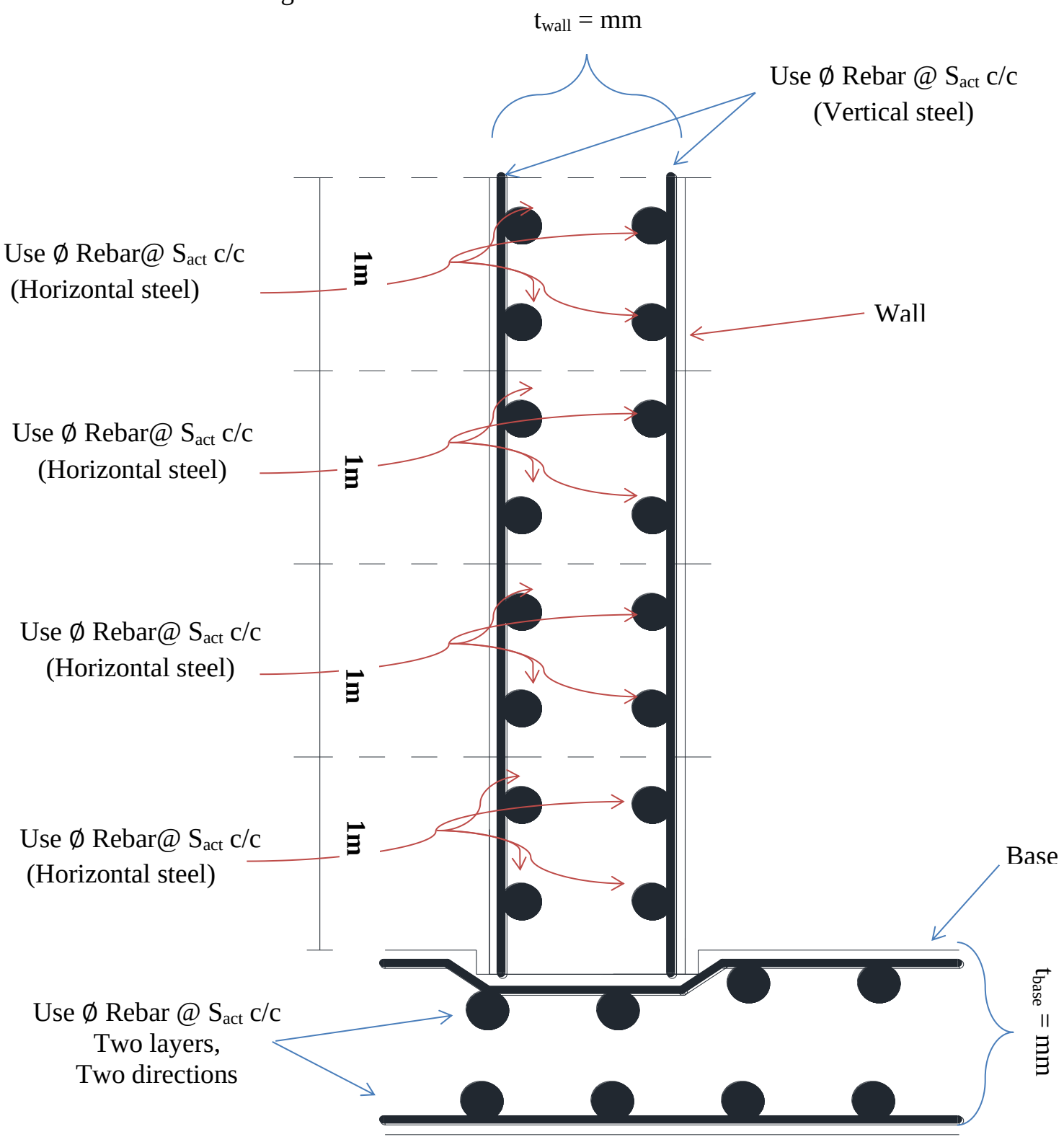
17. Tank Base Design

Use Tank Base Thickness t_{base} = (t_{wall}) Wall Thickness (mm)

Use Ø Rebar and S_{act} as Minimum Steel Reinforcement in *Vertical Steel Reinforcement Design for Tank Walls*

Use Ø (in step 14) @ S_{act} (in step 14)

18.Detailed Design



Design Details (Wall and Base)

Example: Design of a Cylindrical Reinforced Concrete Tank with Flexible Joint at base resting on ground for a capacity of 500 m^3. The Tank top is open with height 4 m.

Use, γ_w = 10 kN/m^3, f_s = 100 N/mm^2, f_c^{-} = 20 N/mm^2, f_t = 1.2 N/mm^2, E_s = 200000 N/mm^2

Solution:

1. Determine The Diameter of The Cylindrical Tank:

$V = \frac{\pi}{4} * D^2 * H$

$500 = \frac{\pi}{4} * D^2 * (4)$

$D = 12.615$ m

Use D = 13 m

2. Horizontal Steel Reinforcement Design for Tank Walls

3. Determine The Hoop Tension force which applied to tank walls:

$T = \gamma_w * H * \frac{D}{2}$

$T = 10 * 4 * \frac{13}{2}$

T= 260 kN\m (multiple by one meter height)

T= 260 kN

4. Determine The Area of Steel Reinforcement

$A_s = \frac{T}{fs}$

$A_s = \frac{260*10\hat{}3}{100}$

$A_s = 2600\ mm^2$

5. Choose Ø 16 and A_b = 201 mm^2 from Rebar Table

6. Determine the Spacing between the Horizontal Steel Reinforcement A_b (mm^2)

   $S_{req} = \frac{2000 * Ab}{As}$

   $S_{req} = \frac{2000 * 201}{2600}$

   S_{req} = 154.615 mm ≈ 155 mm c/c

   Then Determine S_{act} should maximum don't exceed 300 mm

   Let say S_{act} = 150 mm c/c

7. Determine the Actual area Steel Reinforcement

   $A_{S\ act} = \frac{2000 * Ab}{S\ act}$

   $A_{S\ act} = \frac{2000 * 201}{150}$

   $A_{S\ act}$ = 2680 mm^2

8. ∴ Use Ø 16 @ 150 mm c/c in two layers

9. Determine Wall Thickness (**t**) (mm)

   n = $\frac{ES}{EC}$ (Modular Ratio)

   n = $\frac{ES}{5000 * \sqrt{fc}\times}$

   n = $\frac{200000}{5000 * \sqrt{20}}$

   n= 8.944 ≈ 9

$$\mathbf{t = \frac{T - (n-1) * As_{act} * ft}{ft * 1000}}$$

$$\mathbf{t = \frac{260 * 10^3 - (9-1) * 2680 * 1.2}{1.2 * 1000}}$$

$\mathbf{t}$ = 195.226 $\approx$ 196 mm

$\therefore$ Use t = 200 mm

10.Vertical Steel Reinforcement Design for Tank Walls

11.Determine Reinforcement Ratio

$$\% \rho\, min = 0.3 - 0.1 \left(\frac{t-100}{350} \right)$$

$$\% \rho\, min = 0.3 - 0.1 \left(\frac{200-100}{350} \right)$$

$$\% \rho\, min = 0.27\ \%$$

12.Determine Minimum Area of Steel Reinforcement

$$A_{s\,min} = \% \rho\, min * t * 1000$$

$$A_{s\,min} = \frac{0.27}{100} * 200 * 1000$$

$$A_{s\,min} = 540\ mm^2$$

13.Choose Ø 10 and $A_b = 79\ mm^2$ from Rebar Table.

$$S_{req} = \frac{2000 * Ab}{As\ min}$$

$$S_{req} = \frac{2000 * 79}{540}$$

$$S_{req} = 292.592 \approx 293\ mm$$

Then Determine S_{act} should maximum don't exceed 300 mm.

Let say S_{act} = 290 mm c/c

14.∴ Use Ø10 @ 290 mm c/c in two layers

15. Check the Horizontal Steel Reinforcement Area

- If $A_{S\ act} = 2680\ mm^2 > As_{min} = 540\ mm^2$, $\therefore$ O.K.

16. Horizontal Steel Reinforcement Design at Various Depths (repeat the steps from 3 to 7)

Horizontal Steel Reinforcement Table for Tank Walls					
	Formula	*H= 1 m	*H= 2 m	*H= 3 m	*H= 4 m
T (kN)	$= \gamma_w * H * \frac{D}{2}$	65	130	195	260
A_s (mm2)	$= \frac{T}{fs}$	650	1300	1950	2600
S_{req} (mm)	$= \frac{2000 * Ab}{As}$	618	309	206	155
S_{act} (mm)		300	300	200	150
$A_{S\ act}$ (mm^2)	$= \frac{2000 * Ab}{S\ act}$	1340	1340	2010	2680
		Use Ø 16 @ 300	Use Ø 16 @ 300	Use Ø 16 @ 200	Use Ø 16 @ 150

*H= The Distance is Calculated from the Top to the bottom of the Tank.

17. Tank Base Design

Use Tank Base Thickness t_{base} = (t_{wall}) Wall Thickness (mm)

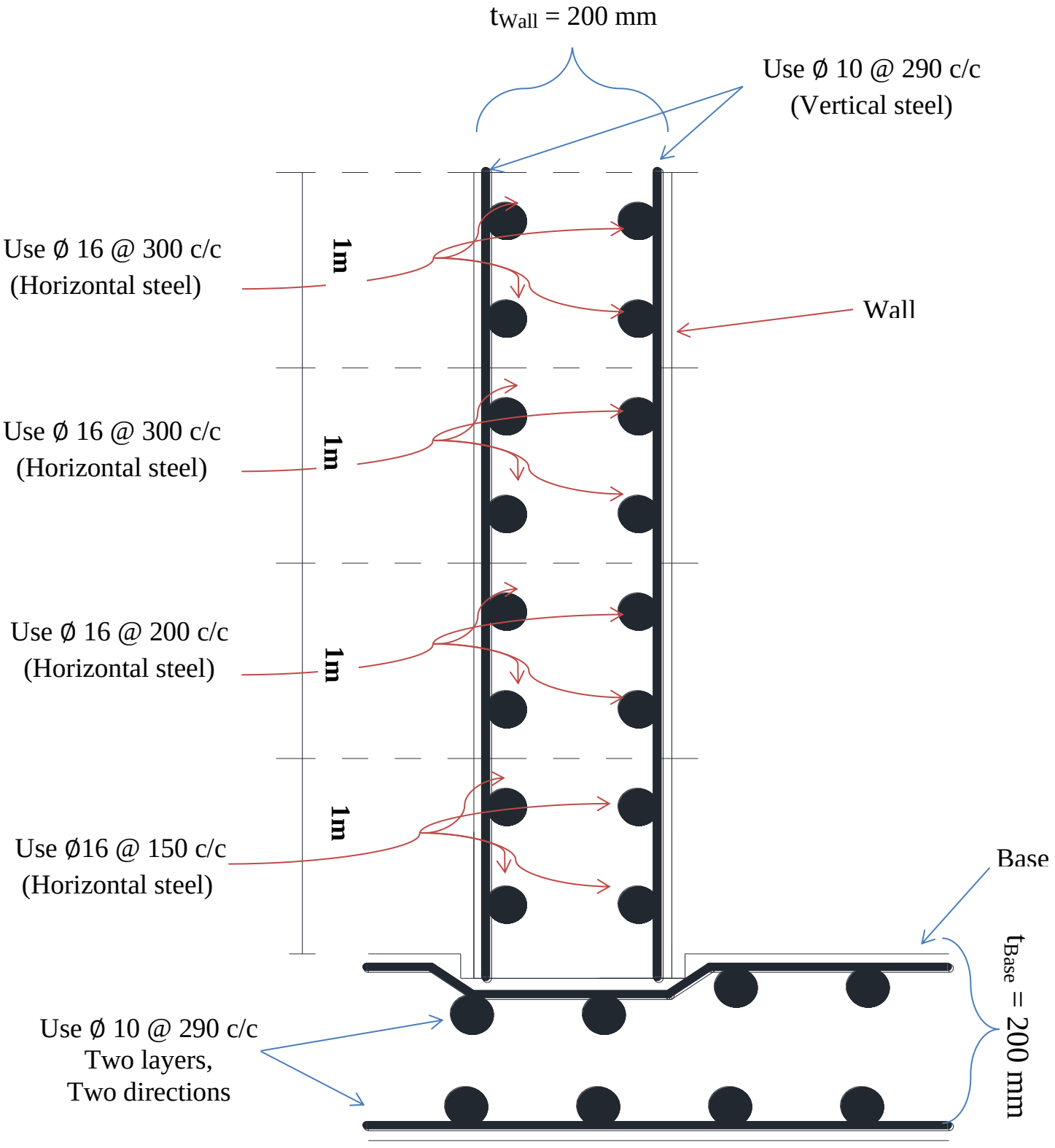
Use Ø Rebar and S_{act} as minimum steel reinforcement in *Vertical steel reinforcement for Tank Wall*

Use Ø (in step 14) @ S_{act} (in step 14)

t_{base} = 200 mm.

Use Ø 10 @ 290 mm c/c in two layers, two Direction

18.Detailed Design



Design Details (Wall and Base)

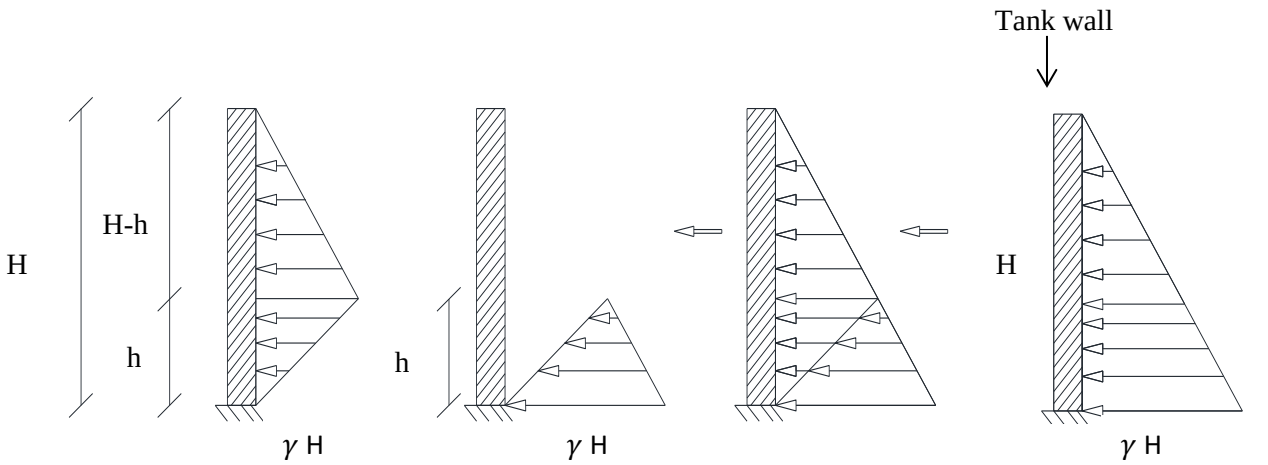
Design of Reinforced Concrete Cylindrical Tank

(Fixed base, on ground)

There are two methods for Design:

A. Approximate Method

Design Steps



Hoop Tension Hydrostatic Pressure

Bending Moment Hydrostatic Pressure

Tank wall Hydrostatic Pressure

1. ***Horizontal Steel Reinforcement Design for Tank Walls***
2. Assume wall thickness, t = mm.
3. Determine the Cylindrical Tank Diameter :

$$V = \frac{\pi}{4} * D^2 * H$$

4. Determine the height of maximum Hoop Tension (h).

   - If $6 < \frac{H\text{^}2}{D*t} < 12$, use $h = \frac{H}{3} \geq 1$ m
   - If $\frac{H\text{^}2}{D*t} = 12$

     , use $h = \frac{H}{3} \geq 1$ m { for Bending Moment } (step 20)

     , use $h = \frac{H}{4} \geq 1$ m { for Hoop Tension} (step 5)
   - If $12 < \frac{H\text{^}2}{D*t} < 30$, use $h = \frac{H}{4} \geq 1$ m

5. Determine The maximum Hoop Tension force which applied to Tank Walls:

   $T = \gamma_w * (H-h) * \frac{D}{2}$ (per meter height)

6. Determine The Area of Steel Reinforcement

   $A_s = \frac{T}{fs}$

7. Choose Ø and A_b from Rebar Table
8. Determine the spacing between the horizontal steel reinforcement A_b (mm^2)

   $S_{req} = \frac{2000 * Ab}{As}$

   Then Determine S_{act} should maximum don't exceed 300 mm

   $S_{act} =$

9. Determine the Actual area of Steel Reinforcement

   $A_{S\ act} = \frac{2000 * Ab}{S\ act}$

10. Use Ø @ S_{act} c/c in two layers
11. Check Wall Thickness (t)

    $n = \frac{Es}{Ec}$ (Modular Ratio)

    $n = \frac{Es}{5000 * \sqrt{fc}\times}$

    $f_t = \frac{T}{(n-1) * As\ act + 1000 * t}$

    If $f_t \leq$ f_t given, $\therefore$ O.K.

    If $f_t >$ f_t given, re assume a new Wall Thickness (t) and repeat design from step 1.

12. ***Design of External Vertical Steel Reinforcement for Tank Walls***
13. Determine Reinforcement Ratio

$$\% \rho min = 0.3 - 0.1 \left(\frac{t-100}{350} \right)$$

14. Determine Minimum Area of Steel Reinforcement

$$A_{s\,min} = \% \rho min * t * 1000$$

15. Choose ∅ and A_b from Rebar Table

$$S_{req} = \frac{2000 * Ab}{As\ min}$$

Then Determine S_{act} should maximum don't exceed 300 mm

S_{act} =

16. Use ∅ @ S_{act} c/c in one layer
17. Check the Horizontal Steel Reinforcement Area
    - If As_{act} for (Horizontal Steel Reinforcement) > As_{min} , ∴ O.K.
    - If As_{act} for (Horizontal Steel Reinforcement) < As_{min} , use $As_{act} = As_{min}$.

18. Horizontal Steel Reinforcement Design at Various Depths (repeat the steps from 5 to 9)

Horizontal Steel Reinforcement Table for Tank Wall					
		Y={H - h }	Y=H - (h +1)	Y=H- (h +2)	Y=H - (h +3)
T (kN)	$T = \gamma_w * \{ Y \} * \frac{D}{2}$				
A_s (mm^2)	$A_s = \frac{T}{fs}$				
S_{req} (mm)	$S_{req} = \frac{2000 * Ab}{As}$				
S_{act} (mm)					
$A_{S\ act}$ (mm^2)	$A_{S\ act} = \frac{2000 * Ab}{S\ act}$				
		Use ∅ @ Sact mm c/c in two layers	Use ∅ @ Sac mm c/c in two layers t	Use ∅ @ Sact mm c/c in two layers	Use ∅ @ Sact mm c/c in two layers

19. ***Design of Internal Vertical Steel Reinforcement for Tank Walls***

20. Determine the Bending Moment for{ Bending Moment Hydrostatic Pressure}

$$M = \frac{\gamma w * H * h^2}{6}$$

21. Assume concrete cover = 50 mm.

22. Determine the effective depth {d}

$$d = \sqrt{\frac{2 * M}{fc * k * j * b}}$$

Where:

$fc = 0.35\, f\bar{c}$

$n = \frac{Es}{Ec}$ (Modular Ratio)

$r = \frac{fs}{fc}$ (Stress Ratio)

$$K = \frac{n}{n+r}$$

$$J = 1 - \frac{K}{3}$$

23. Check Wall thickness

$t_{check} = d + cover$

- If $t_{check} \leq$ t assumption , $\therefore$ O.K. use t assumption.
- If $t_{check} >$ t assumption , use t_{check} and repeat design from step 1

24. Determine The Area of for Internal Vertical Steel Reinforcement for (h) = m.

$$As = \frac{M}{fs * j * d}$$

- If $A_s = \frac{M}{fs * j * d} > \frac{As\ min}{2}$, ∴ o.k.
- If $A_s = \frac{M}{fs * j * d} < \frac{As\ min}{2}$, use $A_s = \frac{As\ min}{2}$

25. Choose ∅ and A_b from Rebar Table

26. Determine the Spacing between The Internal Vertical Steel Reinforcement

$$S_{req} = \frac{1000 * Ab}{As}$$

Then Determine S_{act} should maximum don't exceed 300 mm

S_{act} =

27. Determine the Actual area of Internal vertical Steel Reinforcement

$$A_{S\ act} = \frac{1000 * Ab}{S\ act}$$

28. Use ∅ @ S_{act} mm c/c in one layer , Internal Vertical Steel Reinforcement for (h) = m.

29.Internal Vertical Steel Reinforcement for (H-h) = m

30.Choose ∅ as in the previous step and Spacing S = x * S_{act} = S mm

$A_{S\,min}$ for one layer = $\frac{AS\,min}{2}$

$A_{S\,min}$ for one layer = mm^2

$A_S = \frac{1000*Ab}{S}$

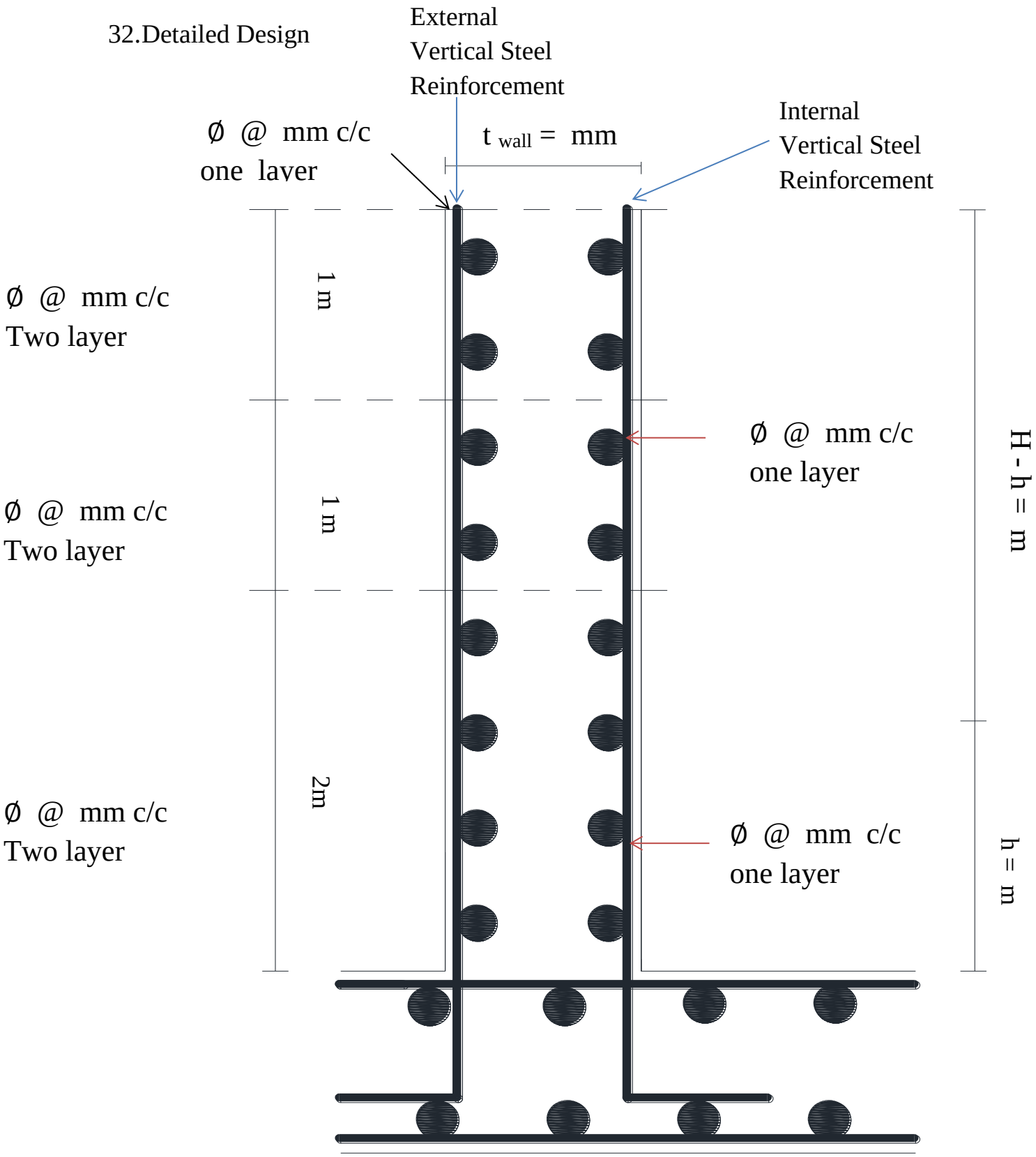
A_S = mm^2

If $A_S \geq (A_{S\,min}$ for one layer) , ∴ O.K.

If $A_S < (A_{S\,min}$ for one layer), try another Spacing and repeat this step

31.Use ∅ @ mm c/c in one layer for Internal Vertical Steel Reinforcement for (H-h) = m

32.Detailed Design



Design Details (Wall)

Example: Design of a Cylindrical Reinforced Concrete Tank with Fixed joint at base resting on ground for a capacity of 500 m^3. The Tank top is open with height 4 m.

Use, γ_w = 10 kN/m^3, f_s = 100 N/mm^2, f_c = 20 N/mm^2, f_t = 1.2 N/mm^2 , E_S = 200000 N/mm^2

Solution:

1. ***Horizontal Steel Reinforcement Design for Tank Walls***.

2. Assume wall thickness, t = 200 mm.

3. Determine the Cylindrical Tank Diameter :

   $V = \frac{\pi}{4} * D^2 * H$

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

   D = 12.615 m

   Use D = 13 m

4. Determine the height of maximum Hoop Tension (h).

   $\frac{H\text{^}2}{D*t} = \frac{4\text{^}2}{13 * 0.2} = 6.15$

   - If $6 < \frac{H\text{^}2}{D*t} < 12$, use $h = \frac{4}{3} = 1.33 > 1$ m ∴ ok

5. Determine The **maximum** Hoop Tension force which applied to Tank Walls:

   $T = \gamma_w * (H-h) * \frac{D}{2}$ (per meter height)

   $T = 10 * (4 - 1.33) * \frac{13}{2}$

   T= 173.55 kN

6. Determine The Area of Steel Reinforcement

$A_s = \frac{T}{fs}$

$A_s = \frac{173.55*10\text{^}3}{100}$

$A_s = 1735.5 \approx 1736 \ mm^2$

7. Choose Ø 12 and $A_b = 113\ mm^2$ from Rebar Table

8. Determine The Spacing between the Horizontal Steel Reinforcement

$S_{req} = \frac{2000*Ab}{As}$

$S_{req} = \frac{2000*113}{1736}$

Sreq = 130.18 mm

Then Determine S_{act} should maximum don't exceed 300 mm

$S_{\mathbf{act}} =$ 130 mm

9. Determine the Actual area of Steel Reinforcement

$A_{S\ act} = \frac{2000*Ab}{S\ act}$

$A_{S\ act} = \frac{2000*113}{130}$

$A_{S\ act} = 1738.46 \approx 1738\ mm^2$

10. Use Ø 12 @ 130 mm c/c in two layers (for the first 2 m from Tank bottom)

11. Check Wall Thickness (t)

$n = \frac{Es}{Ec}$ (Modular Ratio)

$$n = \frac{Es}{5000*\sqrt{fc}\times}$$

$$n = \frac{200000}{5000*\sqrt{20}}$$

$n = 8.944 \approx 9$

$$f_t = \frac{T}{(n-1)*As\ act + 1000*t}$$

$$f_t = \frac{173.55*10\text{^}3}{(9-1)*1738 + 1000*200}$$

$f_t = 0.811\ N/mm^2$

If $f_t = 0.811 \leq f_t$ given $= 1.2$, $\therefore$ O.K.

12. *Design of External Vertical Steel Reinforcement for Tank Walls*

13. Determine Reinforcement Ratio

$$\% \rho\, min = 0.3 - 0.1 * \left(\frac{t-100}{350} \right)$$

$$\% \rho\, min = 0.3 - 0.1 * \left(\frac{200-100}{350} \right)$$

$$\% \rho\, min = 0.27\ \%$$

14. Determine Minimum Area of Steel Reinforcement

$$A_{s\ min} = \% \rho\, min * t * 1000$$

$$A_{s\ min} = \frac{0.27}{100} * 200 * 1000$$

$$A_{s\ min} = 540\ mm^2$$

15. Choose Ø 10 and $A_b = 79\ mm^2$ from Rebar Table

$$S_{req} = \frac{2000 * Ab}{As\ min}$$

$$S_{req} = \frac{2000 * 79}{540}$$

$$S_{req} = 292.59 \approx 292\ mm$$

Then Determine S_{act} should maximum don't exceed 300 mm

$$S_{act} = 290\ mm$$

16. Use Ø 10 @ 290 c/c one layer for External Vertical Steel Reinforcement.

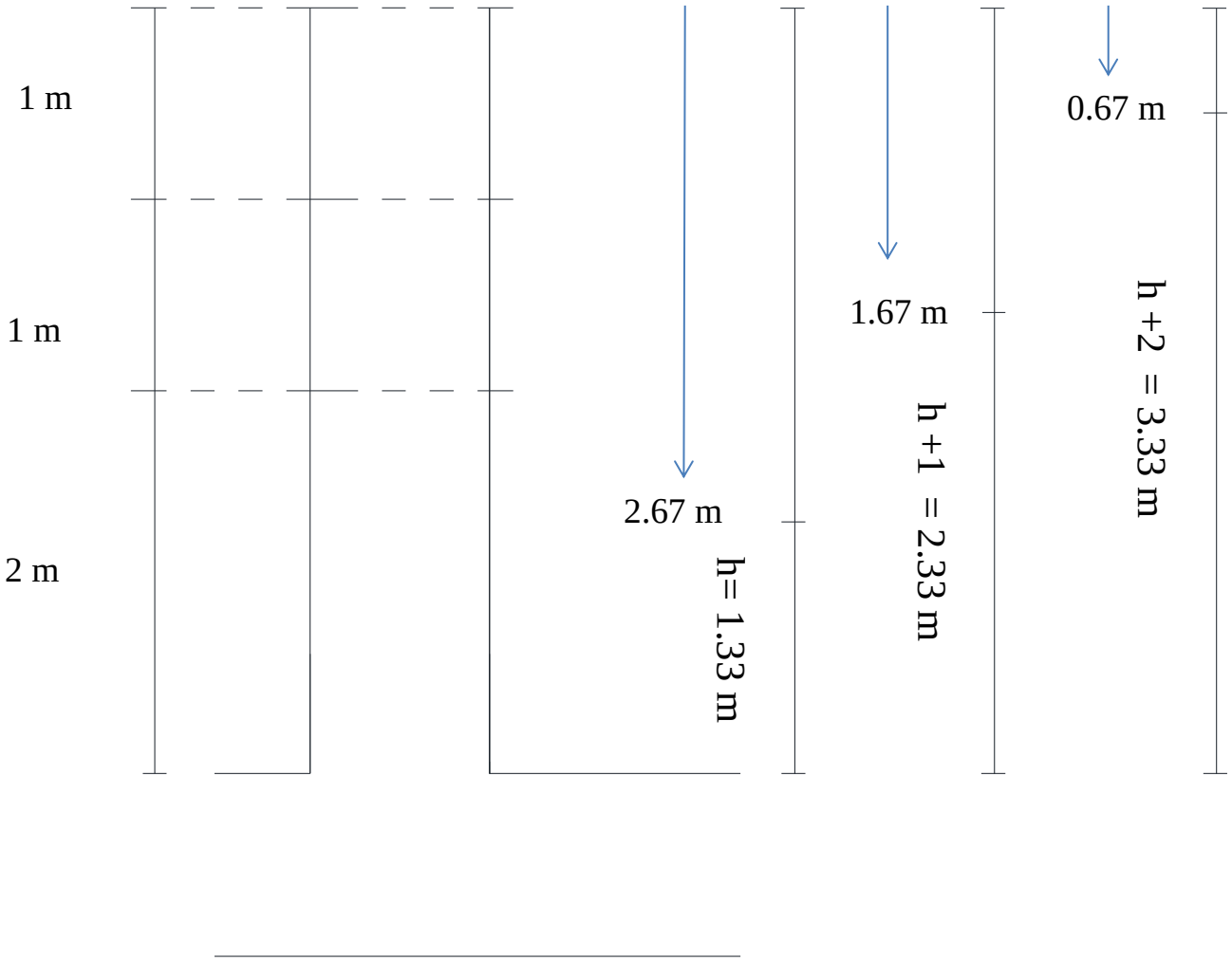
17. Check the Horizontal Steel Reinforcement Area

If $As_{act} = 1738.46\ mm^2$ (Horizontal Steel Reinforcement) $> As_{min} = 540\ mm^2$

$\therefore$ O.K.

18. Horizontal Steel Reinforcement Design at Various Depths (repeat the steps from 5 to 9)

Horizontal Steel Reinforcement Table for Tank Wall				
		Y= H - h	Y=H - (h +1)	Y=H - (h +2)
		2.67	1.67	0.67
T (kN)	$T = \gamma_w * \{ Y \} * \frac{D}{2}$	173.55	108.55	43.55
A_s (mm^2)	$A_s = \frac{T}{fs}$	1735.5	1085.5	435.5
S_{req} (mm)	$S_{req} = \frac{2000 * Ab}{As}$	130.22	208.19	518.94
S_{act} (mm)		130	200	300
A_{Sact} (mm^2)	$A_{S\ act} = \frac{2000 * Ab}{S\ act}$	1738.46	1130	753
		Use Ø 12 @ 130 mm c/c in two layers	Use Ø 12 @ 200 mm c/c in two layers	Use Ø 12 @ 300 c/c in two layers



Horizontal Steel Reinforcement Location

19. ***Design of Internal Vertical Steel Reinforcement for Tank Walls***

20. Determine the Bending Moment for{ Bending Moment Hydrostatic Pressure}

$$M = \frac{\gamma w * H * h^2}{6}$$

$$M = \frac{10 * 4 * (1.33)^2}{6}$$

$$M = 11.79 \text{ kN.m}$$

21. Assume concrete cover = 50 mm.

22. Determine the effective depth {d}

$$d = \sqrt{\frac{2 * M}{fc * k * j * b}}$$

Where:

- $fc = 0.35\, f\bar{c}$

  $fc = 0.35 * 20$

  $fc = 7 \ \frac{N}{mm2}$

- $n = \frac{Es}{Ec}$ (Modular Ratio)

  $n = \frac{Es}{5000 * \sqrt{fc} \times}$

  $n = \frac{200000}{5000 * \sqrt{20}}$

  $n = 8.944 \approx 9$

- $r = \frac{fs}{fc}$ (Stress Ratio)

$$r = \frac{fs}{0.35 * fc'}$$

$$r = \frac{100}{0.35*20}$$

$$r = 14.28$$

- $K = \frac{n}{n+r}$

$$K = \frac{9}{9+14.28}$$

$$K = 0.386$$

- $J = 1 - \frac{K}{3}$

$$J = 1 - \frac{0.386}{3}$$

$$J = 0.871$$

$$d = \sqrt{\frac{2 * M}{fc * k * j * b}}$$

$$d = \sqrt{\frac{2 * 11.79 * 10^6}{7 * 0.386 * 0.871 * 1000}}$$

$$d = 100.09 \approx 100 \text{ mm}$$

23.Check Wall Thickness

$t_{check} = d + cover$
$t_{check} = 100 + 50$
$t_{check} = 150$ mm

- If $t_{check} = 150 \text{ mm} \leq t_{assumption} = 200 \text{ mm}$, $\therefore$ O.K.

24. Determine The Area of Internal Vertical Steel Reinforcement for (h) = 1.33 m.

$$As = \frac{M}{fs * j * d}$$

$$As = \frac{11.79 * (10^6)}{100 * 0.871 * 100}$$

$As = 1353.61 \approx 1354\ mm^2$

- If $A_s = 1354\ mm^2 > \frac{As\ min}{2} = \frac{540}{2} = 270\ mm^2$, $\therefore$ o.k.

25. Choose Ø12 and A_b=113mm^2 from Rebar Table.

26. Determine the Spacing between The Internal Vertical Steel Reinforcement

$$S_{req} = \frac{1000 * Ab}{As}$$

$$S_{req} = \frac{1000 * 113}{1354}$$

$S_{req} = 80.456$ mm

Then Determine S_{act} should maximum don't exceed 300 mm

$S_{act} = 80$

27. Determine the Actual area of Internal vertical Steel Reinforcement

$$A_{S\ act} = \frac{1000 * Ab}{S\ act}$$

$$A_{S\ act} = \frac{1000 * 113}{80}$$

$A_{S\ act} = 1412.5\ mm^2$

28. Use Ø 12 @ 80 mm c/c one layer for Internal Vertical Steel Reinforcement for (h) = 1.33 m.

29. Internal Vertical Steel Reinforcement for (H – h) = 2.67 m

30. Choose Ø as in the previous step and Spacing S = 3 * 80 = 240 mm

$A_{S\ min}$ for one layer $= \frac{540}{2}$

$A_{S\ min}$ for one layer = 270 mm

$A_S = \frac{1000 * Ab}{S}$

$A_S = \frac{1000 * 113}{240}$

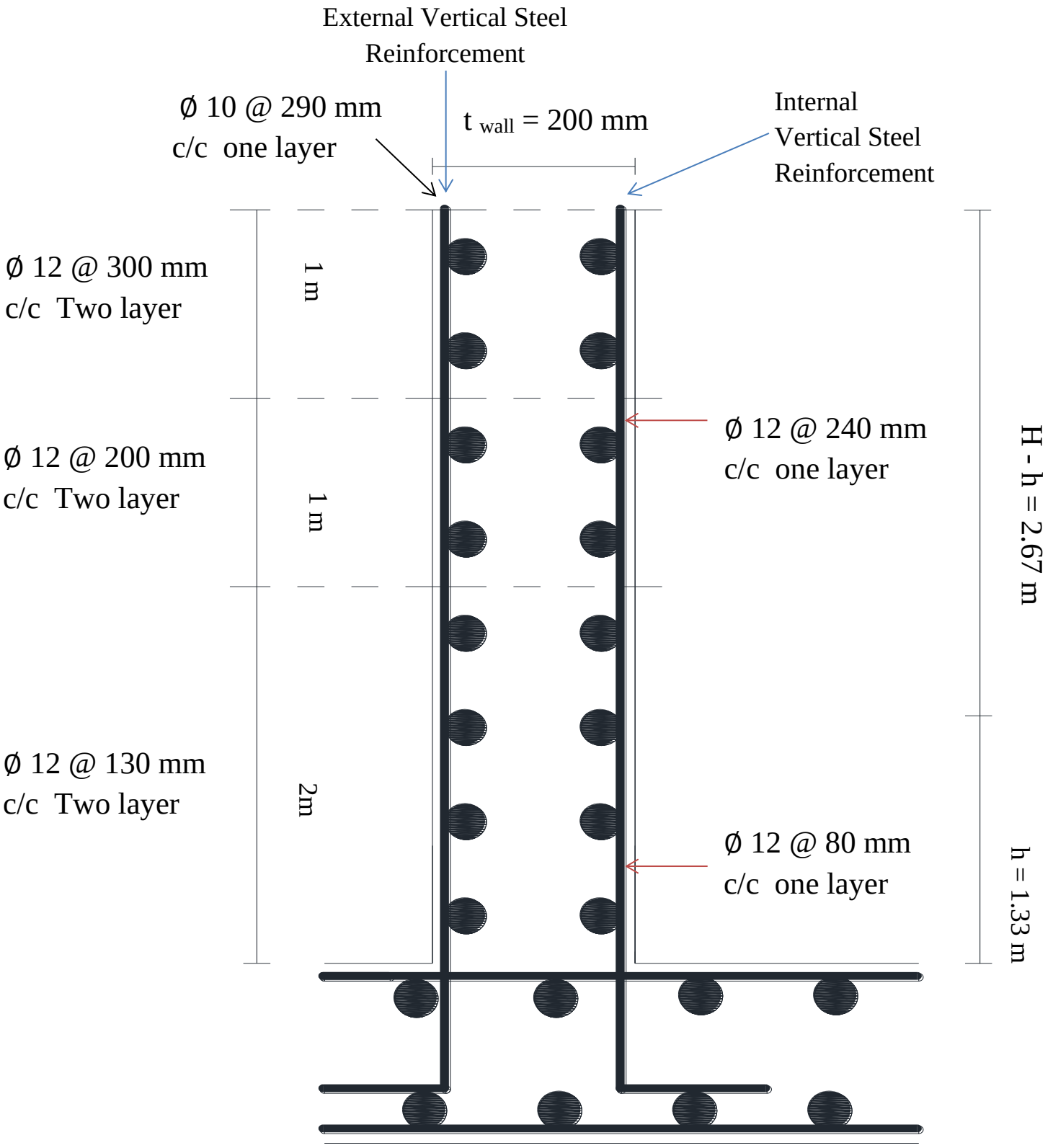
A_S = 470 .83 mm^2

If $A_S > (A_{S\ min}$ for one layer $)$

$\therefore$ OK

31. Use Ø 12 @ 240 mm c/c one layer for Internal Vertical Steel Reinforcement for (H – h) = 2.67 m

32.Detailed Design



Design Details (Wall)

Design of Reinforced Concrete Cylindrical Tank (Fixed base, on ground)

B. Exact Method

Design Steps

1. ***Horizontal Steel Reinforcement Design for Tank Walls (form y_1 H to y_2 H, the direction start from Tank top to bottom).***
2. Assume wall thickness, t = mm.
3. Determine the Cylindrical Tank Diameter :

   $V = \frac{\pi}{4} * D^2 * H$

4. Determine the value below;
   - $\frac{H^2}{D * t}$
5. Determine the Coefficient $C_{1\ max}$ ($C_{1\ max}$ = maximum value at y_{max} H in row of $\frac{H^2}{D * t}$) for Hoop tension in cylindrical ring form Table I.
6. Determine The maximum Hoop Tension force which applied to Tank Walls:

   $T_{max} = C_{1\ max} * \gamma_w * H * \frac{D}{2}$ (per meter height)

7. Determine The Area of Steel Reinforcement

   $A_s = \frac{T}{fs}$

8. Choose Ø and Ab from Rebar Table
9. Determine the spacing between the horizontal steel reinforcement A_b (mm^2)

   $S_{req} = \frac{2000 * Ab}{As}$

   Then Determine S_{act} should maximum don't exceed 300 mm

   $S_{act} =$

10. Determine the Actual area of Steel Reinforcement.

    $A_{S\ act} = \frac{2000 * Ab}{S\ act}$

11. Use Ø @ S_{act} c/c in two layers {start ***form y_1 H to y_2 H***, the direction start from Tank top to bottom }.

12. Check Wall Thickness (t) by Tensile stress of Concrete

$n = \frac{ES}{EC}$ (Modular Ratio)

$n = \frac{ES}{5000 * \sqrt{fc\times}}$

$$f_t = \frac{T\,max}{(n-1) * As\,act + 1000 * t}$$

- If $f_t \leq$ f_t given, $\therefore$ O.K.
- If $f_t >$ f_t given, re assume a new Wall Thickness (t) and repeat design.

13. Check the Wall Thickness (t) by shear stress of concrete f_v for Tank Wall .

$$f_v = \frac{V}{1000 * t}$$

$$f_v = \frac{(C*) * \gamma w * H^2}{1000 * t}$$

- IF $f_v \leq f_{v\,given}$, $\therefore$ ok
- IF $f_v > f_{v\,given}$, re assume a new Wall Thickness (t) and repeat design.

14. Determine Reinforcement Ratio

$\%\,\rho\,min = 0.3 - 0.1\,(\frac{t-100}{350})$

15. Determine Minimum Area of Steel Reinforcement

$A_{s\,min} = \%\,\rho\,min * t * 1000$

16. Check, if $A_{S\,act} \geq A_{s\,min}$, $\therefore$ ok
if $A_{S\,act} < A_{s\,min}$, use $A_s = A_{s\,min}$

17. ***Horizontal Steel Reinforcement Design for Tank Walls (from 0 H to y_1 H, from y_2 H to H).***

18. Determine the Coefficient C_1 at (y_1 H), for Hoop tension in cylindrical ring form Table I.

19. Determine The Hoop Tension force which applied to Tank Walls

$$T = C_1 * \gamma_w * H * \frac{D}{2} \quad \text{(per meter height)}$$

20. Determine The Area of Steel Reinforcement

$$A_s = \frac{T}{fs}$$

21. Check, if $A_S \geq A_{s\,min}$, ∴ ok
if $A_S < A_{s\,min}$, use $A_s = A_{s\,min}$

22. Choose Ø and A_b from Rebar Table

23. Determine the spacing between the horizontal steel reinforcement A_b (mm^2)

$$S_{req} = \frac{2000 * Ab}{As}$$

Then Determine S_{act} should maximum don't exceed 300 mm

S_{act} =

24. Determine the Actual area of Steel Reinforcement.

$$A_{S\,act} = \frac{2000 * Ab}{S\,act}$$

25. Use Ø @ S_{act} c/c in two layers ***(from 0 H to y_1 H, from y_2 H to H).***

26. *Design of Internal Vertical Steel Reinforcement for Tank Walls*

27. Determine the negative Bending Moment

$M^-_{max} = (C_2^-) * \gamma_w * (H^3)$

C_2^- = Maximum Negative value in Table II at row of $\frac{H^2}{D * t}$.

28. Assume concrete cover = 50 mm.

29. Determine the effective depth {d}

$$d = \sqrt{\frac{2 * (M- max)}{fc * k * j * b}}$$

Where:

$fc = 0.35 f\bar{c}$

$n = \frac{Es}{Ec}$ (Modular Ratio)

$r = \frac{fs}{fc}$ (Stress Ratio)

$K = \frac{n}{n+r}$

$J = 1 - \frac{K}{3}$

30. Check Wall thickness

$t_{check} = d + cover$

- If $t_{check} \leq$ t assumption , $\therefore$ O.K. use t assumption.
- If $t_{check} >$ t assumption , use t_{check} and repeat design.

31. Determine The Area of Internal Vertical Steel Reinforcement.

$$As^{-} = \frac{(M-max)}{fs * j * d}$$

- If $As^{-} = \frac{(M-max)}{fs * j * d} \geq \frac{As\ min}{2}$, ∴ o.k.
- If $As^{-} = \frac{(M-max)}{fs * j * d} < \frac{As\ min}{2}$, use $As = \frac{As\ min}{2}$

32. Choose Ø and A_b from Rebar Table.
33. Determine the Spacing between The Internal Vertical Steel Reinforcement

$$S_{req} = \frac{1000 * Ab}{As-}$$

Then Determine S_{act} should maximum don't exceed 300 mm

S_{act} =

34. Determine the Actual area of Internal vertical Steel Reinforcement

$$A_S{}^{-}{}_{act} = \frac{1000 * Ab}{S\ act}$$

35. Use Ø @ S_{act} mm c/c in one layer, Internal Vertical Steel Reinforcement {form $y_{v\ max}$ H to H }

36. Use Ø mm @ S mm c/c in one layer , Internal Vertical Steel Reinforcement {form 0H to $y_{v\ max}$ H}

- Check A_s
- $A_S = \frac{1000 * Ab}{S} > \frac{As\ min}{2}$, ∴ OK

37. ***Design of External Vertical Steel Reinforcement for Tank Walls { form 0 to H}***

38. Determine Positive negative Bending Moment

$M^{+}_{max} = (C_2{}^{+}) * \gamma_w * (H^3)$

$C_2{}^{+}$ = maximum positive value at ($y_{v\,max}$ H) in row of $\frac{H^2}{D * t}$.

39. Determine The Area of External Vertical Steel Reinforcement.

$$As^{+} = \frac{(M+max)}{fs * j * d}$$

- If $As^{+} = \frac{(M+max)}{fs * j * d} \geq \frac{As\ min}{2}$, $\therefore$ o.k.
- If $As^{+} = \frac{(M+max)}{fs * j * d} < \frac{As\ min}{2}$, use $As = \frac{As\ min}{2}$

40. Choose Ø and A_b from Rebar Table.

41. Determine the Spacing between The External Vertical Steel Reinforcement

$$S_{req} = \frac{1000 * Ab}{As+}$$

Then Determine S_{act} should maximum don't exceed 300 mm

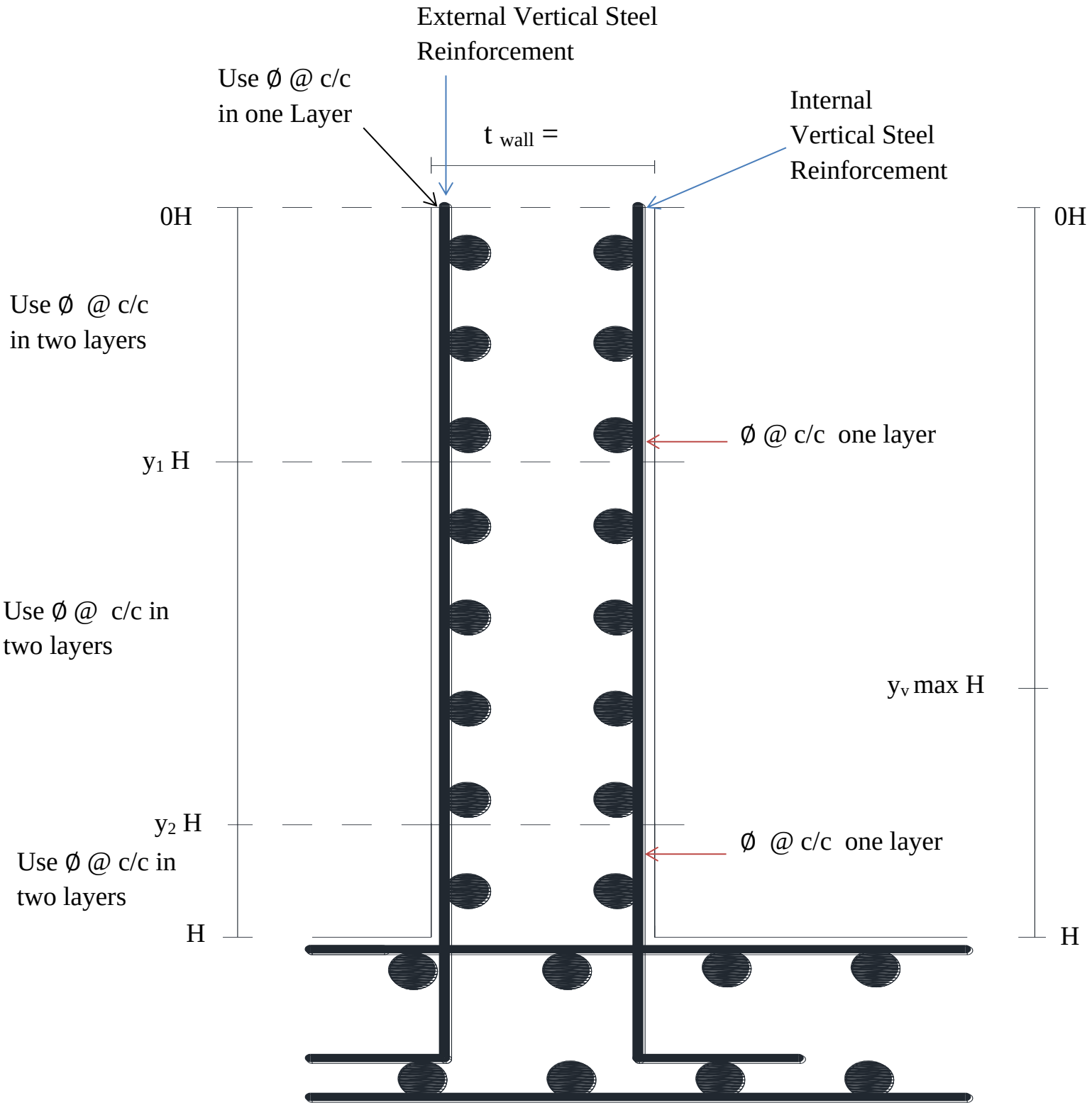
S_{act} =

42. Determine the Actual area of External vertical Steel Reinforcement

$$As^{+}{}_{act} = \frac{1000 * Ab}{S\,act}$$

43. Use Ø @ S_{act} mm c/c in one layer , External Vertical Steel Reinforcement.

44.Detailed Design



Design Details (Wall)

Table I Hoop Tension Coefficient ($C_{1\,max}$, C_1) in cylindrical ring and Shear Coefficient (C^*)

↓H^2/Dt	0.0H	0.1H	0.2H	0.3H	0.4H	0.5H	0.6H	0.7H	0.8H	0.9H	Shear* coeff.
0.4	0.149	0.134	0.120	0.101	0.082	0.066	0.049	0.029	0.014	0.004	0.436
0.8	0.263	0.239	0.215	0.190	0.160	0.130	0.096	0.063	0.034	0.010	0.374
1.2	0.283	0.271	0.254	0.234	0.209	0.180	0.142	0.099	0.054	0.016	0.339
1.6	0.265	0.268	0.268	0.266	0.250	0.226	0.185	0.134	0.075	0.023	0.317
2.0	0.234	0.251	0.273	0.285	0.285	0.274	0.232	0.172	0.104	0.031	0.299
3.0	0.134	0.203	0.267	0.322	0.357	0.362	0.303	0.262	0.157	0.052	0.262
4.0	0.067	0.164	0.256	0.339	0.403	0.429	0.409	0.334	0.210	0.073	0.236
5.0	0.025	0.137	0.245	0.346	0.428	0.477	0.469	0.398	0.259	0.092	0.213
6.0	0.018	0.119	0.234	0.344	0.441	0.504	0.514	0.447	0.301	0.112	0.197
8.0	-0.011	0.104	0.218	0.335	0.443	0.534	0.575	0.530	0.381	0.151	0.174
10.0	-0.011	0.098	0.208	0.323	0.437	0.542	0.608	0.589	0.440	0.179	0.158
12.0	-0.005	0.097	0.202	0.312	0.429	0.543	0.628	0.633	0.494	0.211	0.145
14.0	-0.002	0.098	0.200	0.306	0.420	0.539	0.639	0.666	0.541	0.241	0.135
16.0	0.00	0.099	0.199	0.304	0.443	0.531	0.641	0.687	0.582	0.265	0.127

Table II Bending Moment Coefficient (C_2) = { C_2^+ , C_2^-}

H^2/Dt	0.1H	0.2H	0.3H	0.4H	0.5H	0.6H	0.7H	0.8H	0.9H	1.0H
0.40	0.0005	0.0014	0.0021	0.0007	-.0042	-0.015	-.0302	-0.0529	-0.0816	-0.1205
0.80	0.0011	0.0037	0.0063	0.008	0.007	0.0023	-.0068	-0.0224	-0.0465	-0.0705
1.20	0.0012	0.0042	0.0077	0.0103	0.0112	0.0090	0.0022	-0.0108	-0.0311	-0.0602
1.60	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	0.000	0.0001	0.0002	0.0008	0.0016	0.0028	0.0038	0.0029	-0.0022	-0.0146
10.0	"	0.000	0.0001	0.0004	0.0007	0.0019	0.0029	0.0028	-0.0012	-0.0122
12.0	"	-.0001	0.0001	0.0002	0.0003	0.0013	0.0023	0.0026	-0.0005	-0.0104
14.0	"	0.000	0.000	0.000	0.0001	0.0008	0.0019	0.0023	-0.0001	-0.0090
16.0	"	"	-.0001	-.0001	-.0001	0.0004	0.0013	0.0019	0.0001	-0.0079

Example: Design of a Cylindrical Reinforced Concrete Tank with Fixed joint at base resting on ground for a capacity of 314 m^3. The Tank top is open with height 4 m.

Use, γ_w = 10 kN/m^3, f_s = 100 N/mm^2, f_c = 20 N/mm^2, f_t = 1.2 N/mm^2, E_S = 200000 N/mm^2, f_v = 1.7 N/mm^2.

Solution:

1. ***Horizontal Steel Reinforcement Design for Tank Walls (form 0.3H to 0.8H, the direction start from Tank top to bottom).***
2. Assume wall thickness, t = 200 mm.
3. Determine the Cylindrical Tank Diameter :

$$V = \frac{\pi}{4} * D^2 * H$$

$$V = \frac{\pi}{4} * D^2 * H$$

$$314 = \frac{\pi}{4} * D^2 * 4$$

D = 9.995 m

Use D = 10 m

4. Determine the value below.

$$\frac{H^2}{D * t}$$

$$\frac{4^2}{10*0.2} = 8$$

5. Determine the Coefficient $C_{1\,max}$ ($C_{1\,max}$ = maximum value at y_{max} H in row of $\frac{H^2}{D * t}$) for Hoop tension in cylindrical ring form Table I.

$C_{1\,max}$ = 0.575

6. Determine The maximum Hoop Tension force which applied to Tank Walls:

$T_{max} = C_{1\,max} * \gamma_w * H * \frac{D}{2}$ (per meter height)

$T_{max} = 0.575 * 10 * 4 * \frac{10}{2}$

$T_{max} = 115$ kN

7. Determine The Area of Steel Reinforcement

$$A_s = \frac{T\,max}{fs}$$

$$A_s = \frac{115*10^3}{100}$$

$A_s = 1150$ mm^2

8. Choose ∅12 mm and 113 mm^2 from Rebar Table

9. Determine the spacing between the horizontal steel reinforcement A_b (mm^2)

$$S_{req} = \frac{2000 * Ab}{As}$$

$$S_{req} = \frac{2000 * 113}{1150}$$

$S_{req} = 196.521 \approx 196$ mm

Then Determine S_{act} {The maximum Spacing value shall not exceed 300 mm}.

$S_{act} = 190$ mm

10. Determine the Actual area of Steel Reinforcement.

$$A_{S\ act} = \frac{2000 * Ab}{S\ act}$$

$$A_{S\ act} = \frac{2000*113}{190}$$

$$A_{S\ act} = 1189.473 \approx 1189\ mm^2$$

11. Use Ø 12 mm @ 190 mm c/c in two layers { form 0.3H to 0.8H, the direction start from Tank top to bottom }.

12. Check Wall Thickness (t) by Tensile stress of Concrete

$n = \frac{Es}{Ec}$ (Modular Ratio)

$$n = \frac{Es}{5000*\sqrt{fc\times}}$$

$$n = \frac{200000}{5000*\sqrt{20}}$$

$$n = 8.944$$

$$n = 9$$

$$f_t = \frac{T\ max}{(n-1)* As\ act\ +\ 1000 * t}$$

$$f_t = \frac{115*10\text{^}3}{(9-1)*\ 1189\ +\ 1000 * 200}$$

$$f_t = 0.548\ N/mm^2$$

- $f_t = 0.548\ N/mm^2 < f_t$ given $= 1.2\ N/mm^2$, $\therefore$ O.K.

13. Check the Wall Thickness (t) by shear stress of concrete f_v for Tank Wall .

Shear Coefficient (C*) = 0.174

V (Shear Force) = $(C*) * \gamma w * H^2$

$V = 0.174 * 10 * 4^2$

v = 27.84 kN (per meter Height)

$f_v = \frac{V}{1000 * t}$

$f_v = \frac{27.84 * 10^3}{1000 * 200}$

$f_v = 0.139$ N/mm^2

- fv = 0.139 N/mm^2 $<$ $f_{v\ given}$ = 1.7 N/mm^2 , $\therefore$ ok

14. Determine Reinforcement Ratio

$\% \rho min = 0.3 - 0.1 * \left(\frac{t-100}{350} \right)$

$\% \rho min = 0.3 - 0.1 * \left(\frac{200-100}{350} \right)$

$\% \rho min = 0.271\ \%$

15. Determine Minimum Area of Steel Reinforcement

$A_{s\,min} = \%\,\rho\,min * t * 1000$

$A_{s\,min} = \frac{0.271}{100} * 200 * 1000$

$A_{s\,min} = 542\ mm^2$

16. Check, $A_{S\,act} = 1189\ mm^2 > A_{s\,min} = 542\ mm^2$, $\therefore$ ok

17. ***Horizontal Steel Reinforcement Design for Tank Walls (from 0 to0.3H, from 0.8H to H).***

18. Determine the Coefficient C_1 at (y_1 H =) 0.3H, for Hoop tension in cylindrical ring form Table I.

    The Coefficient C_1 = The value at 0.3H

    $C_1 = 0.335$

19. Determine The Hoop Tension force which applied to Tank Walls

    $T = C_1 * \gamma_w * H * \frac{D}{2}$ (per meter height)

    $T = 0.335 * 10 * 4 * \frac{10}{2}$

    $T = 67$ kN

20. Determine The Area of Steel Reinforcement

    $A_s = \frac{T}{fs}$

    $A_s = \frac{67*10\text{^}3}{100}$

    $A_s = 670\ mm^2$

21. Check, $A_S = 670 > A_{s\,min} = 542\ mm^2$, ∴ OK

22. Choose ∅ 10 mm and 79 mm^2 from Rebar Table

23. Determine the spacing between the horizontal steel reinforcement A_b ($_{mm}^2$)

$$S_{req} = \frac{2000 * Ab}{As}$$

$$S_{req} = \frac{2000*79}{670}$$

S_{req} = 235.820 mm^2

Then Determine S_{act} should maximum don't exceed 300 mm

S_{act} = 230 mm^2

24. Determine the Actual area of Steel Reinforcement.

$$A_{S\ act} = \frac{2000 * Ab}{S\ act}$$

$$A_{S\ act} = \frac{2000 * 79}{230}$$

$A_{S\ act}$ = 686.956 mm^2

25. Use ∅ 10 mm @ 230 mm c/c in two layers {form 0 to 0.3H, from 0.8H to H}.

26. ***Design of Internal Vertical Steel Reinforcement for Tank Walls.***

27. Determine the Negative Bending Moment

C_2^- = Maximum Negative value in Table II at row of $\{ \frac{H^2}{D * t} = 8\}$

$M^-_{max} = (C_2^-) * \gamma w * (H^3)$

$M^-_{max} = (0.0146) * 10 * (4^3)$

$M^-_{max} = 9.344$ kN.m

28. Assume concrete cover = 50 mm.

29. Determine the effective depth {d}

$$d = \sqrt{\frac{2 * (M- max)}{fc * k * j * b}}$$

Where:

$fc = 0.35 f\bar{c}$

$n = \frac{Es}{Ec}$ (Modular Ratio)

$n = 9$

$r = \frac{fs}{fc}$ (Stress Ratio)

$r = \frac{fs}{0.35 * fc^{-}}$

$r = \frac{100}{0.35*20}$

$r = 14.285$

$K = \frac{n}{n+r}$

$K = \frac{9}{9 + 14.285}$

$K = 0.386$

$J = 1- \frac{K}{3}$

$J = 1- \frac{0.386}{3}$

$J = 0.871$

$d = \sqrt{\frac{2*(M-max)}{fc * k * j * b}}$

$d = \sqrt{\frac{2 * (9.344 * 10^{6})}{(0.35*20) * 0.386 * 0.871 * 1000}}$

$d = 89.110 \approx 89$ mm

30. Check Wall thickness

$t_{check} = d + cover$

$t_{check} = 89 + 50$

$t_{check} = 139$ mm

- If $t_{check} = 139$ mm $\leq t_{assumption} = 200$ mm, $\therefore$ O.K. use $t_{assumption}$

31. Determine The Area of Internal Vertical Steel Reinforcement.

$$As^{-} = \frac{(M-max)}{fs * j * d}$$

$$As^{-} = \frac{(9.344 * 10^{6})}{100 * 0.871 * 89}$$

$As^{-} = 1205.381$ mm^2

If $As^{-} = \frac{(M-max)}{fs * j * d} = 1205.381$ mm$^2 \geq \frac{As\ min}{2} = \frac{542}{2} = 271$mm^2 , $\therefore$ o.k.

32. Choose Ø 16 mm and $A_b = 201$ mm^2 from Rebar Table.

33. Determine the Spacing between The Internal Vertical Steel Reinforcement

$$S_{req} = \frac{1000 * Ab}{As-}$$

$$S_{req} = \frac{1000 * 201}{1205.381}$$

$S_{req} = 166.752$ mm

Then Determine S_{act} {The maximum Spacing value shall not exceed 300 mm}.

$S_{act} = 150$ mm

34. Determine the Actual area of Internal vertical Steel Reinforcement

$$A_{S\text{-}act} = \frac{1000 * Ab}{S\,act}$$

$$A_{S\text{-}act} = \frac{1000 * 201}{150}$$

$$A_{S\text{-}act} = 1340\ mm^2$$

35. Use ∅ 16 mm @ 150 mm c/c in one layer , Internal Vertical Steel Reinforcement. {form $y_{v\ max}$ H to H } from 0.7H to H

36. Use ∅ 16 mm @ 300 mm c/c in one layer , Internal Vertical Steel Reinforcement {form 0H to $y_{v\ max}$ H} from 0H to 0.7H.

- Check A_s
- $A_S = \frac{1000 * 201}{300} = 670\ mm^2 > \frac{As\ min}{2} = 271\ mm^2$, ∴ OK

37. ***Design of External Vertical Steel Reinforcement for Tank Walls {from 0H to H}.***

38. Determine Positive Bending Moment

$C_2{}^+$ = Maximum Positive value in Table II at $\{ \frac{H^2}{D * t} = 8\}$

$C_2{}^+ = 0.0038$

$M^+{}_{max} = (C_2{}^+) * \gamma_w * (H^3)$

$M^+{}_{max} = (0.0038) * 10 * (4^3)$

$M^+{}_{max} = 2.432$ kN.m

39. Determine The Area of External Vertical Steel Reinforcement.

$$As^+ = \frac{(M+max)}{fs * j * d}$$

$$As^+ = \frac{(2.432*10^6)}{100 * 0.871 * 89}$$

$As^+ = 313.729$ mm^2

- If $As^+ = \frac{(M+max)}{fs * j * d} = 313.729 \text{ mm}^2 \geq \frac{As\ min}{2} = \frac{542}{2} = 271\text{mm}^2$,

  $\therefore$ O.K.

40. Choose ∅ 10 mm and A_b = 79 mm^2 from Rebar Table.

41. Determine the Spacing between The External Vertical Steel Reinforcement

$$S_{req} = \frac{1000 * Ab}{As+}$$

$$S_{req} = \frac{1000*79}{313.729}$$

S_{req} = 251.809 mm

Then Determine S_{act} {The maximum Spacing value shall not exceed 300 mm}.

S_{act} = 250 mm

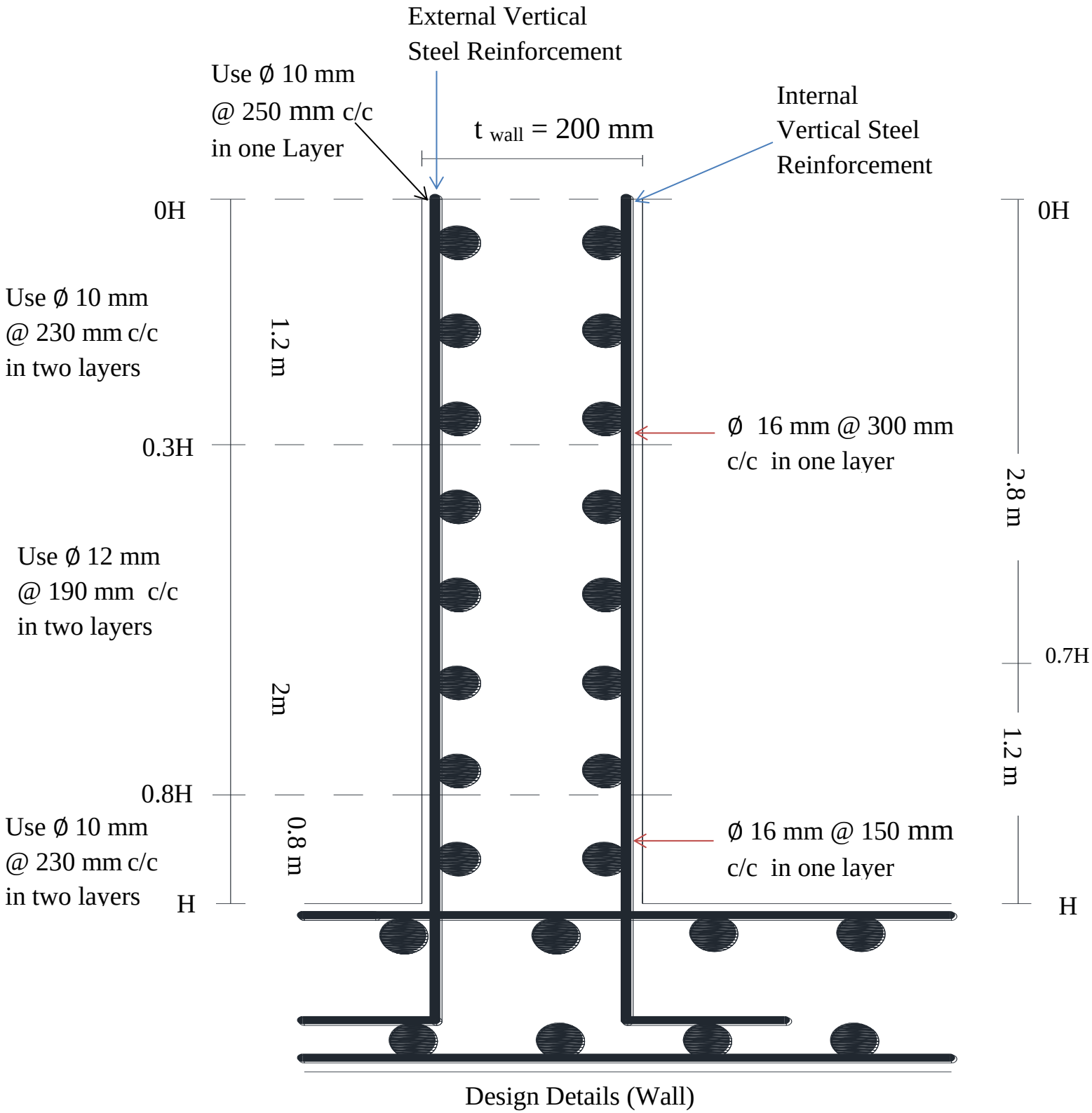
42. Determine the Actual area of External vertical Steel Reinforcement.

$$A_{S^+ act} = \frac{1000 * 79}{250}$$

$A_{S^+ act}$ = 316 mm^2

43. Use ∅ 10 mm @ 250 mm c/c in one layer , External Vertical Steel Reinforcement.

44.Detailed Design



Design Details (Wall)

Rectangular Tank

Position: Underground

Design of Reinforced Concrete Underground Rectangular Tank

$$\frac{L}{B} \leq 2$$

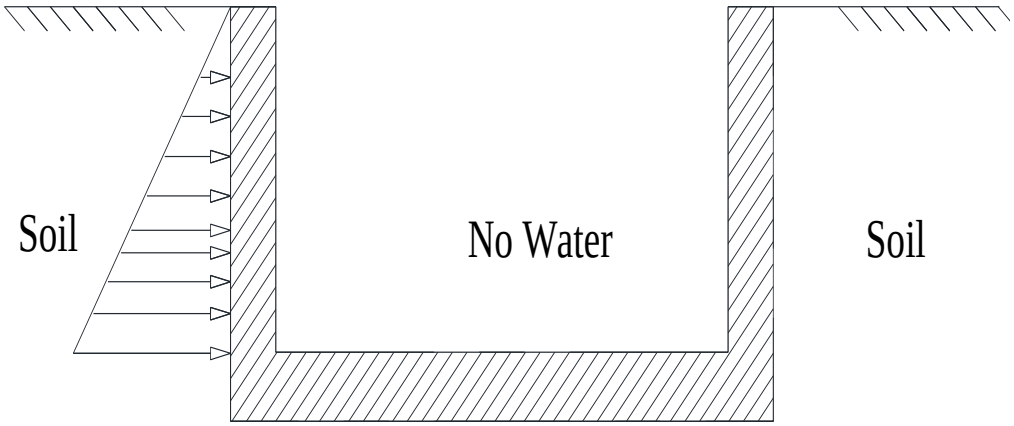
Design of Reinforced Concrete Underground Rectangular Tank, $\frac{L}{B} \leq 2$

Design Steps

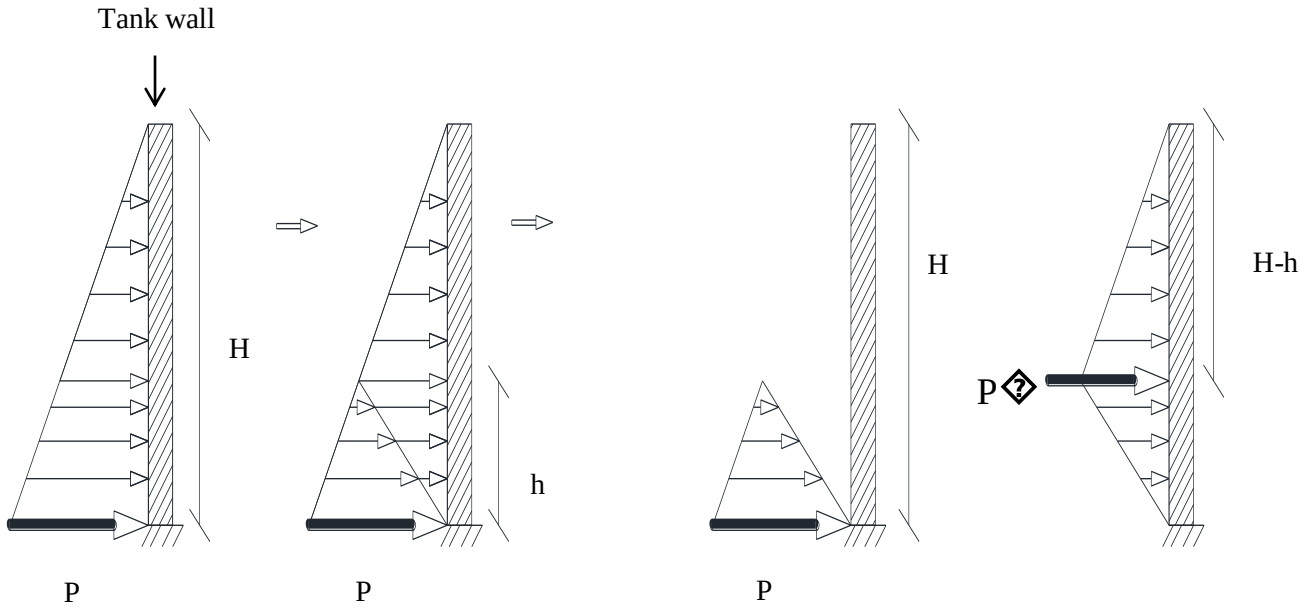
1. Check $\frac{L}{B}$ **Ratio**

   $\frac{L}{B} \leq 2$, $\therefore$ OK

2. Condition I : Tank Under Earth Pressure Only.



Underground Recantgular Tank Section - Condition I



Tank wall Hydrostatic Pressure

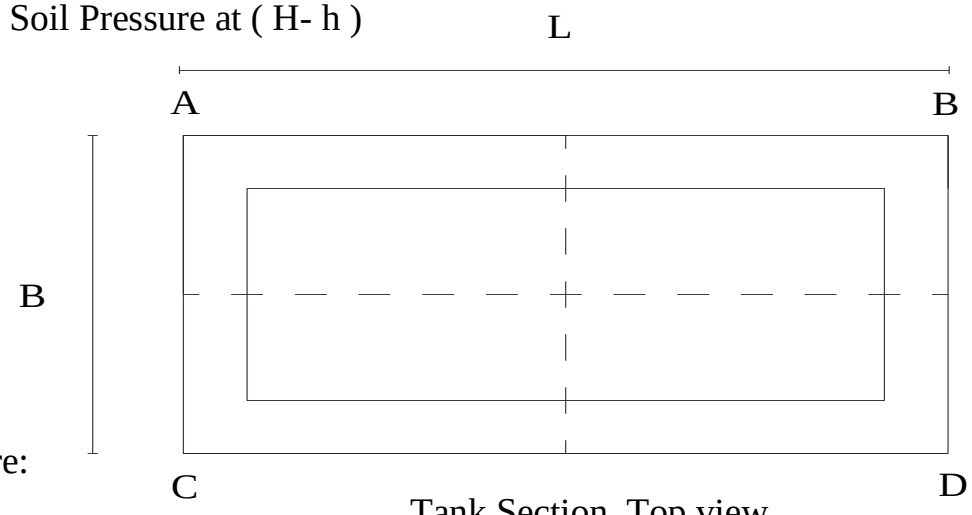
Vertical Moment Hydrostatic Pressure

Horizontal Moment Hydrostatic Pressure

Where:

P = Soil Pressure at H

P× = Soil Pressure at (H- h)



Tank Section, Top view

Where:

L = Long Direction

B = Short Direction

3. Determine the Stiffness factor

$K_{AB} = \frac{2\,EI}{L}$

$K_{AC} = \frac{2\,EI}{B}$

4. Determine the Distribution factor

$D.F_{AB} = \frac{Kab}{Kab+Kac}$

$D.F_{AC} = \frac{Kac}{Kac+Kab}$

5. Determine The Soil Pressures

   - $P = \gamma w * H + (\gamma s - \gamma w)\ H\ * \frac{1-\sin\theta}{1+\sin\theta}$ (per meter width)
   - $h = \frac{H}{4}$, $h \geq 1$
   - $P\times = P * \frac{(H-h)}{H}$

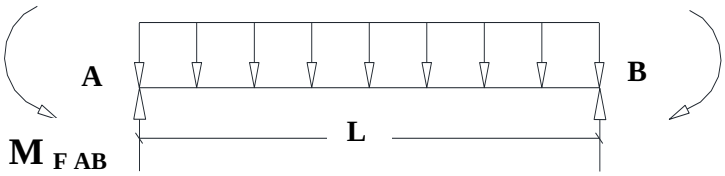
6. Determine The Fixed End Moment & (M_{END}) M_{FINAL} .

$M_{\text{Fixed End AB}} = -\ \frac{P\times * L^2}{12}$

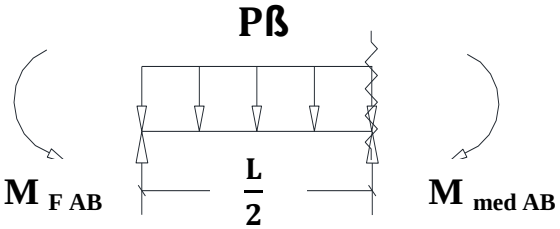
$M_{\text{Fixed End Ac}} = \frac{P\times * B^2}{12}$

Member	AB	AC
D.F		
F.E.M		
Bal		
M_{Final}	$M^{-}_{Final\ AB}$	$M_{Final\ AC}$

7. Determine Moment at mid span of Long Wall (M med AB)



$$R_L = \frac{P\beta\, L}{2}$$



$$R_L = \frac{P\beta\, L}{2}$$

8. Assume concrete cover = 50 mm.

9. Determine the effective depth {d}mm

$$d = \sqrt{\frac{2 * (M)\,max}{fc * k * j * b}}$$

Where:

- fc = 0.35 $f\bar{c}$
- $n = \frac{Es}{Ec}$ (Modular Ratio),

  $n = \frac{Es}{5000 * \sqrt{fc}\times}$
- $r = \frac{fs}{fc}$ (Stress Ratio)
- $K = \frac{n}{n+r}$
- $J = 1 - \frac{K}{3}$

10. Determine The Wall Thickness (t) mm

    t = d + cover

11. Determine Reinforcement Ratio

    $\%\ \rho\ min = 0.3 - 0.1\ (\ \frac{t-100}{350}\ )$

12. Determine Minimum Area of Steel Reinforcement

    $A_{s\ min} = \%\ \rho\ min * t * 1000$

13. **Long Wall, L = AB m**

14. External Horizontal Steel Reinforcement.

15. Determine the Area of Steel Reinforcement .

$$As_{AB} = \frac{(M\ Final\ AB)}{fs * j * d}$$

- If $As_{AB} = \frac{(M\ Final\ AB)}{fs * j * d} \geq \frac{As\ min}{2}$, ∴ O.K.
- If $As^{-}_{AB} = \frac{(M\ Final\ AB)}{fs * j * d} < \frac{As\ min}{2}$, use $As = \frac{As\ min}{2}$

16. Choose Ø and A_b from Rebar Table.
17. Determine the Spacing between The External Horizontal Steel Reinforcement.

$$S_{req} = \frac{1000 * Ab}{As - AB}$$

Then Determine S_{act} {The maximum Spacing value shall not exceed 300 mm}.

S_{act} =

18. Determine the Actual area of External Horizontal Steel Reinforcement

$$A_{S^{-}\ AB\ act} = \frac{1000 * Ab}{S\ act}$$

19. Use Ø @ S **act** mm c/c in one layer , External Horizontal Steel Reinforcement.

20. Internal Horizontal Steel Reinforcement.

21. Determine the Area of Steel Reinforcement.

$$As_{\ med} = \frac{(M\ med\ \ AB)}{fs * j * d}$$

- If $As_{\ med} = \frac{(M\ med\ \ AB)}{fs * j * d} \geq \frac{As\ min}{2}$, $\therefore$ o.k.
- If $As\ \ med = \frac{(M\ med\ \ AB)}{fs * j * d} < \frac{As\ min}{2}$, use $As = \frac{As\ min}{2}$

22. Choose Ø and A_b from Rebar Table.
23. Determine the Spacing between The Internal Horizontal Steel Reinforcement

$$S_{req} = \frac{1000 * Ab}{As\ med}$$

Then Determine S_{act} {The maximum Spacing value shall not exceed 300 mm}.

S_{act} =

24. Determine the Actual area of Internal Horizontal Steel Reinforcement

$$A_{S\ med\ act} = \frac{1000 * Ab}{S\ act}$$

25. Use Ø @ S_{act} mm c/c in one layer , Internal Horizontal Steel Reinforcement.

26. External Vertical Steel Reinforcement. { for h}

27. Determine The Vertical Moment

$$M_{\text{Vertical}} = \frac{P * h^2}{6}$$

28. Determine the Area of Steel Reinforcement.

$$As_{\text{Vertical}} = \frac{M\ \text{Vertical}}{fs * j * d}$$

- If $As_{\text{Vertical}} = \frac{M\ \text{Vertical}}{fs * j * d} \geq \frac{As\ min}{2}$, ∴ O.K.
- If $As_{\text{Vertical}} = \frac{M\ \text{Vertical}}{fs * j * d} < \frac{As\ min}{2}$, use $As = \frac{As\ min}{2}$

29. Choose ∅ and A_b from Rebar Table.
30. Determine the Spacing between The External Vertical Steel Reinforcement.

$$S_{req} = \frac{1000 * Ab}{As\ \text{Vertical}}$$

Then Determine S_{act} {The maximum Spacing value shall not exceed 300 mm}.

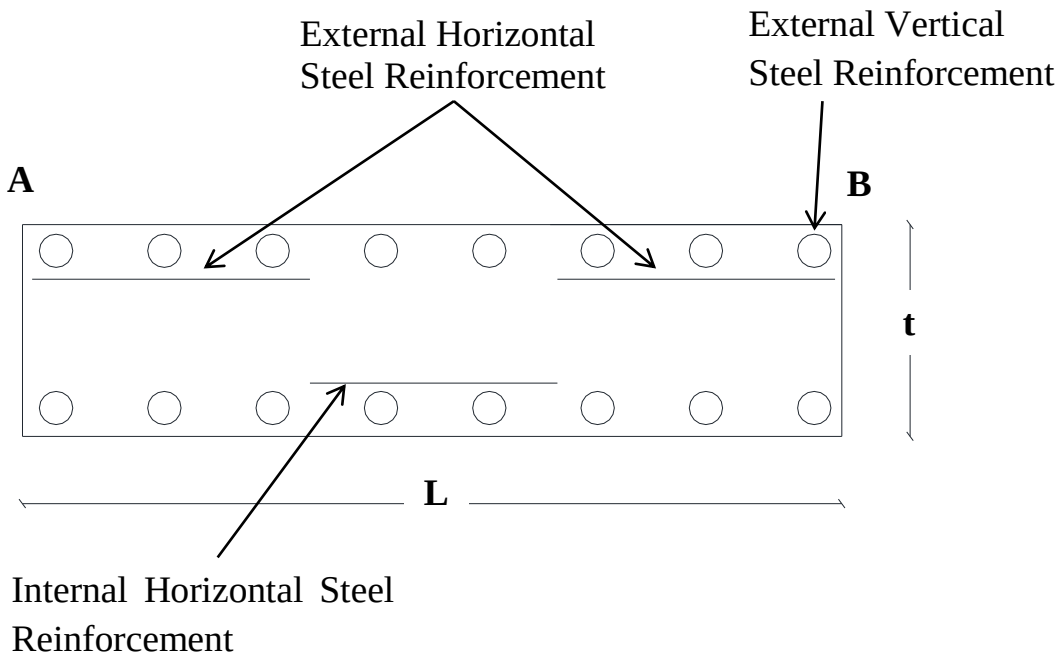
$S_{\mathbf{act}}$ =

31. Determine the Actual area of External Vertical Steel Reinforcement

$$As_{\text{Vertical act}} = \frac{1000 * Ab}{S\ act}$$

32. Use ∅ @ $S_{\mathbf{act}}$ mm c/c in one layer , External Vertical Steel Reinforcement for Height = h .

Use As_{min} for External Vertical Steel Reinforcement for Height = (H – h) .



The Long Wall Design Details Due to Earth Pressure (Top View)

33. **Short Wall, B = AC m .**

34. External Horizontal Steel Reinforcement.

35. Determine the Area of Steel Reinforcement.

$$As_{Ac} = \frac{(M\ Final\ AC)}{fs * j * d}$$

- If $As_{Ac} = \frac{(M\ Final\ AC)}{fs * j * d} \geq \frac{As\ min}{2}$, ∴ O.K.
- If $As_{Ac} = \frac{(M\ Final\ AC)}{fs * j * d} < \frac{As\ min}{2}$, use $As = \frac{As\ min}{2}$

36. Choose Ø and A_b from Rebar Table.
37. Determine the Spacing between The External Horizontal Steel Reinforcement.

$$S_{req} = \frac{1000 * Ab}{As\ AC}$$

Then Determine S_{act} {The maximum Spacing value shall not exceed 300 mm}.

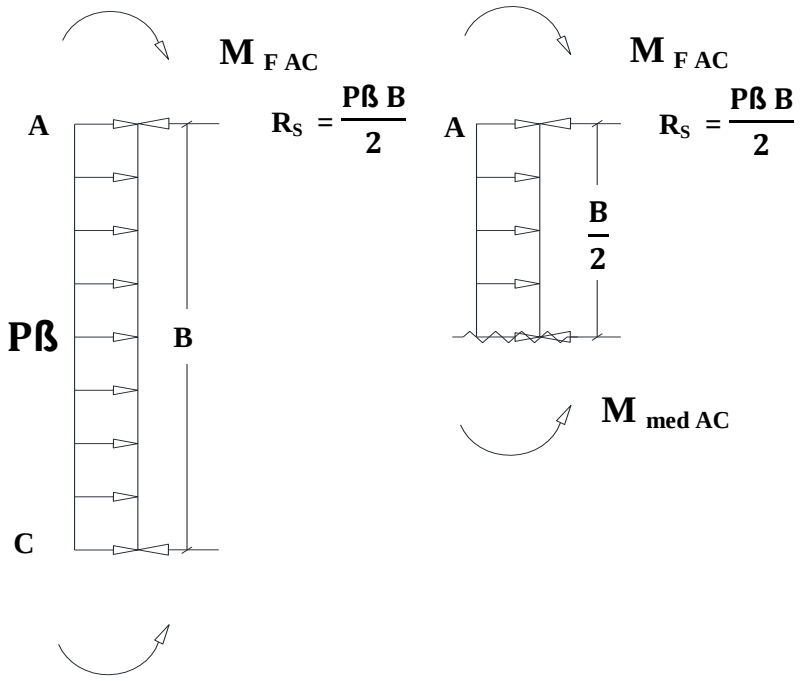
$S_{act} =$

38. Determine the Actual area of External Horizontal Steel Reinforcement

$$A_{S\ AC\ act} = \frac{1000 * Ab}{S\ act}$$

39. Use Ø @ S_{act} mm c/c in one layer , External Horizontal Steel Reinforcement.

40. Internal Horizontal Steel Reinforcement.



41. Determine the Area of Steel Reinforcement.

$$As_{med} = \frac{(M\ med\ AC)}{fs * j * d}$$

- If $As_{med} = \frac{(M\ med\ AC)}{fs * j * d} \geq \frac{As\ min}{2}$, ∴ o.k.
- If $As_{med} = \frac{(M\ med\ AC)}{fs * j * d} < \frac{As\ min}{2}$, Use $As = \frac{As\ min}{2}$

42. Choose Ø and A_b from Rebar Table.
43. Determine the Spacing between The Internal Horizontal Steel Reinforcement

$$S_{req} = \frac{1000 * Ab}{As\ med}$$

Then Determine S_{act} {The maximum Spacing value shall not exceed 300 mm}.

S_{act} =

44. Determine the Actual area of Internal Horizontal Steel Reinforcement

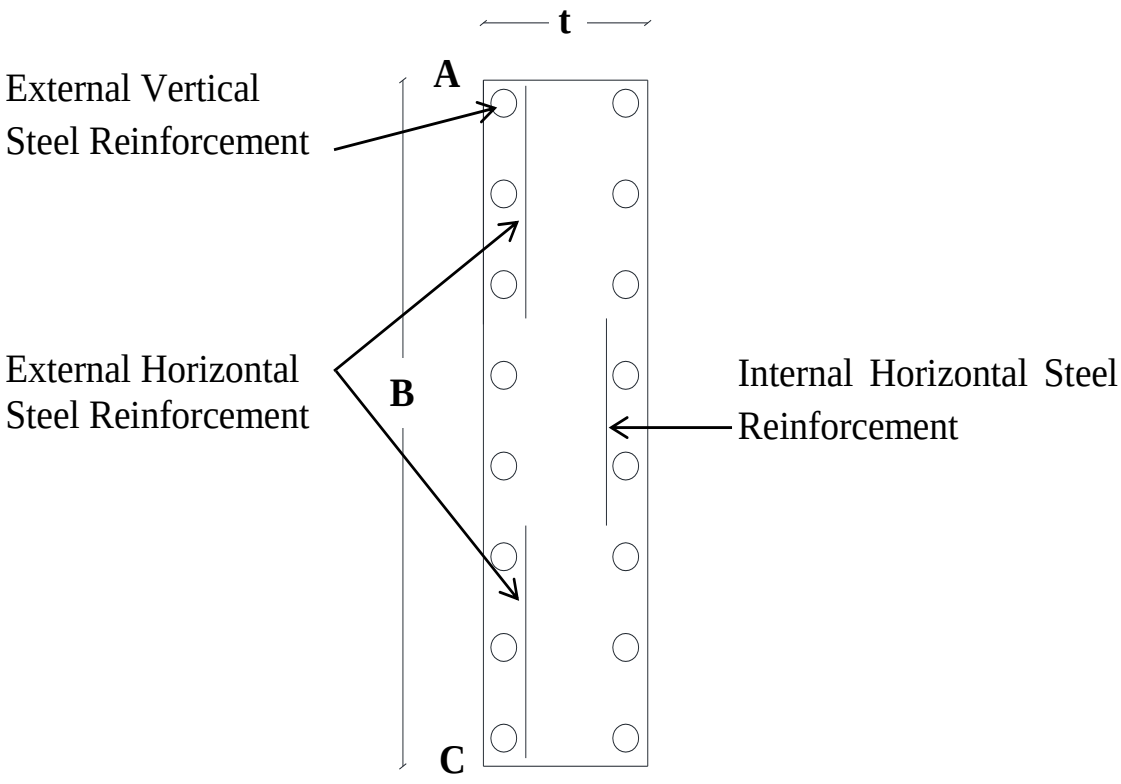
$$A_{S\ med\ act} = \frac{1000 * Ab}{S\ act}$$

45. Use Ø @ S_{act} mm c/c in one layer , Internal Horizontal Steel Reinforcement.

46. Use External Vertical Steel Reinforcement for Short B = External Vertical Steel Reinforcement for Long L .

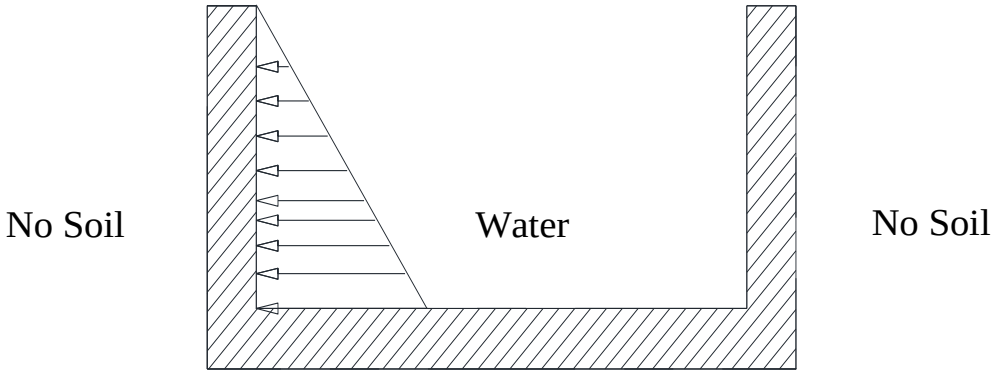
47. Use Ø @ S_{act} mm c/c in one layer , External Vertical Steel Reinforcement for Height = h .

    - Use As_{min} for External Vertical Steel Reinforcement for Height = (H – h) .

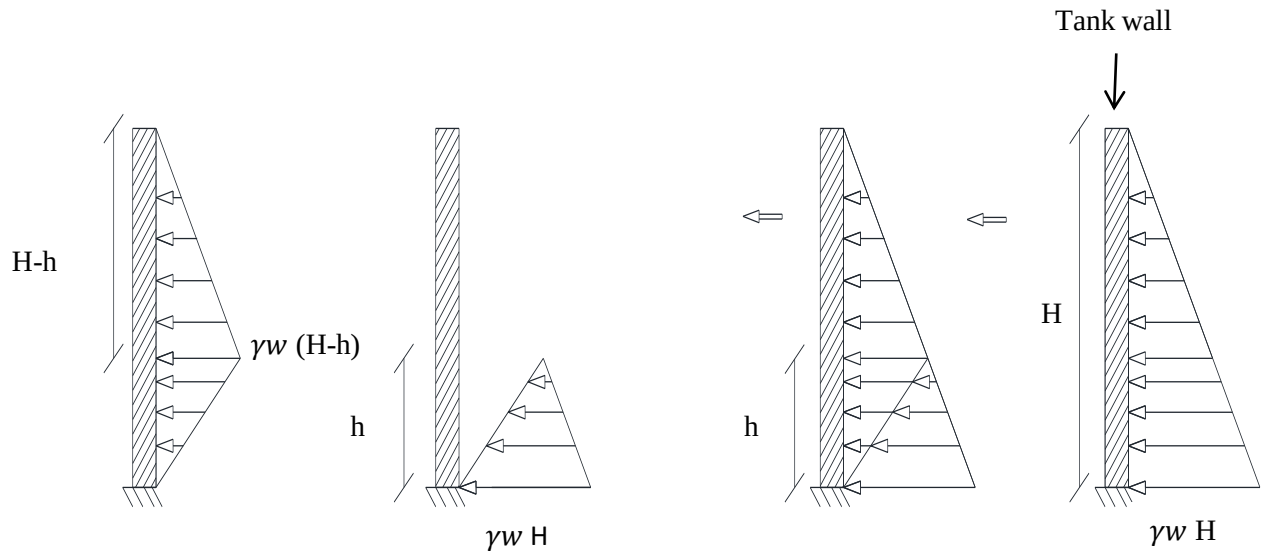


The Short Wall Design Details Due to Earth Pressure (Top View)

48. Condition II : Tank Under Water Pressure Only.



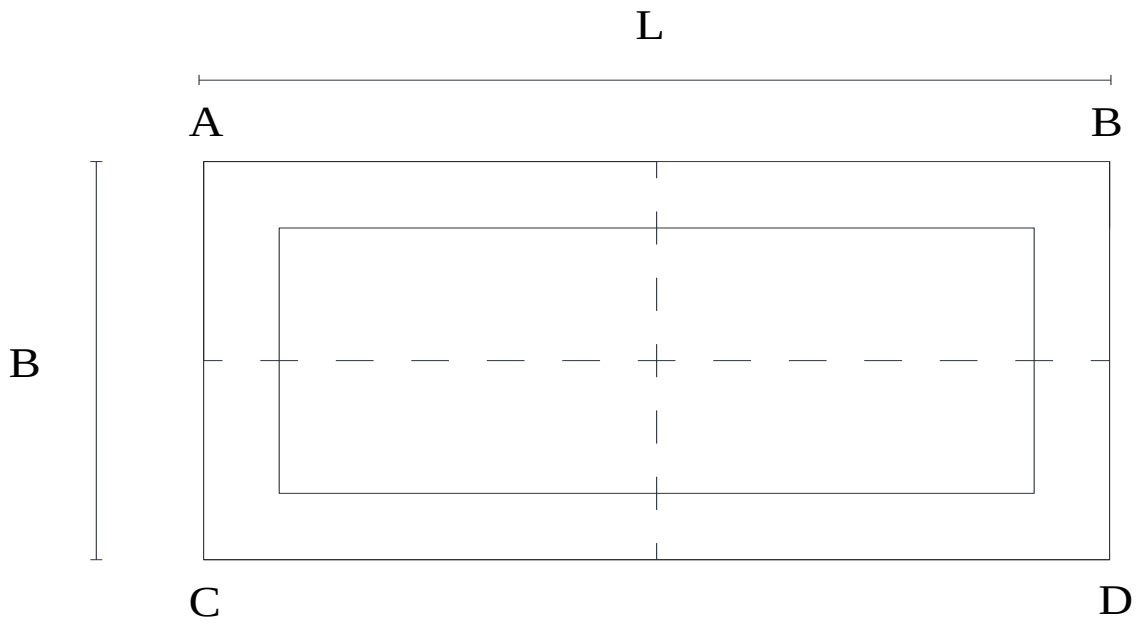
Underground Recantgular Tank Section - Condition II



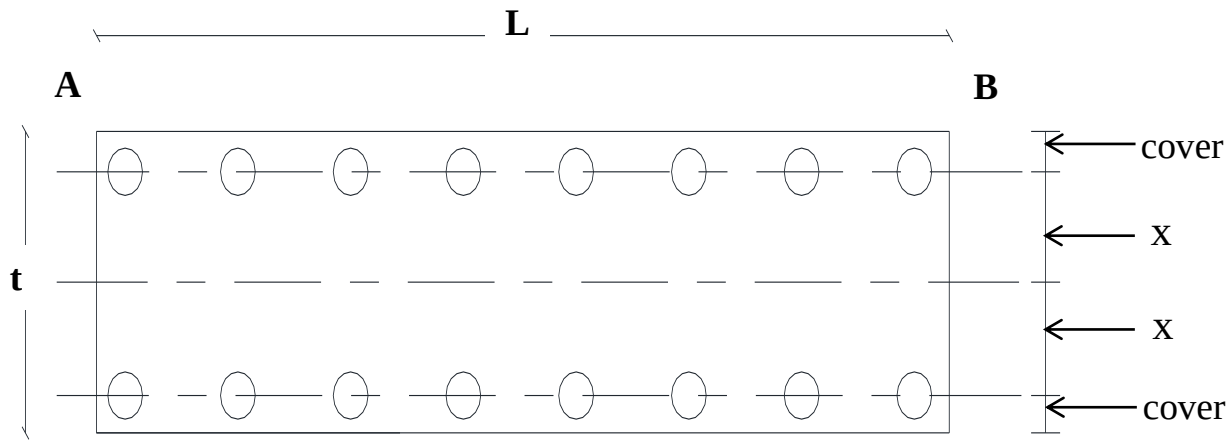
Horizontal Moment Hydrostatic Pressure

Vertical Moment Hydrostatic Pressure

Tank wall Hydrostatic Pressure



Tank Section, Top view



x = $\frac{t}{2}$ - Cover

49. **Long Wall, L = AB m**

50. Internal Horizontal Steel Reinforcement.

51. Determine The Fixed End Moment & (M_{END}) M_{FINAL} .

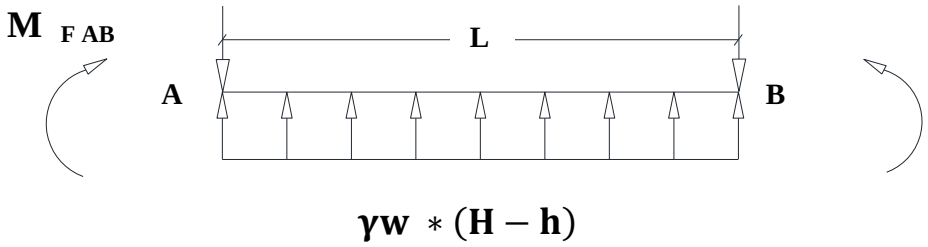
$$M_{\text{Fixed End AB}} = + \frac{\gamma w * (H-h) * L^2}{12} \text{ (Per meter width)}$$

$$M_{\text{Fixed End AC}} = - \frac{\gamma w * (H-h) * B^2}{12} \text{ (Per meter width)}$$

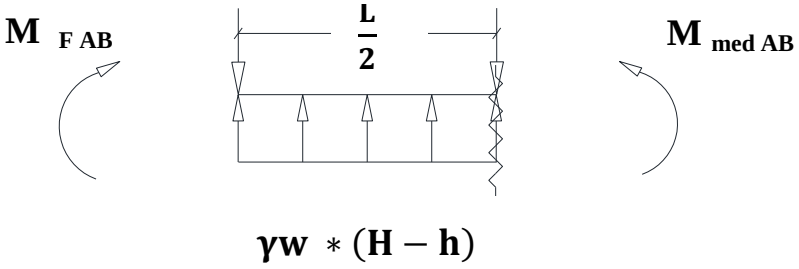
Member	AB	AC
D.F		
F.E.M		
Bal		
M_{Final}	$M_{Final\ AB}$	$M^{-}_{Final\ AC}$

52. Determine T_S and $M_{med\ AB}$ for L, T_L and $M_{med\ AC}$ for B

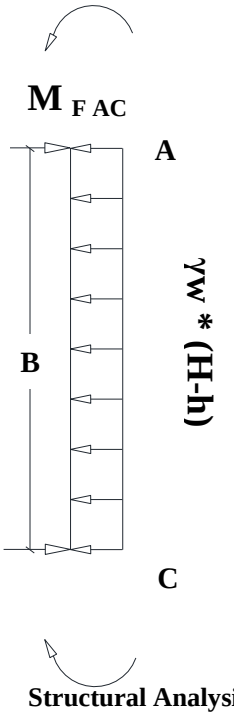
$$R_L = T_S = \frac{\gamma w * (H-h) * L}{2}$$



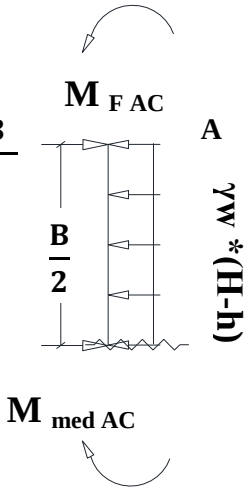
$$R_L = T_S = \frac{\gamma w * (H-h) * L}{2}$$



$$Rs = T_L = \frac{\gamma w * (H-h) * B}{2}$$



$$Rs = T_L = \frac{\gamma w * (H-h) * B}{2}$$



53. Determine The Net Moment

$$M_{net\ AB} = M_{Final\ AB} - T_L * x$$

54. Determine the Area of Steel Reinforcement.

$$As_{AB} = \frac{(M\ net\ AB)}{fs * j * d} + \frac{TL}{fs}$$

- If $As_{AB} = \frac{(M\ net\ AB)}{fs * j * d} + \frac{TL}{fs} \geq \frac{As\ min}{2}$, ∴ O.K.
- If $As_{AB} = \frac{(M\ net\ AB)}{fs * j * d} + \frac{TL}{fs} < \frac{As\ min}{2}$, use $As = \frac{As\ min}{2}$

55. Choose Ø and A_b from Rebar Table.
56. Determine the Spacing between The Internal Horizontal Steel Reinforcement.

$$S_{req} = \frac{1000 * Ab}{As\ net\ AB}$$

Then Determine S_{act} {The maximum Spacing value shall not exceed 300 mm}.

$S_{act} =$

57. Determine the Actual area of Internal Horizontal Steel Reinforcement

$$As_{net\ AB} = \frac{1000 * Ab}{S\ act}$$

Use Ø @ S_{act} mm c/c in one layer, Internal Horizontal Steel Reinforcement.

58. External Horizontal Steel Reinforcement.

59. Determine the Area of Steel Reinforcement.

$$M_{net,\ med\ AB} = M_{med\ AB} - T_L * x$$

$$As_{med} = \frac{(M\ net\ med\ AB)}{fs * j * d} + \frac{TL}{fs}$$

- If $As_{med} = \frac{(M\ net\ med\ AB)}{fs * j * d} + \frac{TL}{Fs} \geq \frac{As\ min}{2}$, $\therefore$ o.k.
- If $As_{med} = \frac{(M\ net\ med\ AB)}{fs * j * d} + \frac{TL}{fs} < \frac{As\ min}{2}$, use $As = \frac{As\ min}{2}$

60. Choose Ø and A_b from Rebar Table.
61. Determine the Spacing between The External Horizontal Steel Reinforcement

$$S_{req} = \frac{1000 * Ab}{As\ med}$$

Then Determine S_{act} {The maximum Spacing value shall not exceed 300 mm}.

$S_{\mathbf{act}} =$

62. Determine the Actual area of External Horizontal Steel Reinforcement

$$As_{net,\ med} = \frac{1000 * Ab}{S\ act}$$

Use Ø @ $S_{\mathbf{act}}$ mm c/c in one layer , External Horizontal Steel Reinforcement.

63. Internal Vertical Steel Reinforcement. {for h},{ For Long & Short Wall}

64. Determine The Vertical Moment

$$M_{Vertical} = \frac{\gamma w * H * h^2}{6}$$

65. Determine the Area of Steel Reinforcement.

$$As_{Vertical} = \frac{M\ Vertical}{fs * j * d}$$

- If $As_{Vertical} = \frac{M\ Vertical}{fs * j * d} \geq \frac{As\ min}{2}$, ∴ O.K.
- If $As_{Vertical} = \frac{M\ Vertical}{fs * j * d} < \frac{As\ min}{2}$, use $As = \frac{As\ min}{2}$

66. Choose Ø and A_b from Rebar Table.
67. Determine the Spacing between The Internal Vertical Steel Reinforcement.

$$S_{req} = \frac{1000 * Ab}{As\ Vertical}$$

Then Determine S_{act} {The maximum Spacing value shall not exceed 300 mm}.

S_{act} =

68. Determine the Actual area of Internal Vertical Steel Reinforcement

$$As_{Vertical\ act} = \frac{1000 * Ab}{S\ act}$$

69. Use Ø @ S_{act} mm c/c in one layer , Internal Vertical Steel Reinforcement for Height = h .
    - Use As_{min} for Internal Vertical Steel Reinforcement for Height = (H – h) .

70. **Short Wall, B = AC m**

71. Internal Horizontal Steel Reinforcement.

72. Determine The Net Moment

$$M_{net\ AC} = M_{Final\ AC} - T_S * x$$

73. Determine the Area of Steel Reinforcement.

$$As_{AC} = \frac{(M\ net\ AC)}{fs * j * d} + \frac{Ts}{fs}$$

- If $As_{AC} = \frac{(M\ net\ AC)}{fs * j * d} + \frac{Ts}{fs} \geq \frac{As\ min}{2}$, ∴ O.K.
- If $As_{AC} = \frac{(M\ net\ AC)}{fs * j * d} + \frac{Ts}{fs} < \frac{As\ min}{2}$, use $As = \frac{As\ min}{2}$

74. Choose Ø and A_b from Rebar Table.
75. Determine the Spacing between The Internal Horizontal Steel Reinforcement.

$$S_{req} = \frac{1000 * Ab}{As - net\ AC}$$

Then Determine S_{act} {The maximum Spacing value shall not exceed 300 mm}.

$S_{act} =$

76. Determine the Actual area of Internal Horizontal Steel Reinforcement

$$As_{net\ AC} = \frac{1000 * Ab}{S\ act}$$

Use Ø @ S_{act} mm c/c in one layer, Internal Horizontal Steel Reinforcement.

77. External Horizontal Steel Reinforcement.

78. Determine the Area of Steel Reinforcement.

$$M_{net,\ med\ AC} = M_{med\ AC} - T_S * x$$

$$As_{med} = \frac{(M\ net\ med\ AC)}{fs * j * d} + \frac{Ts}{fs}$$

- If $As_{med} = \frac{(M\ net\ med\ AC)}{fs * j * d} + \frac{Ts}{fs} \geq \frac{As\ min}{2}$, $\therefore$ OK
- If $As_{med} = \frac{(M\ net\ med\ AC)}{fs * j * d} + \frac{Ts}{fs} < \frac{As\ min}{2}$, use $As = \frac{As\ min}{2}$

79. Choose Ø and A_b from Rebar Table.
80. Determine the Spacing between The External Horizontal Steel Reinforcement

$$S_{req} = \frac{1000 * Ab}{As\ med}$$

Then Determine S_{act} {The maximum Spacing value shall not exceed 300 mm}.

$S_{\mathbf{act}} =$

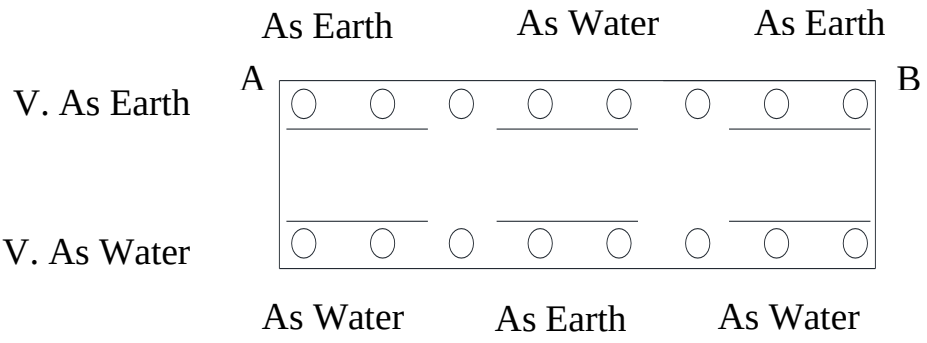
81. Determine the Actual area of External Horizontal Steel Reinforcement

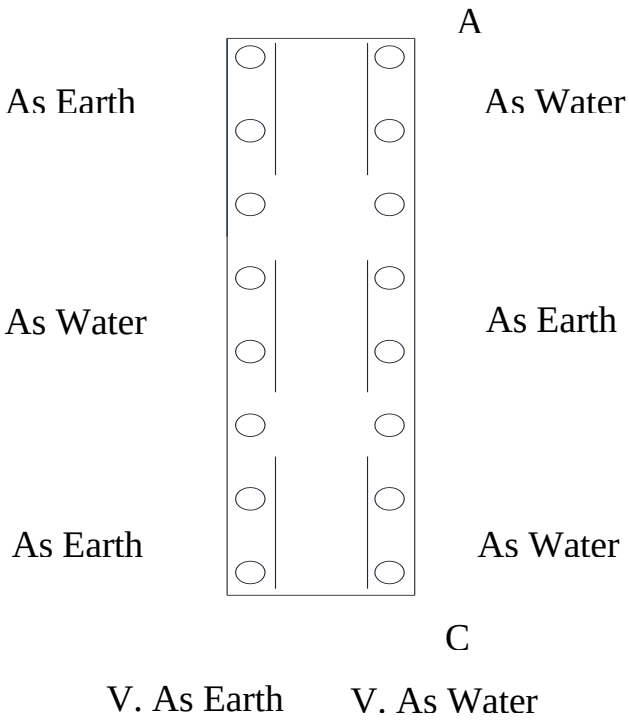
$$As_{net,\ med} = \frac{1000 * Ab}{S\ act}$$

Use Ø @ $S_{\mathbf{act}}$ mm c/c in one layer , External Horizontal Steel Reinforcement.

82. Internal Vertical Steel Reinforcement. { for h},{ For Long = Short Wall}

83. Design Details





Design Details (Walls)

Example: Design of open Reinforced Concrete Underground Rectangular Tank for a capacity of 252 m^3 and the angle of repose of soil 30° . L = 9 m, B = 7 m, Height = 4 m.

Use, γ_w = 10 kN/m^3, γ_s = 18 kN/m^3, f_s = 150 N/mm^2, f_c = 14 N/mm^2, n = 10.

Solution:

1. Check $\frac{\mathbf{L}}{\mathbf{B}}$ Ratio**.**
   - $\frac{\mathbf{L}}{\mathbf{B}} = \frac{9}{7}$
   - $\frac{\mathbf{L}}{\mathbf{B}} = 1.285 \leq 2$, $\therefore$ OK.

2. Condition I : Tank Under Earth Pressure Only.

3. Determine The Stiffness factor

$K_{AB} = \frac{2\ EI}{L}$

$K_{AB} = \frac{2\ EI}{9}$

$K_{AB} = 0.222\ \ EI$

$K_{AC} = \frac{2\ EI}{B}$

$K_{AC} = \frac{2\ EI}{7}$

$K_{AC} = 0.285\ EI$

4. Determine The Distribution factor

$D.F_{AB} = \frac{Kab}{Kab + Kac}$

$D.F_{AB} = \frac{0.222\ EI}{0.222\ EI + 0.285\ EI}$

$D.F_{AB} = 0.438$

$D.F_{AC} = \frac{Kac}{Kac + Kab}$

$D.F_{AC} = \frac{0.285\ EI}{0.285\ EI + 0.222\ EI}$

$D.F_{AC} = 0.562$

5. Determine The Soil Pressures

   - $P = \gamma w * H + (\gamma s - \gamma w)\ H\ * \frac{1- \sin\theta}{1+ \sin\theta}$ (per meter width)

     $P = 10 * 4\ + (18 - 10) * 4 * \frac{1- \sin 30}{1+ \sin 30}$

     $P = 50.666$ kN/m

   - $h = \frac{H}{4}$

     $h = \frac{4}{4}$

     $h = 1$ m , $h \geq 1$ OK

   - $P\times = P * \frac{(H-h)}{H}$

     $P\times = 50.666 * \frac{(4-1)}{4}$

     $P\times = 38$ kN/m

6. Determine The Fixed End Moment & (M_{END}) M_{FINAL} .

$M_{\text{Fixed End AB}} = - \frac{P\times * L^2}{12}$

$M_{\text{Fixed End AB}} = \frac{38 * 9^2}{12}$

$M_{\text{Fixed End AB}} = - 256.5$ kN.m

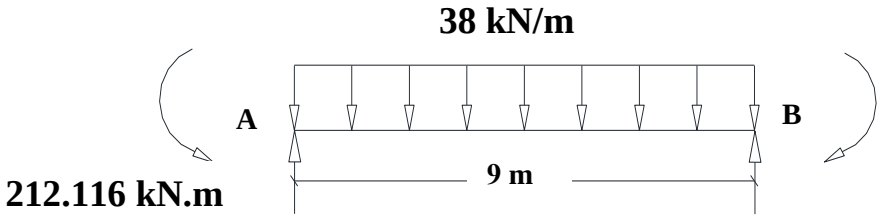
$M_{\text{Fixed End Ac}} = \frac{P\times * B^2}{12}$

$M_{\text{Fixed End Ac}} = \frac{38 * 7^2}{12}$

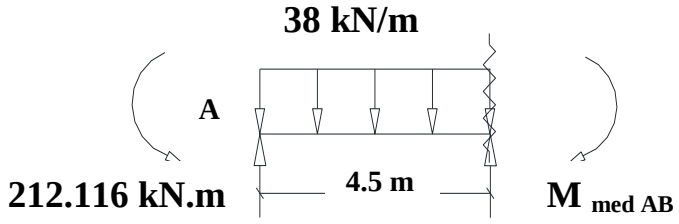
$M_{\text{Fixed End Ac}} = 155.166$ kN.m

Member	AB	AC
D.F	0.438	0.562
F.E.M	- 256.5	155.166
Bal	44.384	56.95
M_{Final} (kN.m)	- 212.116	212.116

7. Determine Moment at mid span of Long Wall (M med AB)



$$R_L = \frac{38 * 9}{2}$$



$$R_L = \frac{38 * 9}{2}$$

$\sum M = 0 \circlearrowright$

$M_{med\ AB} - 38 * 4.5 \left(\frac{4.5}{2}\right) + \frac{38 * 9}{2} * 4.5 - 212.116 = 0$

$M_{med\ AB} = -172.634$

$M_{med\ AB} = 172.634$ kN.m $\circlearrowleft$

8. Assume concrete cover = 50 mm.

9. Determine the effective depth {d}mm

$$d = \sqrt{\frac{2 * (M)\,max}{fc * k * j * b}}$$

Where:

- fc = 14 N/mm^2
- n = 10 (Modular Ratio)
- $r = \frac{fs}{fc}$ (Stress Ratio)

  $r = \frac{150}{14}$

  r = 10.714

- $K = \frac{n}{n+r}$

  $K = \frac{10}{10 + 10.714}$

- K = 0.482

- $J = 1 - \frac{K}{3}$

  $J = 1 - \frac{0.482}{3}$

  J = 0.839

$$d = \sqrt{\frac{2 * (M)\,max}{fc * k * j * b}}$$

$$d = \sqrt{\frac{2 * (212.116) * 10^6}{14 * 0.482 * 0.839 * 1000}}$$

d = 273.736 mm

10. Determine The Wall Thickness (t) mm

t = d + cover

t = 273.736 + 50

t = 323.736 ≅ 330 mm

11. Determine Reinforcement Ratio

$\% \rho min = 0.3 - 0.1 \left(\frac{t-100}{350} \right)$

$\% \rho min = 0.3 - 0.1 \left(\frac{330-100}{350} \right)$

$\% \rho min = 0.234 \%$

12. Determine Minimum Area of Steel Reinforcement

$A_{s\ min} = \% \rho min * t * 1000$

$A_{s\ min} = \frac{0.234}{100} * 330 * 1000$

$A_{s\ min} = 772.2\ mm^2$

13. **Long Wall, L = 9 m**

14. External Horizontal Steel Reinforcement.

15. Determine the Area of Steel Reinforcement.

$$As_{AB} = \frac{(M_{AB})}{fs * j * d}$$

$$As_{AB} = \frac{(212.116 * 10^6)}{150 * 0.839 * 273.736}$$

$$As_{AB} = 6157.271 \text{ mm}^2 \geq \frac{772.2}{2} \quad , \therefore \text{O.K.}$$

16. Choose Ø 25 and $A_b = 490$ mm^2 from Rebar Table.

17. Determine the Spacing between The External Horizontal Steel Reinforcement.

$$S_{req} = \frac{1000 * Ab}{As - AB}$$

$$S_{req} = \frac{1000 * 490}{6157.271}$$

$$S_{req} = 79.580 \text{ mm}$$

Then Determine S_{act} {The maximum Spacing value shall not exceed 300 mm}.

$$S_{act} = 70 \text{ mm}$$

18. Determine the Actual area of External Horizontal Steel Reinforcement

$$A_{S^-\ AB\ act} = \frac{1000 * Ab}{S\ act}$$

$$A_{S^-\ AB\ act} = \frac{1000 * 490}{70}$$

$$A_{S^-\ AB\ act} = 7000\ mm^2$$

19. Use ∅ 25 mm @ 70 mm c/c in one layer , External Horizontal Steel Reinforcement.

20. Internal Horizontal Steel Reinforcement.

21. Determine the Area of Steel Reinforcement.

$$As_{med} = \frac{(M\ med\ AB)}{fs * j * d}$$

$$As_{med} = \frac{(172.634 * 10^6)}{150 * 0.839 * 273.736}$$

$$As_{med} = 5011.193\ mm^2 \geq \frac{772.2}{2}\ ,\ \therefore O.K.$$

22. Choose Ø 25 mm and 490 mm^2 from Rebar Table.
23. Determine the Spacing between The Internal Horizontal Steel Reinforcement

$$S_{req} = \frac{1000 * 490}{5011.193}$$

$$S_{req} = 97.781\ mm$$

Then Determine S_{act} {The maximum Spacing value shall not exceed 300 mm}.

$$S_{act} = 90\ mm$$

24. Determine the Actual area of Internal Horizontal Steel Reinforcement

$$A_{S\ med\ act} = \frac{1000 * 490}{90}$$

$$A_{S^-\ med\ act} = 5444.444\ mm^2$$

25. Use Ø 25 mm @ 90 mm c/c in one layer , Internal Horizontal Steel Reinforcement.

26. External Vertical Steel Reinforcement. { for h}

27. Determine The Vertical Moment

$$M_{Vertical} = \frac{P * h^2}{6}$$

$$M_{Vertical} = \frac{50.666 * 1^2}{6}$$

$$M_{Vertical} = 8.444 \text{ kN.m}$$

28. Determine the Area of Steel Reinforcement.

$$As_{Vertical} = \frac{M\,Vertical}{fs * j * d}$$

$$As_{Vertical} = \frac{8.444 * 10^6}{150 * 0.839 * 273.736}$$

$$As_{Vertical} = 245.111 \text{ mm}^2 < \frac{772.2}{2} \text{ , } \therefore \text{use } As_{Vertical} = 386.1 \text{ mm}^2$$

29. Choose Ø 10 mm and $A_b = 79 \text{ mm}^2$ from Rebar Table.

30. Determine the Spacing between The External Vertical Steel Reinforcement.

$$S_{req} = \frac{1000 * Ab}{As\,Vertical}$$

$$S_{req} = \frac{1000 * 79}{386.1}$$

$$S_{req} = 204.610$$

Then Determine S_{act} {The maximum Spacing value shall not exceed 300 mm}.

$$S_{act} = 200 \text{ mm}$$

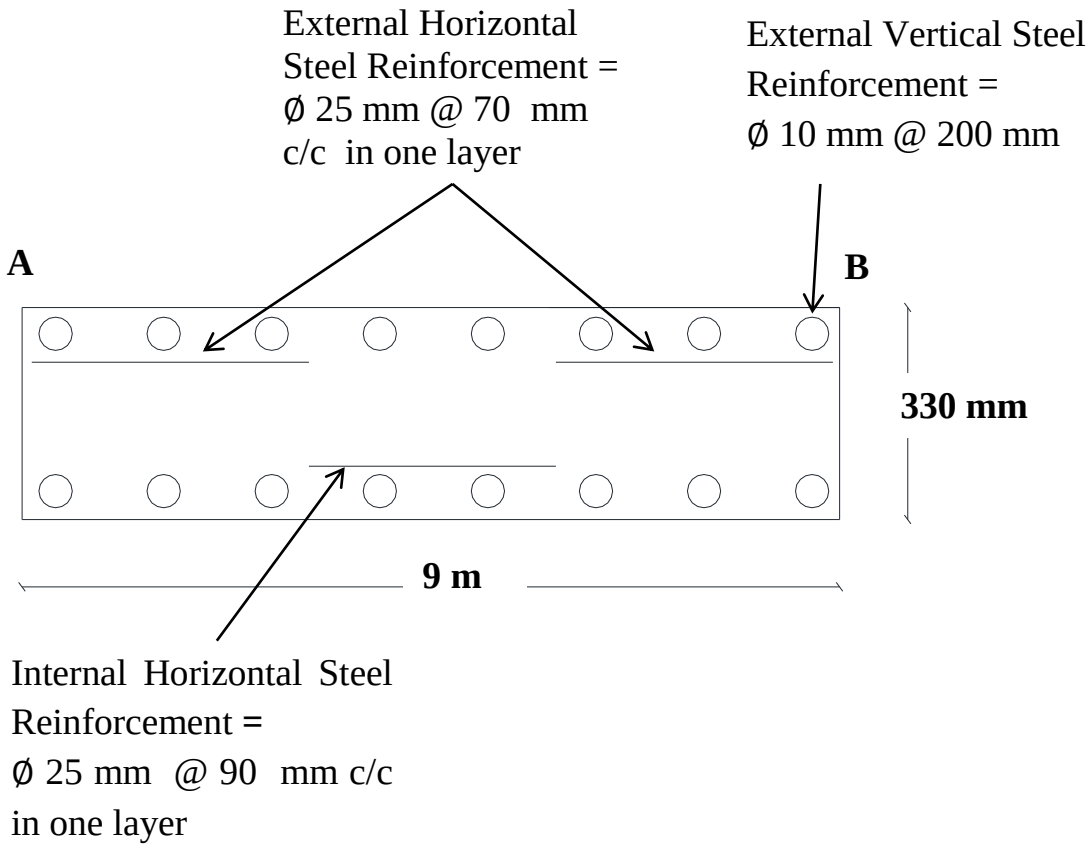
31. Determine the Actual area of External Vertical Steel Reinforcement.

$$As_{\text{Vertical act}} = \frac{1000 * Ab}{S\,act}$$

$$As_{\text{Vertical act}} = \frac{1000 * 79}{200}$$

$$As_{\text{Vertical act}} = 395\ mm^2$$

32. Use ∅ 10 mm @ 200 mm c/c in one layer , External Vertical Steel Reinforcement .



The Long Wall Design Details Due to Earth Pressure (Top View)

33. **Short Wall, B = 7 m .**

34. External Horizontal Steel Reinforcement.

35. Determine the Area of Steel Reinforcement.

$$As_{Ac} = \frac{(M\ Final\ AC)}{fs * j * d}$$

$$As_{Ac} = \frac{(212.116 * 10^6)}{150 * 0.839 * 273.736}$$

$As_{Ac} = 6157.271\ mm^2 \quad \geq \frac{772.2}{2}$, ∴ O.K.

36. Choose Ø 25 mm and $A_b = 490\ mm^2$ from Rebar Table.

37. Determine the Spacing between The External Horizontal Steel Reinforcement.

$$S_{req} = \frac{1000 * Ab}{As\ AC}$$

$$S_{req} = \frac{1000 * 490}{6157.271}$$

$S_{req} = 79.580$ mm

Then Determine S_{act} {The maximum Spacing value shall not exceed 300 mm}.

$S_{act} = 70$ mm

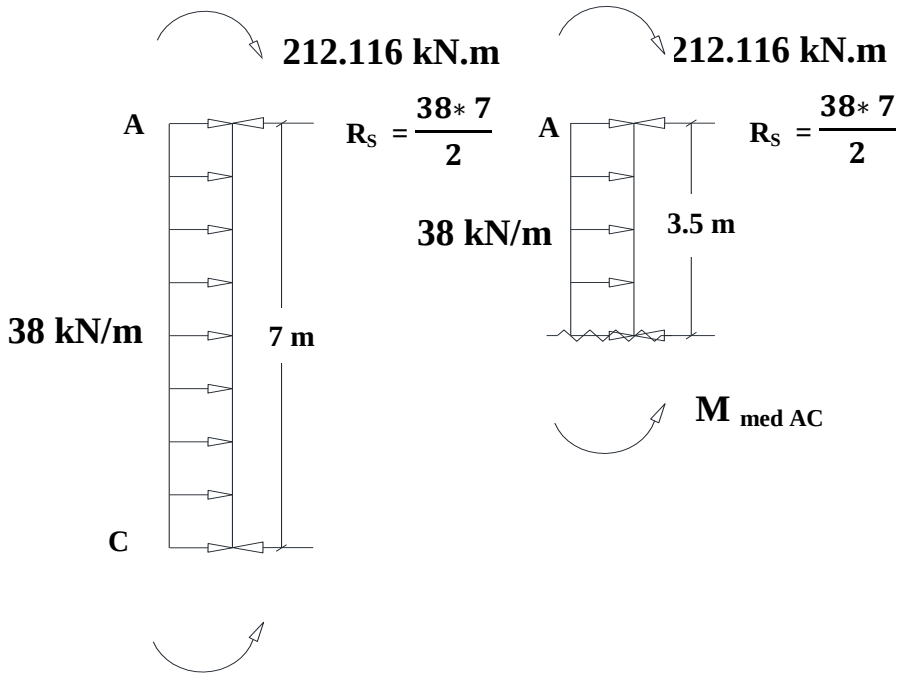
38. Determine the Actual area of External Horizontal Steel Reinforcement

$$A_{S\ AC\ act} = \frac{1000 * 490}{70}$$

$$A_{S\ AC\ act} = 7000\ mm^2$$

39. Use Ø 25 mm @ 70 mm c/c in one layer , External Horizontal Steel Reinforcement.

40. Internal Horizontal Steel Reinforcement.



$\sum M = 0 \circlearrowleft$

$$212.116 - \frac{38 * 7}{2} * 3.5 + 38 * 3.5 * \frac{3.5}{2} - M_{med\ AC} = 0$$

$$M_{med\ AC} = -20.634$$

$$M_{med\ AC} = 20.634 \text{ kN.m} \circlearrowleft$$

41. Determine the Area of Steel Reinforcement for B = 7 m

$$As_{med} = \frac{(M\ med\ AC)}{fs * j * d}$$

$$As_{med} = \frac{(20.634 * 10^6)}{150 * 0.839 * 273.736}$$

$$As_{med} = 598.960 \text{ mm}^2 \geq \frac{772.2}{2} \quad , \therefore \text{ o.k.}$$

42. Choose Ø 8 mm and A_b = 50 mm^2 from Rebar Table.

43. Determine the Spacing between The Internal Horizontal Steel Reinforcement

$$S_{req} = \frac{1000 * Ab}{As\ med}$$

$$S_{req} = \frac{1000 * 50}{598.960}$$

S_{req} = 83.478 mm

Then Determine S_{act} {The maximum Spacing value shall not exceed 300 mm}.

S_{act} = 80 mm

44. Determine the Actual area of Internal Horizontal Steel Reinforcement

$$A_{S\ med\ act} = \frac{1000 * Ab}{S\ act}$$

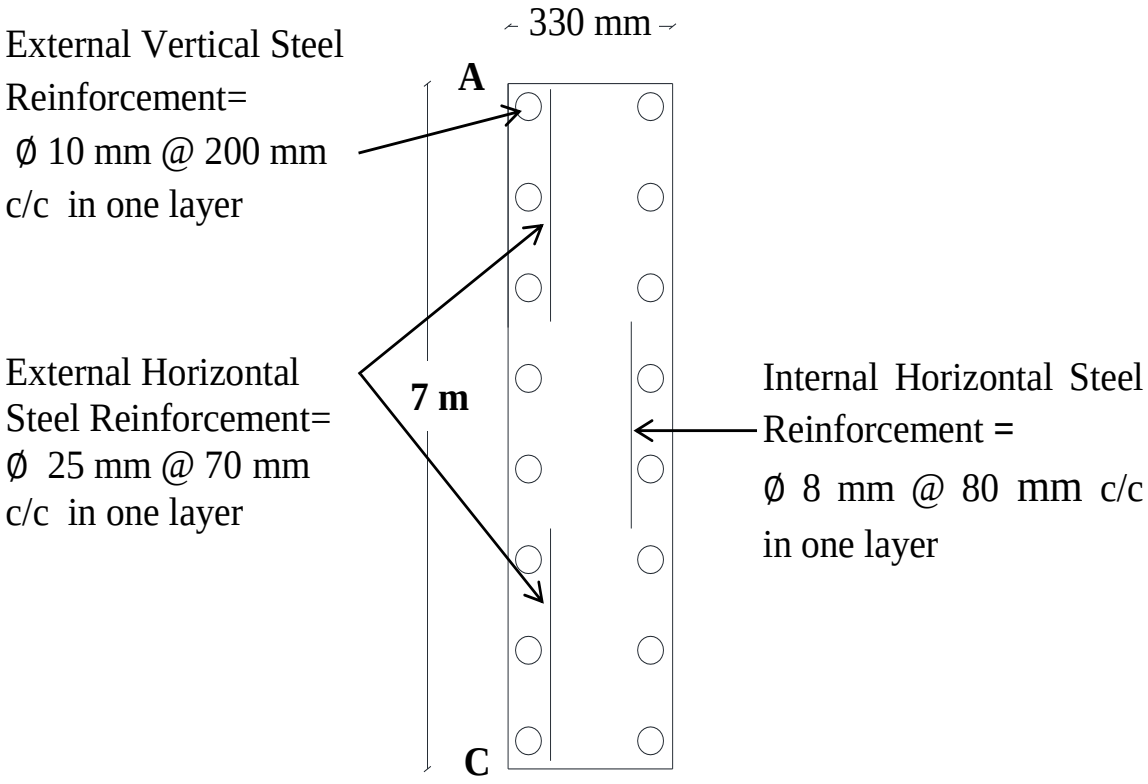
$$A_{S\ med\ act} = \frac{1000 * 50}{80}$$

$A_{S\ med\ act}$ = 625 mm^2

45. Use Ø 8 mm @ 80 mm c/c in one layer , Internal Horizontal Steel Reinforcement.

46. Use External Vertical Steel Reinforcement for Short B = External Vertical Steel Reinforcement for Long L .

47. Use ∅ 10 mm @ 200 mm c/c in one layer , External Vertical Steel Reinforcement.



The Short Wall Design Details Due to Earth Pressure (Top View)

48. **Condition II : Tank Under Water Pressure Only.**

49. **Long Wall, L = 9 m**

50. Internal Horizontal Steel Reinforcement.

51. Determine The Fixed End Moment & (M_{END}) M_{FINAL} .

$$M_{\text{Fixed End AB}} = + \frac{\gamma w * (H-h) * L^2}{12}$$

$$M_{\text{Fixed End AB}} = \frac{10 * (4-1) * 9^2}{12}$$

$$M_{\text{Fixed End AB}} = 202.5 \text{ kN.m}$$

$$M_{\text{Fixed End AC}} = - \frac{\gamma w * (H-h) * B^2}{12}$$

$$M_{\text{Fixed End AC}} = - \frac{10 * (4-1) * 7^2}{12}$$

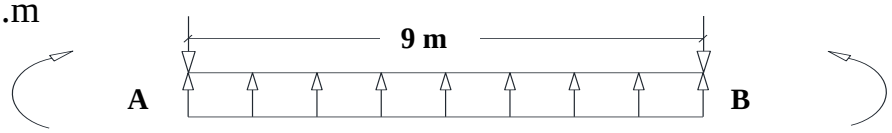
$$M_{\text{Fixed End AC}} = - 122.5 \text{ kN.m}$$

Member	AB	AC
D.F	0.438	0.562
F.E.M	202.5	-122.5
Bal	- 35.04	-44.96
M Final kN.m	167.46	-167.46

52. Determine T_S and $M_{\text{med AB}}$ for L, T_L and $M_{\text{med AC}}$ for B

$$R_L = T_S = \frac{10 * (4-1) * 9}{2}$$

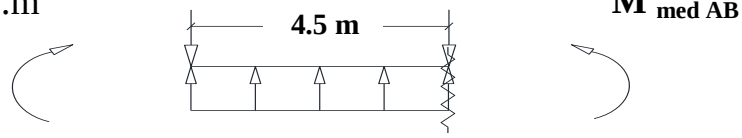
167.46 kN.m



$$10 * (4-1)\ \text{kN/m}$$

$$R_L = T_S = \frac{10 * (4-1) * 9}{2}$$

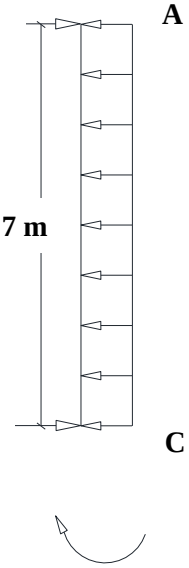
167.46 kN.m



$$10 * (4-1)\ \text{kN/m}$$

167.46 kN.m

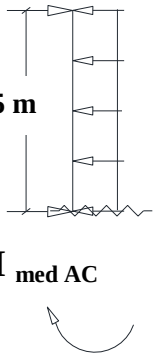
$$Rs = T_L = \frac{10 * (4-1) * 7}{2}$$



$$10 * (4-1)$$

167.46 kN.m

$$Rs = T_L = \frac{10 * (4-1) * 7}{2}$$



$$10 * (4-1)$$

53. Determine The Net Moment

   - x = $\frac{t}{2}$ - Cover
   - x = $\frac{330}{2}$ - 50
   - x = 115 mm

$$M_{net\ AB} = M_{Final\ AB} - T_L * x$$

$$M_{net\ AB} = 167.46 - \frac{\mathbf{10} * (\mathbf{4-1}) * \mathbf{7}}{\mathbf{2}} * 0.115$$

$$M_{net\ AB} = 155.385\ kN.m$$

54. Determine the Area of Steel Reinforcement.

$$As_{AB} = \frac{(M\ net\ AB)}{fs * j * d} + \frac{TL}{fs}$$

$$As_{AB} = \frac{(155.385 * 10^6)}{150 * 0.839 * 260} + \frac{\frac{\mathbf{10} * (\mathbf{4-1}) * \mathbf{7}}{\mathbf{2}} * \mathbf{10^3}}{150}$$

$$As_{AB} = 5448.785\ mm^2 \geq \frac{744}{2}\ , \therefore O.K.$$

55. Choose ∅ 25 and $A_b = 490\ mm^2$ from Rebar Table.
56. Determine the Spacing between The Internal Horizontal Steel Reinforcement.

$$S_{req} = \frac{1000 * Ab}{As - net\ AB}$$

$$S_{req} = \frac{1000 * 490}{5448.785}$$

$$S_{req} = 89\ mm$$

Then Determine S_{act} {The maximum Spacing value shall not exceed 300 mm}.

$S_{act} = 80$ mm

57. Determine the Actual area of Internal Horizontal Steel Reinforcement

$$As_{net\ act\ AB} = \frac{1000 * Ab}{S\,act}$$

$$As_{net\ act\ AB} = \frac{1000 * 490}{80}$$

$$As_{net\ act\ AB} = 6125\ mm^2$$

Use Ø 25 @ 80 mm c/c in one layer, Internal Horizontal Steel Reinforcement.

58. External Horizontal Steel Reinforcement.

59. Determine the Area of Steel Reinforcement

- $\sum M = 0$ ⤾
- $167.46 - \frac{10*(4-1)*9}{2} * 4.5 + 10 * (4-1) * 4.5 * \frac{4.5}{2} - M_{\text{med AB}} = 0$
- $M_{\text{med AB}} = -136.29$
- $M_{\text{med AB}} = 136.29$ kN.m ⤾

$$M_{\text{net med AB}} = M_{\text{med AB}} - T_L * x$$

$$M_{\text{net med AB}} = 136.29 - \frac{10*(4-1)*7}{2} * 0.115$$

$$M_{\text{net med AB}} = 124.215 \text{ kN.m}$$

$$As_{\text{med}} = \frac{(M \text{ net med AB})}{fs * j * d} + \frac{TL}{fs}$$

$$As_{\text{med}} = \frac{(124.215 * 10^6)}{150 * 0.839 * 260} + \frac{\frac{10*(4-1)*7}{2} * 10^3}{150}$$

$$As_{\text{med}} = 4496.185 \text{ mm}^2 \geq \frac{744}{2} \text{ , } \therefore \text{ o.k.}$$

60. Choose Ø 25 mm and A_b = 490 mm^2 from Rebar Table.

61. Determine the Spacing between The External Horizontal Steel Reinforcement

$$S_{req} = \frac{1000 * Ab}{As\ med}$$

$$S_{req} = \frac{1000 * 490}{4496.185}$$

S_{req} = 108 mm

Then Determine S_{act} {The maximum Spacing value shall not exceed 300 mm}.

S_{act} = 80 mm

62. Determine the Actual area of External Horizontal Steel Reinforcement

$$As_{net,\ med} = \frac{1000 * Ab}{S\ act}$$

$$As_{net,\ med} = \frac{1000 * 490}{80}$$

$As_{net,\ med}$ = 6125 mm^2

Use Ø 25 @ 80 mm c/c in one layer , External Horizontal Steel Reinforcement.

63. Internal Vertical Steel Reinforcement. {for h},{ For Long & Short Wall}

64. Determine The Vertical Moment

$$M_{Vertical} = \frac{\gamma w * H * h^2}{6} \text{ (Per meter Height)}$$

$$M_{Vertical} = \frac{10 * 4 * 1^2}{6}$$

$$M_{Vertical} = 6.666 \text{ kN.m}$$

65. Determine the Area of Steel Reinforcement.

$$As_{Vertical} = \frac{M\,Vertical}{fs * j * d}$$

$$As_{Vertical} = \frac{6.666 * 10^6}{150 * 0.839 * 260}$$

$$As_{Vertical} = 203.722 \text{ mm}^2 < \frac{744}{2},$$

$$\therefore \text{ use } As_{Vertical} = 372 \text{ mm}^2$$

66. Choose Ø and A_b from Rebar Table.

67. Determine the Spacing between The Internal Vertical Steel Reinforcement.

$$S_{req} = \frac{1000 * Ab}{As\,Vertical}$$

$$S_{req} = \frac{1000 * 79}{372}$$

$$S_{req} = 212 \text{ mm}$$

Then Determine S_{act} {The maximum Spacing value shall not exceed 300 mm}.

$S_{act} = 210$ mm

68. Determine the Actual area of Internal Vertical Steel Reinforcement

$$As_{\text{Vertical act}} = \frac{1000 * Ab}{S\,act}$$

$$As_{\text{Vertical act}} = \frac{1000 * 50}{130}$$

$As_{\text{Vertical act}} = 384.615\ mm^2$

69. Use ∅ 10 @ 210 mm c/c in one layer , Internal Vertical Steel Reinforcement.

70. **Short Wall, B = 7 m**

71. Internal Horizontal Steel Reinforcement.

72. Determine The Net Moment

$$M_{net\ AC} = M_{Final\ AC} - T_S * x$$

$$M_{net\ AC} = 167.46 - \frac{\mathbf{10} * (\mathbf{4-1}) * \mathbf{9}}{\mathbf{2}} * 0.115$$

$$M_{net\ AC} = 151.935\ kN.m$$

73. Determine the Area of Steel Reinforcement for B =7 m

$$As_{AC} = \frac{(M\ net\ AC)}{fs * j * d} + \frac{Ts}{fs}$$

$$As_{AC} = \frac{(151.935 * 10^6)}{150 * 0.839 * 260} + \frac{\frac{\mathbf{10} * (\mathbf{4-1}) * \mathbf{9}}{\mathbf{2}} * \mathbf{10^3}}{150}$$

$As_{AC} = 5543.348\ mm^2 \geq \frac{744}{2}$, ∴ O.K.

74. Choose Ø 25 mm and A_b =490 mm^2 from Rebar Table.

75. Determine the Spacing between The Internal Horizontal Steel Reinforcement.

$$S_{req} = \frac{1000 * Ab}{As\ net\ AC}$$

$$S_{req} = \frac{1000 * 490}{5543.348}$$

$S_{req} = 88\ mm$

Then Determine S_{act} {The maximum Spacing value shall not exceed 300 mm}.

$S_{act} = 80$ mm

76. Determine the Actual area of Internal Horizontal Steel Reinforcement

$$As_{net\ AC} = \frac{1000 * Ab}{S\,act}$$

$$As_{net\ AC} = \frac{1000 * 490}{80}$$

$$As_{net\ AC} = 6125\ mm^2$$

Use Ø 25 @ 80 mm c/c in one layer, Internal Horizontal Steel Reinforcement.

77. External Horizontal Steel Reinforcement.

78. Determine the Area of Steel Reinforcement.

$\sum M = 0 \circlearrowleft$

$$M_{\text{med Ac}} - 10 * (4-1) * 3.5 * \frac{3.5}{2} + \frac{10 * (4-1) * 7}{2} * 3.5 - 167.46 = 0$$

$M_{\text{med Ac}} = -16.29$

$M_{\text{med Ac}} = 16.29 \text{ kN.m} \circlearrowright$

$$M_{\text{net, med AC}} = M_{\text{med AC}} - T_S * x$$

$$M_{\text{net, med AC}} = 16.29 - \frac{\mathbf{10 * (4-1) * 9}}{\mathbf{2}} * 0.115$$

$M_{\text{net, med AC}} = 0.765 \text{ kN.m}$

$$As_{\text{med}} = \frac{(M \text{ net med AC})}{fs * j * d} + \frac{Ts}{fs}$$

$$As_{\text{med}} = \frac{(0.765 * 10^6)}{150 * 0.839 * 260} + \frac{\frac{\mathbf{10 * (4-1) * 9}}{\mathbf{2}} * \mathbf{10^3}}{150}$$

$As_{\text{med}} = 923.379 \text{ mm}^2 \geq \frac{744}{2}$, $\therefore$ OK

79. Choose Ø 16 and A_b = 490 mm^2 from Rebar Table.

80. Determine the Spacing between The External Horizontal Steel Reinforcement

$$S_{req} = \frac{1000 * Ab}{As\ med}$$

$$S_{req} = \frac{1000 * 201}{923.379}$$

$$S_{req} = 217$$

Then Determine S_{act} {The maximum Spacing value shall not exceed 300 mm}.

S_{act} = 140 mm

81. Determine the Actual area of External Horizontal Steel Reinforcement

$$As_{net,\ med} = \frac{1000 * Ab}{S\ act}$$

$$As_{net,\ med} = \frac{1000 * 201}{140}$$

$As_{net,\ med}$ = 1435.714 mm^2

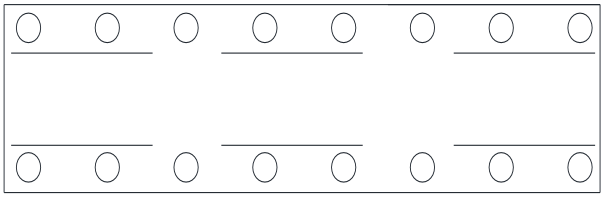
Use Ø 16 @ 140 mm c/c in one layer , External Horizontal Steel Reinforcement.

82. Internal Vertical Steel Reinforcement. { for h},{ For Long = Short Wall}

Use ∅ 10 @ 210 mm c/c in one layer , Internal Vertical Steel Reinforcement.

83. Design Details

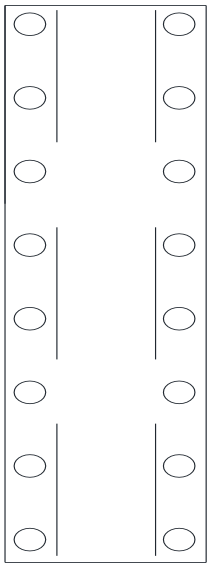
Ø 25 mm @ 70 mm Ø 25 mm @ 80 mm **Ø 25 mm @ 70 mm**

Ø 10 mm @ 200 mm A  B

Ø 10 mm @ 210 mm

Ø 25 mm @ 80 mm **Ø 25 mm @ 90 mm** Ø 25 mm @ 80 mm

A



Ø 25 mm @ 80 mm

Ø 25 mm @ 70 mm

Ø 16 mm @ 140 mm **Ø 8 mm @ 80 mm**

Ø 25 mm @ 70 mm Ø 25 mm @ 80 mm

Ø 10 mm @ 200 mm Ø 10 mm @ 210 mm

Design Details (Walls)

Design of Reinforced Concrete Underground Rectangular Tank

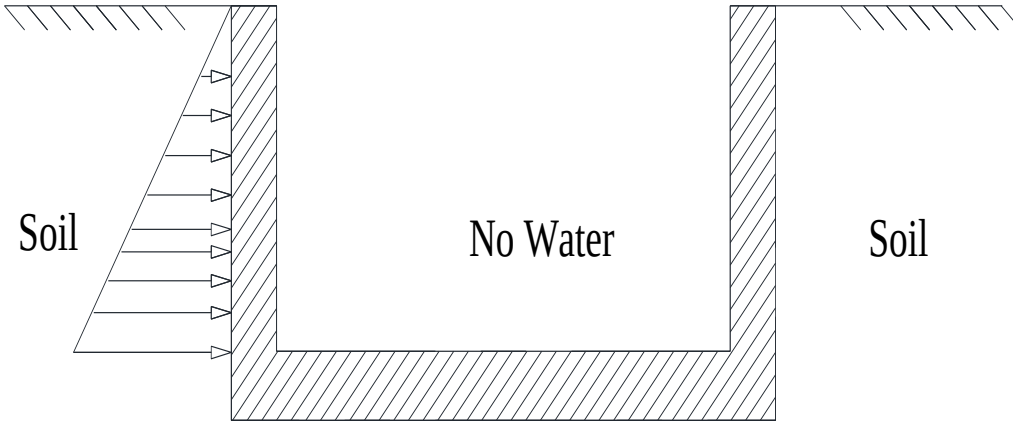
$$\frac{L}{B} > 2$$

Design Steps

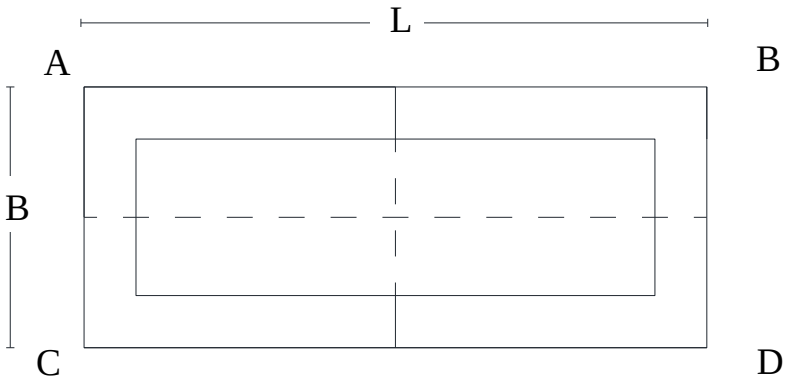
1. Check $\frac{\mathbf{L}}{\mathbf{B}}$ **Ratio.**

$\frac{L}{B} > 2$, $\therefore$ OK

2. Condition I : Tank Under Earth Pressure Only.



Underground Recantgular Tank Section - Condition I



Tank Section, Top view

Where:

L = Long Direction

B = Short Direction

3. Determine The Soil Pressures

- $P = \gamma_w * H + (\gamma_s - \gamma_w)\ H\ * \frac{1- \sin\theta}{1+ \sin\theta}$ (per meter width)
- $h = \frac{H}{4}$, $h \geq 1$

4. Determine The Vertical Moment

$$M_{Vertical} = \frac{P * H^2}{6}$$

5. Assume concrete cover = 50 mm.

6. Determine the effective depth {d}mm

$$d = \sqrt{\frac{2 * (M\ vertical)}{fc * k * j * b}}$$

Where:

- $fc = 0.35\ f\bar{c}$
- $n = \frac{Es}{Ec}$ (Modular Ratio),

$$n = \frac{Es}{5000 * \sqrt{fc} \times}$$

- $r = \frac{fs}{fc}$ (Stress Ratio)
- $K = \frac{n}{n+r}$
- $J = 1 - \frac{K}{3}$

7. Determine The Wall Thickness (t) mm

$t = d + cover$

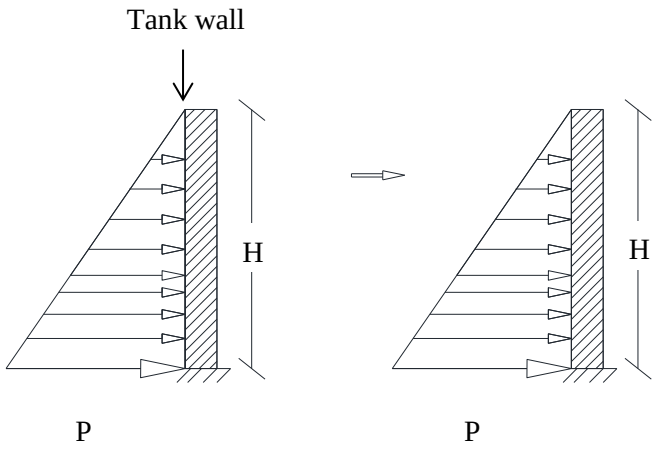
8. Determine Reinforcement Ratio

$$\%\ \rho\ min = 0.3 - 0.1\ (\ \frac{t-100}{350}\ )$$

9. Determine Minimum Area of Steel Reinforcement

$As_{min} = \%\ \rho\ min * t * 1000$

10. **Long Wall, L = AB m**



Tank wall Earth Pressure

Vertical Moment Earth Pressure

Where:

P = Soil Pressure at H

11. External Vertical Steel Reinforcement .

12. Determine the Area of Steel Reinforcement .

$$As = \frac{(M\ Vertical)}{fs * j * d}$$

- If $As = \frac{(M\ Vertical)}{fs * j * d} \geq \frac{As\ min}{2}$, ∴ O.K.
- If $As = \frac{(M\ Vertical)}{fs * j * d} < \frac{As\ min}{2}$, use $As = \frac{As\ min}{2}$

13. Choose Ø and A_b from Rebar Table.
14. Determine the Spacing between The External Vertical Steel Reinforcement.

$$S_{req} = \frac{1000 * Ab}{As}$$

Then Determine S_{act} {The maximum Spacing value shall not exceed 300 mm}.

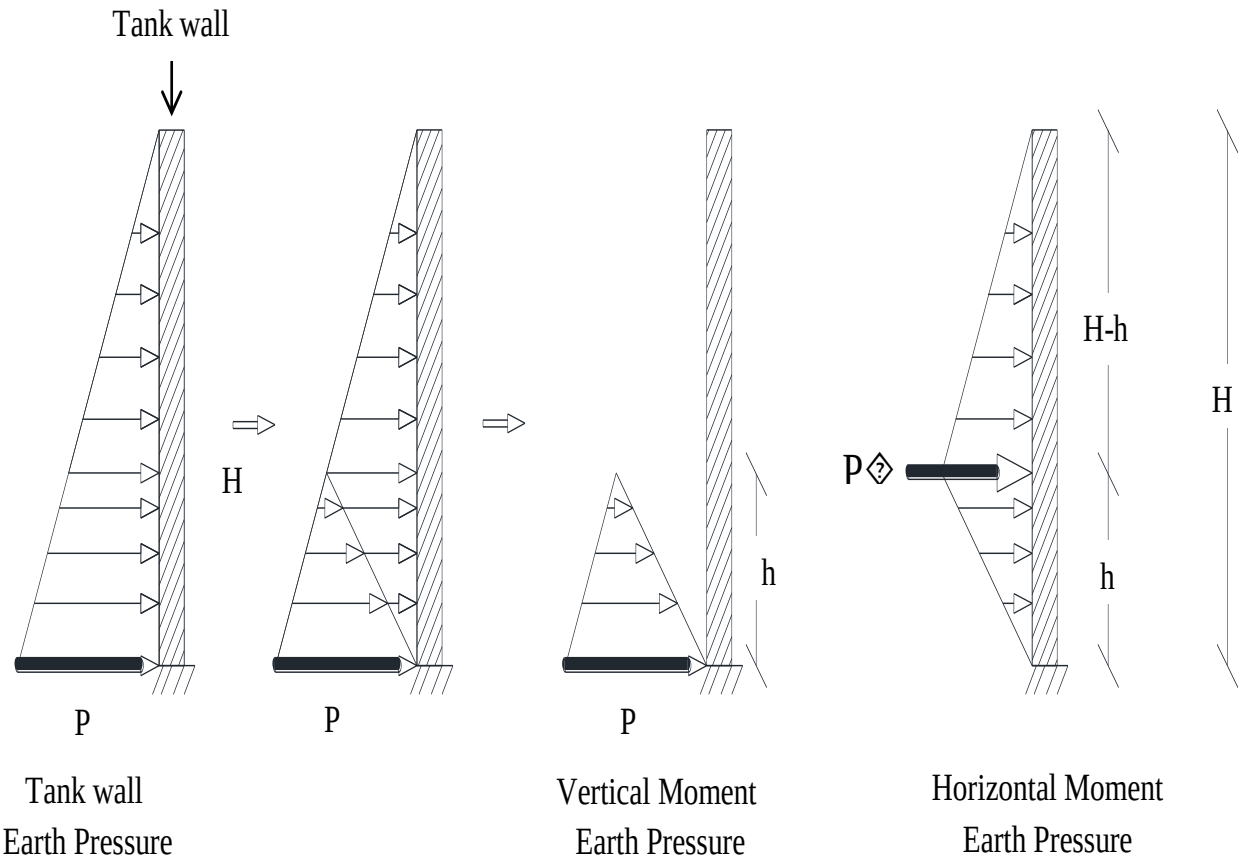
S_{act} =

15. Determine the Actual area of External Vertical Steel Reinforcement

$$A_{S\ act} = \frac{1000 * Ab}{S\ act}$$

16. Use Ø @ S **act** mm c/c in one layer , External Vertical Steel Reinforcement

17. **Short Wall, B = AC m .**



18. Determine The Soil Pressure

$$P\times = P * \frac{(H-h)}{H}$$

Where:

P× = Soil Pressure at (H- h)

19. External Horizontal Steel Reinforcement.

20. Determine The Negative Moment at AC.

$$M^{-}_{AC} = \frac{P \times * B^2}{12}$$

21. Determine the Area of Steel Reinforcement.

$$As_{Ac} = \frac{M^{-}AC}{fs * j * d}$$

- If $As_{Ac} = \frac{M^{-}AC}{fs * j * d} \geq \frac{As\ min}{2}$, ∴ O.K.
- If $As_{Ac} = \frac{M^{-}AC}{fs * j * d} < \frac{As\ min}{2}$, use $As = \frac{As\ min}{2}$

22. Choose Ø and A_b from Rebar Table.

23. Determine the Spacing between The External Horizontal Steel Reinforcement.

$$S_{req} = \frac{1000 * Ab}{As\ AC}$$

Then Determine S_{act} {The maximum Spacing value shall not exceed 300 mm}.

$S_{act} =$

24. Determine the Actual area of External Horizontal Steel Reinforcement

$$A_{S\ AC\ act} = \frac{1000 * Ab}{S\ act}$$

25. Use Ø @ S_{act} mm c/c in one layer , External Horizontal Steel Reinforcement.

26. Internal Horizontal Steel Reinforcement.

27. Determine The Positive Moment at AC.

$$M^{+}_{AC} = \frac{P \times * B^2}{16}$$

28. Determine the Area of Steel Reinforcement.

$$As_{Ac} = \frac{M + AC}{Fs * J * d}$$

- If $As_{Ac} = \frac{M + AC}{fs * j * d} \geq \frac{As\ min}{2}$, $\therefore$ O.K.
- If $As_{Ac} = \frac{M + AC}{fs * j * d} < \frac{As\ min}{2}$, use $As = \frac{As\ min}{2}$

29. Choose Ø and A_b from Rebar Table.

30. Determine the Spacing between The Internal Horizontal Steel Reinforcement.

$$S_{req} = \frac{1000 * Ab}{As\ AC}$$

Then Determine S_{act} {The maximum Spacing value shall not exceed 300 mm}.

S_{act} =

31. Determine the Actual area of Internal Horizontal Steel Reinforcement

$$A_{S\ AC\ act} = \frac{1000 * Ab}{S\ act}$$

32. Use Ø @ S_{act} mm c/c in one layer , Internal Horizontal Steel Reinforcement.

33. External Vertical Steel Reinforcement

34. Determine The Vertical Moment

$$M_{Vertical} = \frac{P * h^2}{6}$$

35. Determine the Area of Steel Reinforcement.

$$As_{Vertical} = \frac{M\ Vertical}{fs * j * d}$$

- If $As_{Vertical} = \frac{M\ Vertical}{fs * j * d} \geq \frac{As\ min}{2}$, ∴ O.K.
- If $As_{Vertical} = \frac{M\ Vertical}{fs * j * d} < \frac{As\ min}{2}$, use $As = \frac{As\ min}{2}$

36. Choose Ø and A_b from Rebar Table.

37. Determine the Spacing between The External Vertical Steel Reinforcement.

$$S_{req} = \frac{1000 * Ab}{As\ Vertical}$$

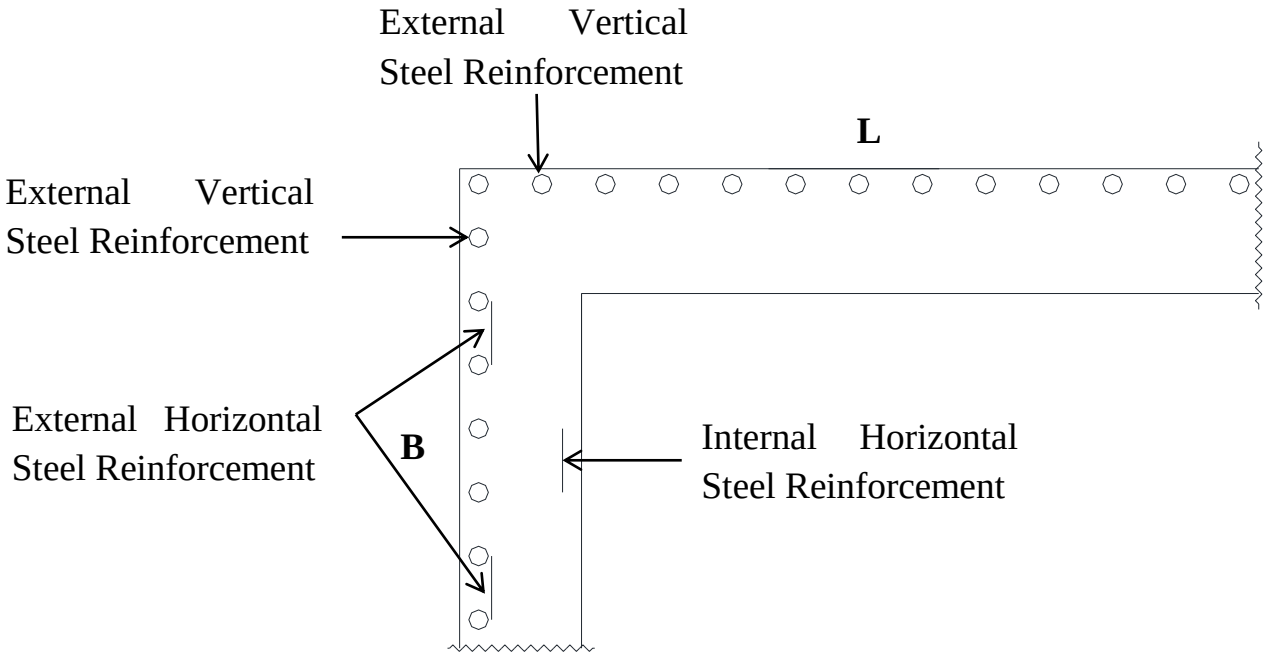
Then Determine S_{act} {The maximum Spacing value shall not exceed 300 mm}.

S_{act} =

38. Determine the Actual area of External Vertical Steel Reinforcement

$$As_{Vertical\ act} = \frac{1000 * Ab}{S\ act}$$

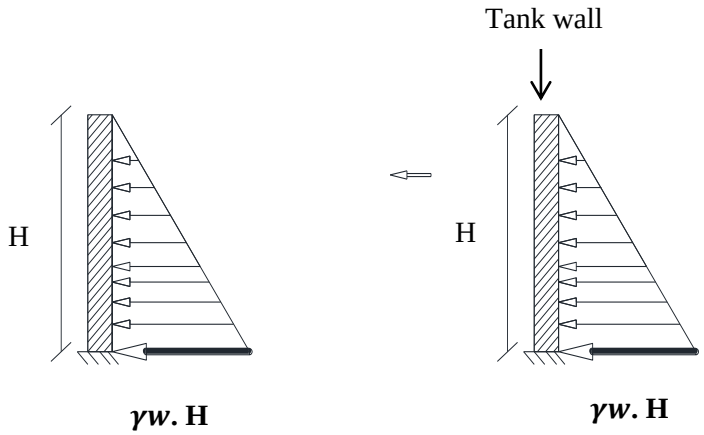
39. Use Ø mm @ mm c/c in one layer for External Vertical Steel Reinforcement for Height = h



Wall Design Details Due to Earth Pressure for Long and Short (Top View)

40. Condition II : Tank Under Water Pressure Only.

41. Long Wall, L = AB m



Vertical Moment
Water Pressure

Tank wall
Water Pressure

42. Internal and External Horizontal Steel Reinforcement.

43. Determine The Tension in long

$$R_S = T_L = \gamma w * (H - h) * \frac{B}{2} \text{ (per meter height)}$$

44. Determine the Area of Steel Reinforcement.

$$As = \frac{TL}{fs}$$

- If $As = \frac{TL}{fs} \geq As_{min}$, $\therefore$ O.K.
- If $As = \frac{TL}{fs} < As_{min}$, use $As = As_{min}$

45. Choose Ø and A_b from Rebar Table.

46. Determine the Spacing between The Internal and External Horizontal Steel Reinforcement.

$$S_{req} = \frac{2000 * Ab}{As}$$

Then Determine S_{act} {The maximum Spacing value shall not exceed 300 mm}.

S_{act} =

47. Determine the Actual area of The Internal and External Horizontal Steel Reinforcement.

$$A_{S\,act} = \frac{2000 * Ab}{S\,act}$$

48. Use Ø @ S_{act} mm c/c in **Two** layer for The Internal and External Horizontal Steel Reinforcement.

49. Internal Vertical Steel Reinforcement.

50. Determine The Vertical Moment

$$M_{Vertical} = \frac{\gamma w * H^3}{6} \text{ (per meter height)}$$

51. Determine the Area of Steel Reinforcement .

$$As = \frac{(M\ Vertical)}{fs * j * d}$$

- If $As = \frac{(M\ Vertical)}{fs * j * d} \geq \frac{As\ min}{2}$, $\therefore$ O.K.
- If $As = \frac{(M\ Vertical)}{fs * j * d} < \frac{As\ min}{2}$, use $As = \frac{As\ min}{2}$

52. Choose Ø and A_b from Rebar Table.

53. Determine the Spacing between The Internal Vertical Steel Reinforcement.

$$S_{req} = \frac{1000 * Ab}{As}$$

Then Determine S_{act} {The maximum Spacing value shall not exceed 300 mm}.

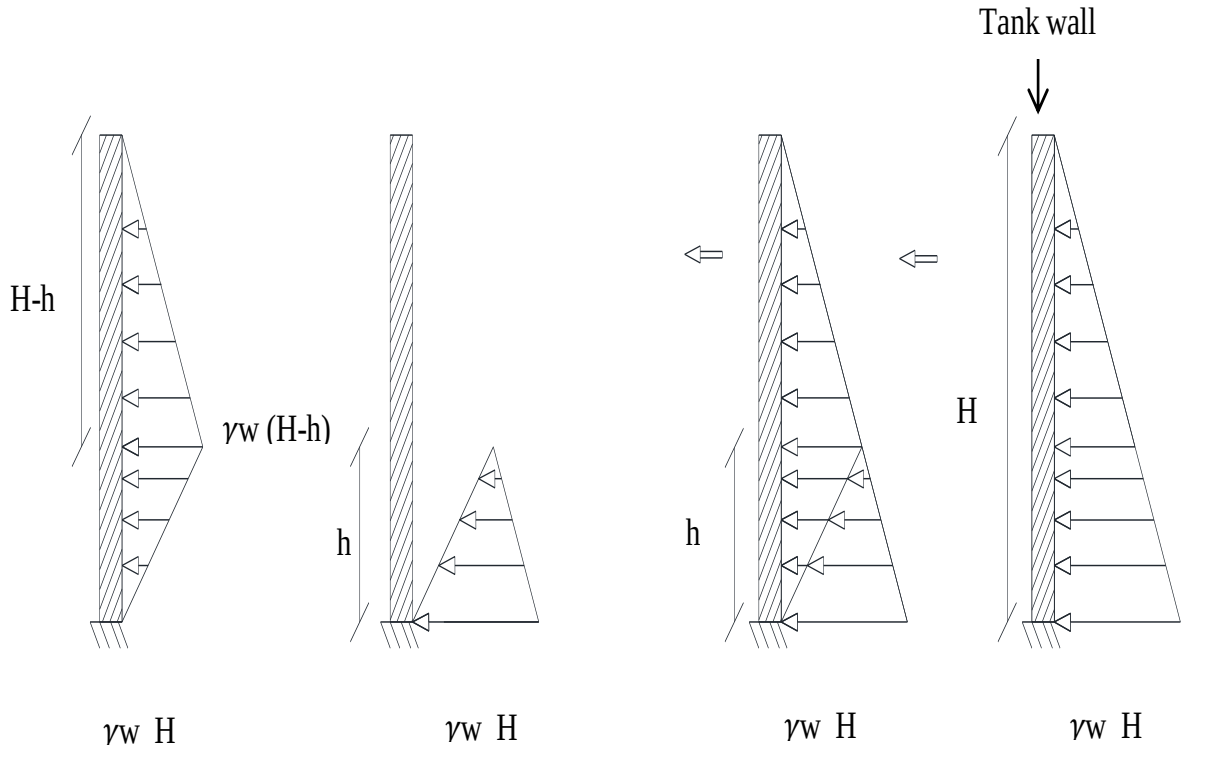
S_{act} =

54. Determine the Actual area of Internal Vertical Steel Reinforcement

$$A_{S\ act} = \frac{1000 * Ab}{S\ act}$$

55. Use Ø @ S_{act} mm c/c in one layer , Internal Vertical Steel Reinforcement.

56. Short Wall, B = AC m



57. Internal Horizontal Steel Reinforcement.

58. Determine The Negative Moment

$$M^{-}_{AC} = \gamma w * (H - h) * \frac{B^2}{12}$$

59. Determine The Tension in Short

- $R_L = T_S = \gamma w * (H - h) * 1$ (per meter height)
- $x = d - \frac{t}{2}$

60. Determine The Net Moment

$$M^{-}_{net\ AC} = M^{-}_{AC} - T_S * x$$

61. Determine the Area of Steel Reinforcement.

$$As_{AC} = \frac{(M - net\ AC)}{fs * j * d} + \frac{Ts}{Fs}$$

- If $As_{AC} = \frac{(M - net\ AC)}{fs * j * d} + \frac{Ts}{fs} \geq \frac{As\ min}{2}$, ∴ O.K.
- If $As_{AC} = \frac{(M - net\ AC)}{fs * j * d} + \frac{Ts}{fs} < \frac{As\ min}{2}$, use $As = \frac{As\ min}{2}$

62. Choose Ø and A_b from Rebar Table.

63. Determine the Spacing between The Internal Horizontal Steel Reinforcement.

$$S_{req} = \frac{1000 * Ab}{As\ \ AC}$$

Then Determine S_{act} {The maximum Spacing value shall not exceed 300 mm}.

$S_{act} =$

64. Determine the Actual area of Internal Horizontal Steel Reinforcement

$$As_{AC} = \frac{1000 * Ab}{S\,act}$$

65. Use Ø @ S_{act} mm c/c in one layer, Internal Horizontal Steel Reinforcement.

66. External Horizontal Steel Reinforcement.

67. Determine The Positive Moment

$$M^{+}_{AC} = \gamma w * (H - h) * \frac{B^2}{16} \quad (\text{per meter height})$$

68. Determine The Net Moment

$$M^{+}_{\text{net AC}} = M^{+}_{AC} - T_S * x$$

69. Determine the Area of Steel Reinforcement.

$$As_{AC} = \frac{(M + \text{net AC})}{fs * j * d} + \frac{Ts}{fs}$$

- If $As_{AC} = \frac{(M + \text{net AC})}{fs * j * d} + \frac{Ts}{fs} \geq \frac{As\ min}{2}$, ∴ O.K.
- If $As_{AC} = \frac{(M + \text{net AC})}{fs * j * d} + \frac{Ts}{fs} < \frac{As\ min}{2}$, use $As = \frac{As\ min}{2}$

70. Choose Ø and A_b from Rebar Table.

71. Determine the Spacing between The External Horizontal Steel Reinforcement.

$$S_{req} = \frac{1000 * Ab}{As\ AC}$$

Then Determine S_{act} {The maximum Spacing value shall not exceed 300 mm}.

$S_{act} =$

72. Determine the Actual area of External Horizontal Steel Reinforcement

$$As_{AC} = \frac{1000 * Ab}{S\ act}$$

73. Use Ø @ S act mm c/c in one layer, External Horizontal Steel Reinforcement.

74. Internal Vertical Steel Reinforcement

75. Determine The Vertical Moment

$$M_{Vertical} = \frac{\gamma w * H * h^2}{6} \quad (\text{per meter height})$$

76. Determine the Area of Steel Reinforcement.

$$As_{Vertical} = \frac{M\ Vertical}{fs * j * d}$$

- If $As_{Vertical} = \frac{M\ Vertical}{fs * j * d} \geq \frac{As\ min}{2}$, ∴ O.K.
- If $As_{Vertical} = \frac{M\ Vertical}{fs * j * d} < \frac{As\ min}{2}$, use $As = \frac{As\ min}{2}$

77. Choose Ø and A_b from Rebar Table.

78. Determine the Spacing between The Internal Vertical Steel Reinforcement.

$$S_{req} = \frac{1000 * Ab}{As\ Vertical}$$

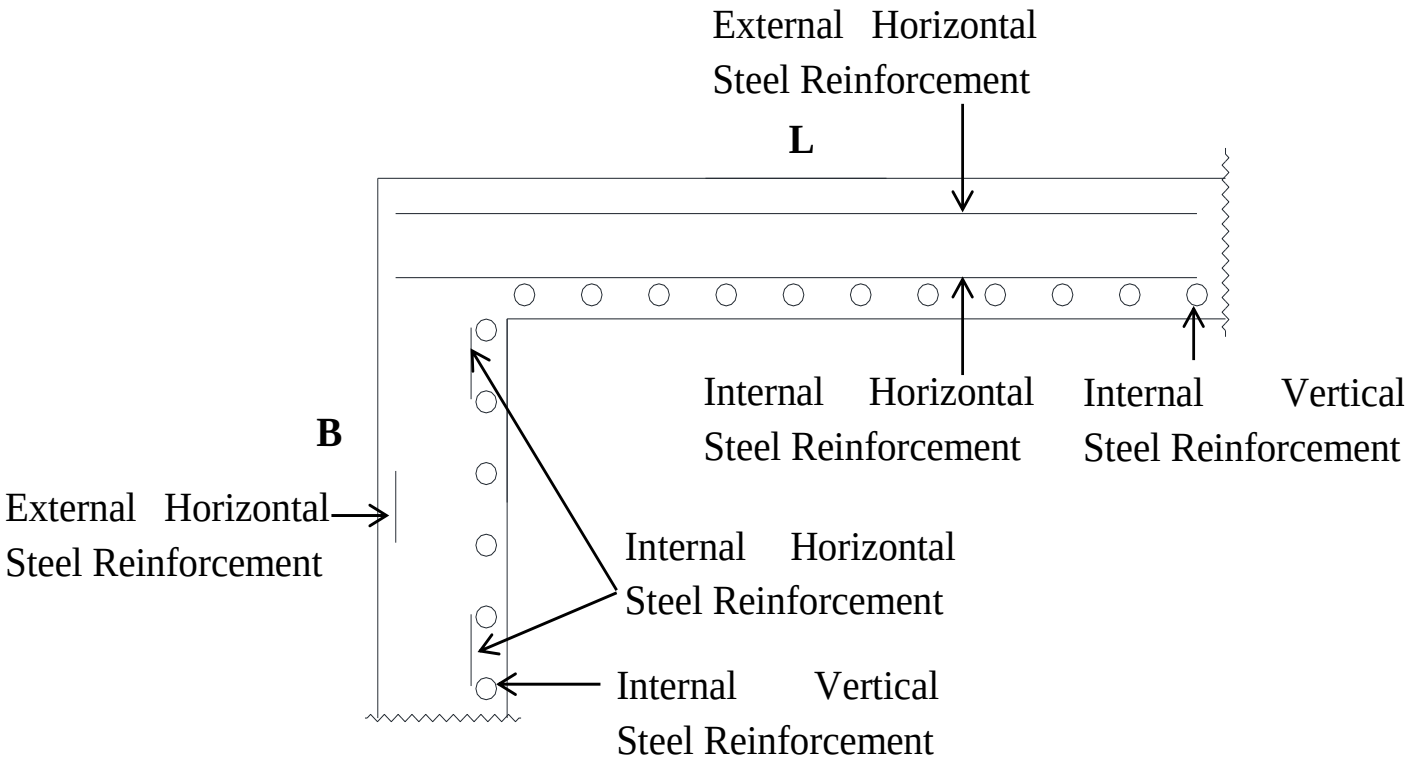
Then Determine S_{act} {The maximum Spacing value shall not exceed 300 mm}.

S_{act} =

79. Determine the Actual area of Internal Vertical Steel Reinforcement

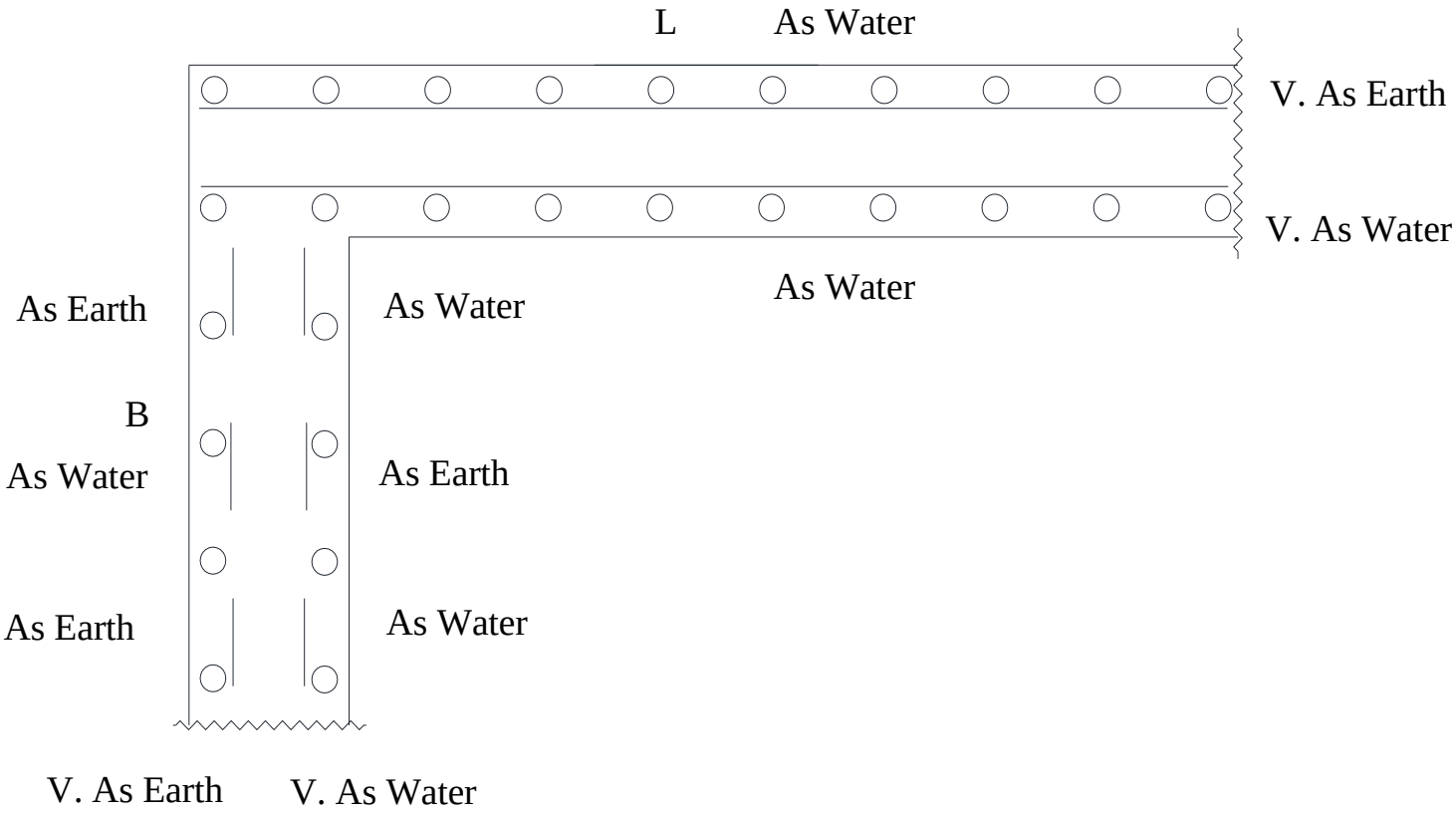
$$As_{Vertical\ act} = \frac{1000 * Ab}{S\ act}$$

80. Use Ø @ Sact mm c/c in one layer for Internal Vertical Steel Reinforcement for Height = h.



Wall Design Details Due to Water Pressure for Long and Short (Top View)

81. Design Details



Walls Design Details (Top View)

Example: Design of open Reinforced Concrete Underground Rectangular Tank for a capacity of 120 m^3 and the angle of repose of soil 30° . L = 10 m, B = 4 m.

Use, γ_w = 10 kN/m^3, γ_s = 17 kN/m^3, f_s = 150 N/mm^2, f_c = 14 N/mm^2, n = 10.

Solution:

1. Check $\frac{\mathbf{L}}{\mathbf{B}}$ Ratio

   - $\frac{10}{4} = 2.5 > 2$

     $\therefore$ OK

2. Condition I : Tank Under Earth Pressure Only.

3. Determine The Soil Pressures

- $P = \gamma_w * H + (\gamma_s - \gamma_w) \ H \ * \ \frac{1- \sin\theta}{1+ \sin\theta}$ (per meter width)

  $P = 10 * 3 + (17 - 10) * 3 * \frac{1- \sin 30}{1+ \sin 30}$

  $P = 37$ kN/m

- $V = L * B * H$

  $120 = 10 * 4 * H$

  $H = 3$ m

- $h = \frac{H}{4}$

  $h = \frac{3}{4}$

  $h = 0.75 \text{ m} < 1$, $\therefore$ use h = 1m $\therefore$OK

4. Determine The Vertical Moment

$$M_{Vertical} = \frac{P * H^2}{6}$$

$$M_{Vertical} = \frac{37 * 3^2}{6}$$

$$M_{Vertical} = 55.5 \text{ kN.m}$$

5. Assume concrete cover = 50 mm.

6. Determine the effective depth {d}mm

$$d = \sqrt{\frac{2*(M\ vertical)}{Fc*k*J*b}}$$

Where:

- fc = 14
- n = 10 (Modular Ratio),

- $r = \frac{fS}{fC}$ (Stress Ratio)

  $r = \frac{150}{14}$

  r = 10.714

- $K = \frac{n}{n+r}$

  $K = \frac{10}{10+10.714}$

  K = 0.482

- $J = 1 - \frac{K}{3}$

  $J = 1 - \frac{0.482}{3}$

  J = 0.839

$$d = \sqrt{\frac{2*(55.5*10\text{^}6)}{14*0.482*0.839*1000}}$$

d = 140 mm

7. Determine The Wall Thickness (t) mm

t = d + cover

t = 140 + 50

t = 190 mm

8. Determine Reinforcement Ratio

$\% \rho min = 0.3 - 0.1 \left(\frac{t-100}{350} \right)$

$\% \rho min = 0.3 - 0.1 \left(\frac{190-100}{350} \right)$

$\% \rho min = 0.274 \%$

9. Determine Minimum Area of Steel Reinforcement

$As_{min} = \% \rho \, min * t * 1000$

$As_{min} = \frac{0.274}{100} * 190 * 1000$

$As_{min} = 520.6 \, mm^2$

10. **Long Wall, L = 10 m**

11. External Vertical Steel Reinforcement.

12. Determine the Area of Steel Reinforcement .

$$As = \frac{(M\ Vertical)}{fs * j * d}$$

$$As = \frac{(55.5*10^6)}{150 * 0.839 * 140}$$

$$As = 3150\ mm^2 \geq \frac{As\ min}{2}\ , \therefore \text{O.K.}$$

13. Choose Ø 25 mm and A_b = 490 mm from Rebar Table.
14. Determine the Spacing between The External Vertical Steel Reinforcement.

$$S_{req} = \frac{1000 * Ab}{As}$$

$$S_{req} = \frac{1000 * 490}{3150}$$

$$S_{req} = 156\ mm$$

Then Determine S_{act} {The maximum Spacing value shall not exceed 300 mm}.

S_{act} = 150 mm

15. Determine the Actual area of External Vertical Steel Reinforcement

$$A_{S\ act} = \frac{1000 * Ab}{S\ act}$$

$$A_{S\ act} = \frac{1000 * 490}{150}$$

$$A_{S\ act} = 3266.666\ mm^2$$

16. Use Ø 25 mm @ 150 mm c/c in one layer , External Vertical Steel Reinforcement.

17. **Short Wall, B = 4 m .**

18. Determine The Soil Pressure

$$P\times = P * \frac{(H-h)}{H}$$

$$P\times = 37 * \frac{(3-1)}{3}$$

$$P\times = 24.666 \text{ kN/m}$$

19. External Horizontal Steel Reinforcement.

20. Determine The Negative Moment at AC.

$$M^{-}_{AC} = \frac{P\times * B^2}{12}$$

$$M^{-}_{AC} = \frac{24.666 * 4^2}{12}$$

$$M^{-}_{AC} = 32.888 \text{ kN.m}$$

21. Determine the Area of Steel Reinforcement.

$$As^{-}_{Ac} = \frac{M^{-}AC}{fs * j * d}$$

$$As^{-}_{Ac} = \frac{32.888 * 10^6}{150 * 0.839 * 140}$$

$$As^{-}_{Ac} = 1866.621 \text{ mm}^2 \geq \frac{As\ min}{2} \quad , \therefore \text{O.K.}$$

22. Choose Ø 16 and A_b = 201 mm^2 from Rebar Table.
23. Determine the Spacing between The External Horizontal Steel Reinforcement.

$$S_{req} = \frac{1000 * Ab}{As\ AC}$$

$$S_{req} = \frac{1000 * 201}{1866.621}$$

S_{req} = 108 mm

Then Determine S_{act} {The maximum Spacing value shall not exceed 300 mm}.

$$S_{act} = \mathbf{100}$$

24. Determine the Actual area of External Horizontal Steel Reinforcement

$$A_{S\ AC\ act} = \frac{1000 * Ab}{S\ act}$$

$$A_{S\ AC\ act} = \frac{1000 * 201}{110}$$

$A_{S\ AC\ act}$ = 2010 mm^2

25. Use Ø 16 mm @ 100 mm c/c in one layer , External Horizontal Steel Reinforcement.

26. Internal Horizontal Steel Reinforcement.

27. Determine The Positive Moment at AC.

$$M + AC = \frac{P \times * B^2}{16}$$

$$M^{+}_{AC} = \frac{24.666 * 4^2}{16}$$

$$M^{+}_{AC} = 24.666 \text{ kN/m}$$

28. Determine the Area of Steel Reinforcement.

$$As_{Ac} = \frac{M + AC}{fs * j * d}$$

$$As_{Ac} = \frac{24.666 * 10^6}{150 * 0.839 * 140}$$

$$As_{Ac} = 1399.965 \text{ mm}^2 \geq \frac{As\ min}{2} \quad , \therefore \text{O.K.}$$

29. Choose Ø 16 mm and $A_b = 201 \text{ mm}^2$ from Rebar Table.

30. Determine the Spacing between The Internal Horizontal Steel Reinforcement.

$$S_{req} = \frac{1000 * Ab}{As\ AC}$$

$$S_{req} = \frac{1000 * 201}{1399.965}$$

$$S_{req} = 144 \text{ mm}$$

Then Determine S_{act} {The maximum Spacing value shall not exceed 300 mm}.

$$S_{act} = \mathbf{140\ mm}$$

31. Determine the Actual area of Internal Horizontal Steel Reinforcement

$$A_{S\ AC\ act} = \frac{1000 * Ab}{S\ act}$$

$$A_{S\ AC\ act} = \frac{1000 * 201}{140}$$

$$A_{S\ AC\ act} = 1435.714\ mm^2$$

32. Use ∅ 16 mm @ 140 mm c/c in one layer , Internal Horizontal Steel Reinforcement.

33. External Vertical Steel Reinforcement

34. Determine The Vertical Moment

$$M_{Vertical} = \frac{P * h^2}{6}$$

$$M_{Vertical} = \frac{37 * 1^2}{6}$$

$$M_{Vertical} = 6.166 \text{ kN.m}$$

35. Determine the Area of Steel Reinforcement.

$$As_{Vertical} = \frac{M\,Vertical}{fs * j * d}$$

$$As_{Vertical} = \frac{6.166 * 10^6}{150 * 0.839 * 140}$$

$$As_{Vertical} = 349.963 \text{ mm}^2 \geq \frac{As\,min}{2} \quad , \therefore \text{O.K.}$$

36. Choose Ø 10 mm and $A_b = 79 \text{ mm}^2$ from Rebar Table.

37. Determine the Spacing between The External Vertical Steel Reinforcement.

$$S_{req} = \frac{1000 * Ab}{As\,Vertical}$$

$$S_{req} = \frac{1000 * 79}{349.963}$$

$$S_{req} = 226 \text{ mm}$$

Then Determine S_{act} {The maximum Spacing value shall not exceed 300 mm}.

S_{act} = 220 mm

38. Determine the Actual area of External Vertical Steel Reinforcement

$$As_{\text{Vertical act}} = \frac{1000 * Ab}{S\,act}$$

$$As_{\text{Vertical act}} = \frac{1000 * 79}{220}$$

$$As_{\text{Vertical act}} = 359.09\ mm^2$$

39. Use Ø 10 mm @ 220 mm c/c in one layer for External Vertical Steel Reinforcement for Height 1 m

Use Ø 10 mm @ 220 mm c/c in one layer for External Vertical Steel Reinforcement for Height 2 m, (or use $As = \frac{As\ min}{2}$)

40. **Condition II : Tank Under Water Pressure Only.**
41. **Long Wall, L = 10 m**

42. Internal and External Horizontal Steel Reinforcement.

43. Determine The Tension in long

$$R_S = T_L = \gamma w * (H - h) * \frac{B}{2} \text{ (per meter height)}$$

$$T_L = 10 * (3 - 1) * \frac{4}{2}$$

$$T_L = 40 \text{ kN}$$

44. Determine the Area of Steel Reinforcement.

$$As = \frac{TL}{fs}$$

$$As = \frac{40 * 10^3}{150}$$

$$As = 266.666 \text{ mm}^2 < As_{min} = 520.6 \text{ mm}^2 \text{ , } \therefore \text{use } As = As_{min}$$

45. Choose Ø 10 mm and A_b =79 mm^2 from Rebar Table.
46. Determine the Spacing between The Internal and External Horizontal Steel Reinforcement.

$$S_{req} = \frac{2000 * Ab}{As}$$

$$S_{req} = \frac{2000 * 79}{520.6}$$

$$S_{req} = 303 \text{ mm}$$

Then Determine S_{act} {The maximum Spacing value shall not exceed 300 mm}.

S_{act} = 300 mm

47. Determine the Actual area of The Internal and External Horizontal Steel Reinforcement.

$$A_{S\,act} = \frac{2000 * Ab}{S\,act}$$

$$A_{S\,act} = \frac{2000 * 79}{300}$$

$$A_{S\,act} = 526.666\ mm^2$$

48. Use ∅ 10 mm @ 300 mm c/c in **Two** layer , The Internal and External Horizontal Steel Reinforcement.

49. Internal Vertical Steel Reinforcement.

50. Determine The Vertical Moment

$$M_{Vertical} = \frac{\gamma w * H^3}{6} \text{ (per meter height)}$$

$$M_{Vertical} = \frac{10 * 3^3}{6}$$

$$M_{Vertical} = 45 \text{ kN.m}$$

51. Determine the Area of Steel Reinforcement .

$$As = \frac{(M\ Vertical)}{fs * j * d}$$

$$As = \frac{(45 * 10^6)}{150 * 0.839 * 140}$$

$$As = 2554.06 \text{ mm}^2$$

52. Choose Ø 25 mm and A_b = 490 mm^2 from Rebar Table.
53. Determine the Spacing between The Internal Vertical Steel Reinforcement.

$$S_{req} = \frac{1000 * Ab}{As}$$

$$S_{req} = \frac{1000 * 490}{2554.06}$$

$$S_{req} = 192 \text{ mm}$$

Then Determine S_{act} {The maximum Spacing value shall not exceed 300 mm}.

$$\mathbf{S_{act} = 190 \text{ mm}}$$

54. Determine the Actual area of Internal Vertical Steel Reinforcement

$$A_{S\ act} = \frac{1000 * Ab}{S\ act}$$

$$A_{S\ act} = \frac{1000 * 490}{190}$$

$$A_{S\ act} = 2578.947\ mm^2$$

55. Use Ø 25 mm @ 190 mm c/c in one layer , Internal Vertical Steel Reinforcement.

56. **Short Wall, B = 4 m**

57. Internal Horizontal Steel Reinforcement.

58. Determine The Negative Moment

$M^-_{AC} = \gamma w * (H - h) * \frac{B^2}{12}$

$M^-_{AC} = 10 * (3-1) * \frac{4^2}{12}$

$M^-_{AC} = 26.666$ kN.m

59. Determine The Tension in Short

- $R_L = T_S = \gamma w * (H - h) * 1$ (per meter height)
- $R_L = T_S = 10 * (3-1) * 1$
- $T_S = 20$ kN

- $x = d - \frac{t}{2}$

  $x = 140 - \frac{190}{2}$

  $x = 45$ mm

  $x = 45 * (10^{\wedge -3}) m$

60. Determine The Net Moment

$M^-_{net\ AC} = M^-_{AC} - T_S * x$

$M^-_{net\ AC} = 26.666 - 20 * \{45 * (10^{\wedge -3}) \}$

$M^-_{net\ AC} = 25.766$ kN.m

61. Determine the Area of Steel Reinforcement.

$$As_{AC} = \frac{(M - \text{net AC})}{fs * j * d} + \frac{Ts}{fs}$$

$$As_{AC} = \frac{(25.766) * 10^6}{150 * 0.839 * 140} + \frac{20 * 10^3}{150}$$

$$As_{AC} = 1595.731 \text{ mm}^2 \geq \frac{As\ min}{2} \quad , \therefore \text{O.K.}$$

62. Choose Ø 16 mm and $A_b = 201$ mm^2 from Rebar Table.
63. Determine the Spacing between The Internal Horizontal Steel Reinforcement.

$$S_{req} = \frac{1000 * Ab}{As - AC}$$

$$S_{req} = \frac{1000 * 201}{1595.731}$$

$$S_{req} = 126 \text{ mm}$$

Then Determine S_{act} {The maximum Spacing value shall not exceed 300 mm}.

$$S_{act} = \mathbf{120\ mm}$$

64. Determine the Actual area of Internal Horizontal Steel Reinforcement

$$As_{AC} = \frac{1000 * Ab}{S\ act}$$

$$As_{AC} = \frac{1000 * 201}{120}$$

$$As_{AC} = 1675 \text{ mm}$$

65. Use Ø 16 mm @ 120 mm c/c in one layer, Internal Horizontal Steel Reinforcement.

66. External Horizontal Steel Reinforcement.

67. Determine The Positive Moment

$$M^{+}_{AC} = \gamma w * (H - h) * \frac{B^2}{16} \quad (\text{per meter height})$$

$$M^{+}_{AC} = 10 * (3\text{-}1) * \frac{4^2}{16}$$

$$M^{+}_{AC} = 20 \text{ kN.m}$$

68. Determine The Net Moment

$$M^{+}_{net\ AC} = M^{+}_{AC} - T_S * x$$

$$M^{+}_{net\ AC} = 20 - 20 * \{45 * (10\text{^}\ \text{-}3) \}$$

$$M^{+}_{net\ AC} = 19.1 \text{ kN.m}$$

69. Determine the Area of Steel Reinforcement.

$$As_{AC} = \frac{(M + \text{net AC})}{Fs * J * d} + \frac{Ts}{Fs}$$

$$As_{AC} = \frac{(19.1) * 10\text{^}6}{150 * 0.839 * 140} + \frac{20 * 10\text{^}3}{150}$$

$$As_{AC} = 1217.39 \text{ mm}^2 \geq \frac{As\ min}{2} \quad , \therefore \text{O.K.}$$

70. Choose Ø 16 mm and $A_b = 201 \text{ mm}^2$ from Rebar Table.

71. Determine the Spacing between The External Horizontal Steel Reinforcement.

$$S_{req} = \frac{1000 * Ab}{As + AC}$$

$$S_{req} = \frac{1000 * 201}{1217.39}$$

$$S_{req} = 165 \text{ mm}$$

Then Determine S_{act} {The maximum Spacing value shall not exceed 300 mm}.

$$S_{act} = \mathbf{160 \text{ mm}}$$

72. Determine the Actual area of External Horizontal Steel Reinforcement

$$As_{AC} = \frac{1000 * Ab}{S\,act}$$

$$As_{AC} = \frac{1000 * 201}{160}$$

$$As_{AC} = 1256.25\ mm^2$$

73. Use ∅ 16 mm @ 160 mm c/c in one layer, External Horizontal Steel Reinforcement.

74. Internal Vertical Steel Reinforcement

75. Determine The Vertical Moment

$$M_{Vertical} = \frac{\gamma w * H * h^2}{6} \quad (\text{per meter height})$$

$$M_{Vertical} = \frac{10 * 3 * 1^2}{6}$$

$$M_{Vertical} = 5 \text{ kN.m}$$

76. Determine the Area of Steel Reinforcement.

$$As_{Vertical} = \frac{M\ Vertical}{fs * J * d}$$

$$As_{Vertical} = \frac{5 * 10\text{^}6}{150 * 0.839 * 140}$$

$$As_{Vertical} = 283.784 \text{ mm}^2 > \frac{As\ min}{2}, \text{ OK}$$

77. Choose Ø 10 mm and $A_b = 79 \text{ mm}^2$ from Rebar Table.

78. Determine the Spacing between The Internal Vertical Steel Reinforcement.

$$S_{req} = \frac{1000 * Ab}{As\ Vertical}$$

$$S_{req} = \frac{1000 * 79}{283.784}$$

$$S_{req} = 278 \text{ mm}$$

Then Determine S_{act} {The maximum Spacing value shall not exceed 300 mm}.

$$S_{act} = \mathbf{270 \text{ mm}}$$

79. Determine the Actual area of Internal Vertical Steel Reinforcement

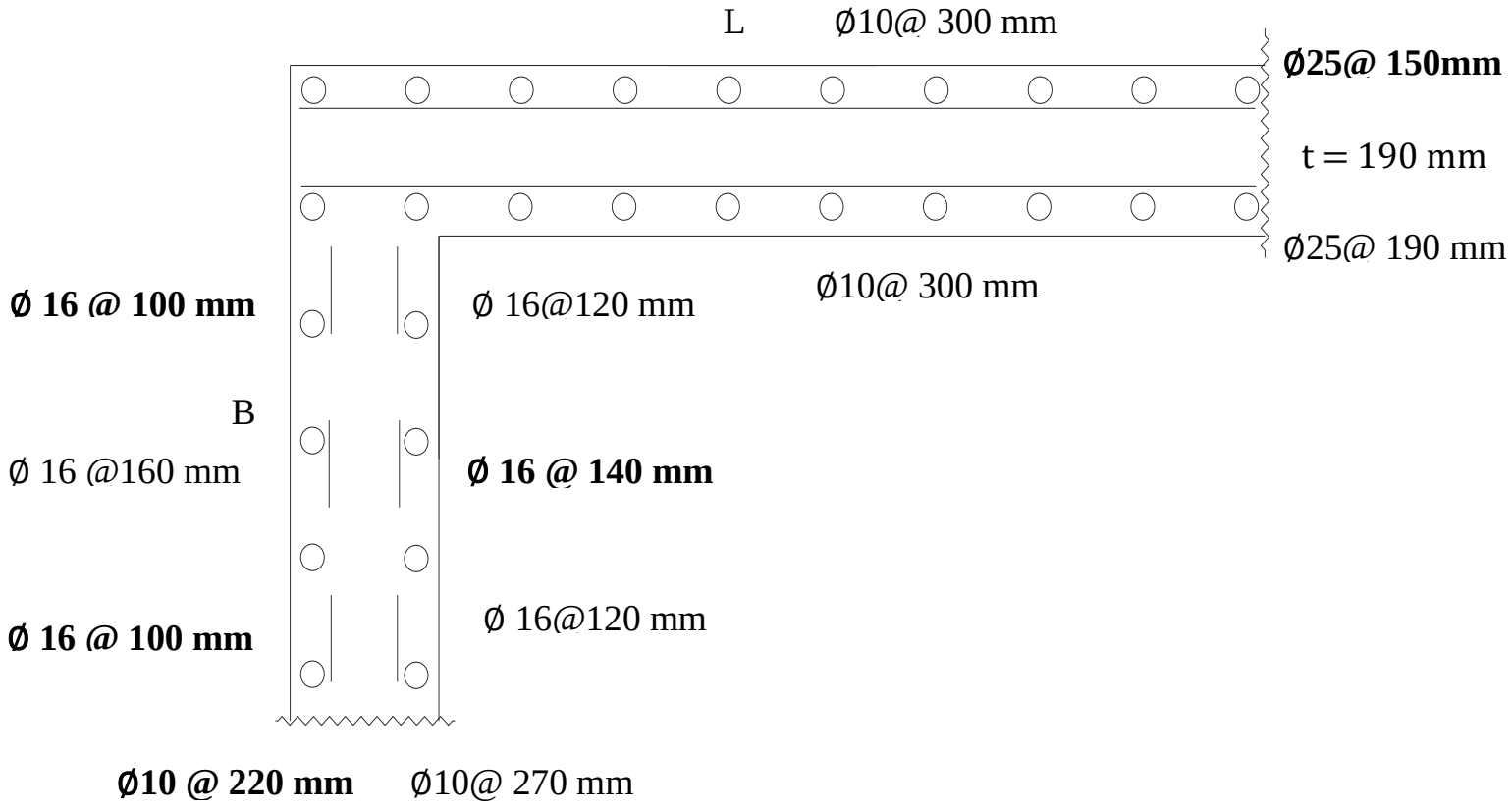
$$As_{\text{Vertical act}} = \frac{1000 * Ab}{S\,act}$$

$$As_{\text{Vertical act}} = \frac{1000 * 79}{270}$$

$$As_{\text{Vertical act}} = 292.592\ mm^2$$

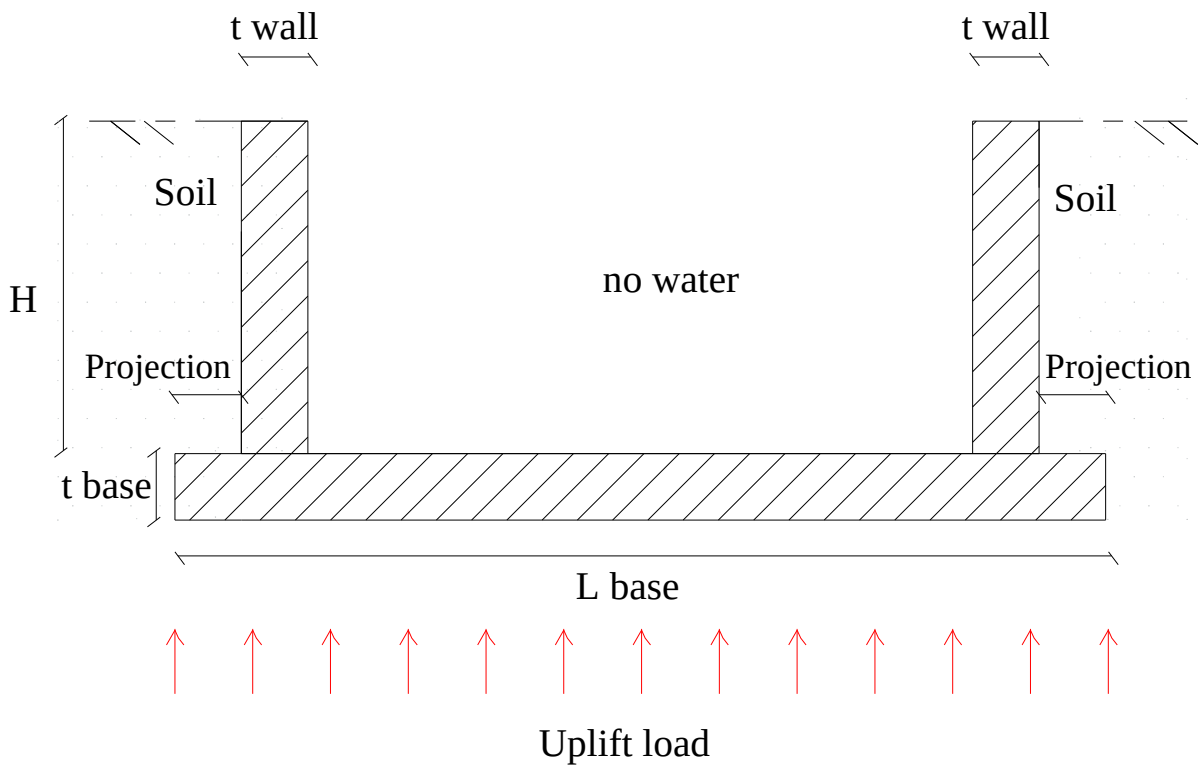
80. Use Ø 10 mm @ 270 mm c/c in one layer for Internal Vertical Steel Reinforcement.

81. Design Details



Uplift Check for underground Rectangular Tanks

Check Uplift Steps



1. Determine Uplift Load to Tank Base

   Uplift Load = { L + 2 t wall + 2 Projection } *{ B + 2 t wall + 2 Projection } * (H + t base) * γw

2. Determine Base slab weight , W_{base}

   $W_{base} = L_{base} + B_{base} + t_{base} * \gamma c$

3. Determine Walls weight , W_{wall}

   $W_{wall} = \{(L + t_{wall}) + (B + t_{wall}) \} * 2 * t_{wall} * H * \gamma c$

4. Determine Projection soil weight , $W_{pro.\ soil}$

$$W_{pro.\ soil} = [\ \{\ (\ L + 2\ t_{wall}\ ) + Projection\ \} + \{\ (\ B + 2\ t_{wall}\ ) + Projection\ \}\ ]\ *\ 2\ *\ Projection\ *\ H\ *\ \gamma s$$

5. Determine the frictional vertical force, F_f

$$P_{base} = \gamma w\ *\ (\ H + t_{base}\ ) + (\ \gamma s - \gamma w\ )\ *\ (\ H + t_{base}\ )\ *\ \frac{1-\sin\theta}{1+\sin\theta}$$

P_{base} = Soil Pressure at (H + t base)

$$P\times_{base} = (\ \frac{1}{2}\ *\ P_{base}\ *\ (\ H + t_{base}\ ))$$

$P\times_{base}$ = Soil Pressure at $\{\ \frac{2}{3}\ *$ (H + t base) $\}$ from tank top.

$$F_f = P\times_{base}\ *\ \{\ (\ L + 2\ t_{wall}\ ) + (\ B + 2\ t_{wall}\ )\}\ *\ 2\ *\ \mu$$

6. Determine the Downward load

$$Downward\ load = W_{base} + W_{wall} + W_{pro.\ soil} + F_f$$

7. Checking if :
   - Uplift Load $\leq$ Downward load , $\therefore$ O.K.
   - Uplift Load $>$ Downward load , $\therefore$ the Tank will lift up

Try to solve this problem.

Example: Check the uplift load for Reinforced Concrete Underground Rectangular Tank, the angle of repose of soil 30° . L = 9 m, B = 7 m, Height = 4 m.

Use;

γ_w = 10 kN/m^3, γ_s = 18 kN/m^3, γc = 27 kN/m^2, μ = 0.3 ,

t_{wall} = 0.31 m , t_{base} = 0.4 m

1. Determine Uplift Load to Tank Base

Uplift Load = $L_{base} * B_{base} * (H + t_{base}) * \gamma w$

Uplift Load = { L + 2 t wall + 2 Projection } *{ B + 2 t wall + 2 Projection } * (H + t base) * γw

Uplift Load = { 9 + 2 * 0.31 + 2 * 0.5 } * { 7 + 2 *0.31 + 2 * 0.5 } * (4 + 0.4) * 10

Uplift Load = 4027.953 kN

2. Determine Base slab weight , W_{base}

$W_{base} = L_{base} * B_{base} * t_{base} * \gamma c$

W_{base} = 10.62 * 8.62 * 0.4 * 27

W_{base} = 988.679 kN

3. Determine Walls weight , W_{wall}

$$W_{wall} = \{(L + t_{wall}) + (B + t_{wall}) \} * 2 * t_{wall} * H * \gamma c$$

$$W_{wall} = \{(9 + 0.31) + (7 + 0.31) \} * 2 * 0.31 * 4 * 27$$

$$W_{wall} = 1112.875 \text{ kN}$$

4. Determine Projection soil weight , $W_{pro.\ soil}$

$$W_{pro.\ soil} = [\{ (L + 2\ t_{wall}) + \text{Projection} \} + \{ (B + 2\ t_{wall}) + \text{Projection} \}] * 2 * \text{Projection} * H * \gamma s$$

$$W_{pro.\ soil} = [\{ (9 + 2 * 0.31) + 0.5 \} + \{(7 + 2 * 0.31) + 0.5\}] * 2 * 0.5 * 4 * 18$$

$$W_{pro.\ soil} = 1313.28 \text{ kN}$$

5. Determine the frictional vertical force, F_f

$$P_{base} = \gamma w * (H + t_{base}) + (\gamma s - \gamma w) \ (H + t_{base}) \ * \ \frac{1 - \sin\theta}{1 + \sin\theta}$$

$$P_{base} = 10 * (4 + 0.4) + (18 - 10) * (4 + 0.4) \ * \ \frac{1 - \sin 30}{1 + \sin 30}$$

$$P_{base} = 55.733 \text{ kN/m}^2$$

$$P_{\times base} = \left(\frac{1}{2} * P_{base} * (H + t_{base}) \right)$$

$$P_{\times base} = \left[\frac{1}{2} * 55.733 * (4 + 0.4) \right]$$

$$P_{\times base} = 122.612 \text{ kN/m}$$

$$F_f = P_{\times base} * \{ (L + 2\, t_{wall}) + (B + 2\, t_{wall}) \} * 2 * \mu$$

$$F_f = 122.612 * \{ (9 + 2 * 0.31) + (7 + 2 * 0.31) \} * 2 * 0.3$$

$$F_f = 1268.298 \text{ kN}$$

6. Determine the Downward load

$$\text{Downward load} = W_{base} + W_{wall} + W_{pro.\ soil} + F_f$$

$$\text{Downward load} = 988.679 + 1112.875 + 1313.28 + 1268.298$$

$$\text{Downward load} = 4683.132 \text{ kN}$$

7. Checking
   - Uplift Load = 4027.953 kN $\leq$ Downward load = 4683.132 kN ,
     $\therefore$ O.K.