PROPORTIONING RETAINING WALLS

When designing retaining walls, the *proportioning* of retaining wall allows the engineer to check trial sections for stability. If the stability checks yield undesirable results, the sections can be changed and rechecked. The figure below shows the general proportions of various retaining walls components that can be used for initial checks.

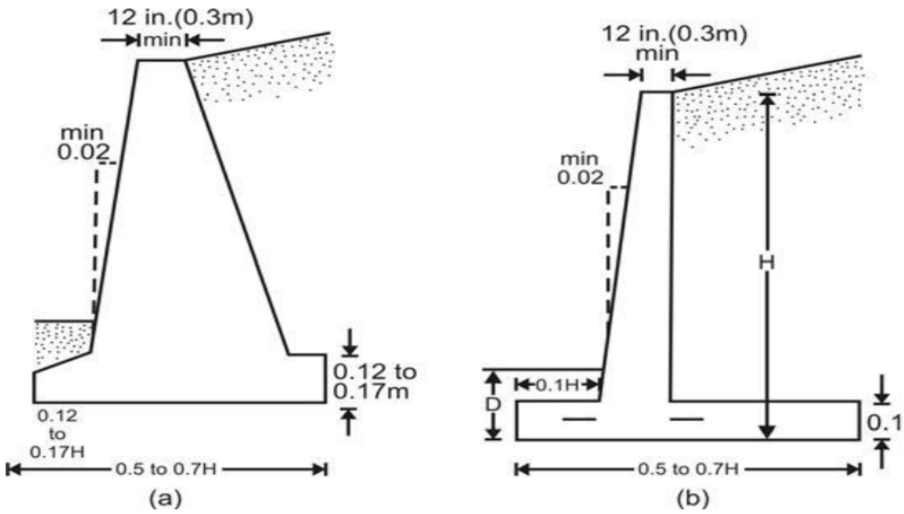


Figure: Approximate dimensions for various components of retaining wall for initial stability is a) gravity wall; (b) cantilever wall

Rankines theory:

It is suitable for cohesionless soil in partially immersed and submerged conditions.

Assumption of Rankines theory:

i. The soil mass is semi infinite, homogeneous, dry and cohesion less.
ii. The ground surface is plane which may be vertical or inclined.
iii. The surface of the wall is vertical and smooth.
iv. The wall yields about the base and satisfies the deflection condition for plastic equilibrium.

The following cases are considered for cohesion less backfill

i. Dry or moist backfill with no surcharge
ii. Submerged backfill
iii. Backfill with uniform surcharge
iv. Backfill with sloping surface

Case (i) Dry or moist backfill with no surcharge:

$p_a = K_a \gamma H$

$Ka = ((1 - \sin \Phi)/(1 + \sin \Phi))$

$P_a = ½ (K_a \gamma H^2)$

Case (ii) Submerged backfill:

$p_a = K_a \gamma' H + \gamma_w H$

Case (iii) Backfill with uniform surcharge:

$p_a = K_a \gamma H + K_a w$

Case (iv) Backfill with sloping surcharge:

$p_a = K_a \gamma H$

$$K_a = \cos\beta \, . \, \frac{\cos\beta - \sqrt{\cos^2\beta + \cos^2\phi}}{\cos\beta + \sqrt{\cos^2\beta - \cos^2\phi}}$$

Passive earth pressure:

$P_p = K_p \gamma H$

$K_p = 1/ K_a$

$P_p = K_p \gamma (h^2)/2$

$$K_p = \cos\beta \, . \, \frac{\cos\beta + \sqrt{\cos^2\beta + \cos^2\phi}}{\cos\beta - \sqrt{\cos^2\beta - \cos^2\phi}}$$

To check the stability of a retaining wall, the following steps are necessary:

1. Check for *overturning* about its toe
2. Check for *sliding* along its base
3. Check for *bearing capacity failure* of the base
4. Check for *settlement*
5. Check for *overall stability*

a) **Check for *overturning* about its toe:**
Overturning in retaining wall is due to unbalanced moments.

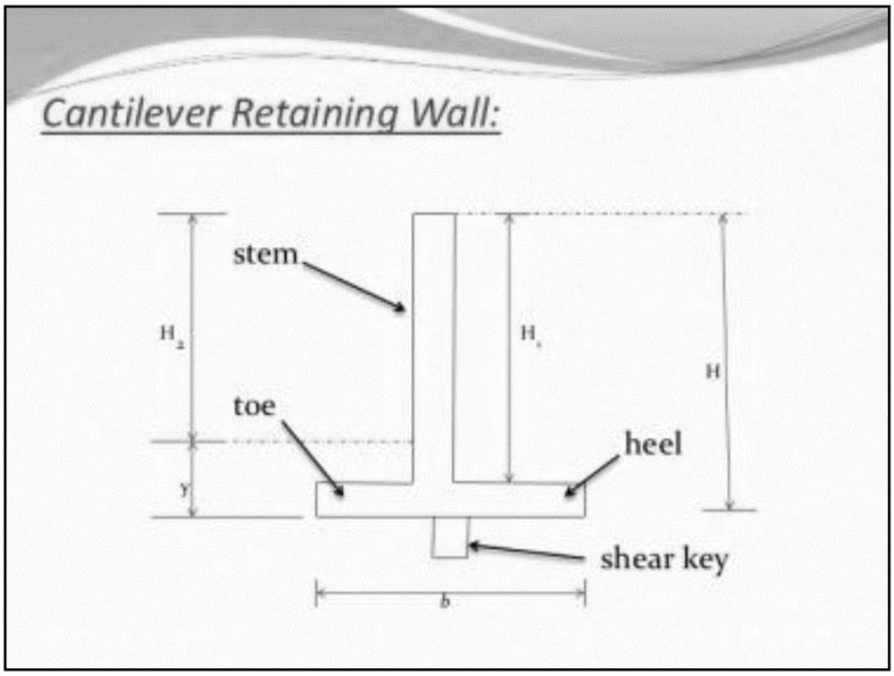
$Mo=K_p \gamma(H^3/6)$

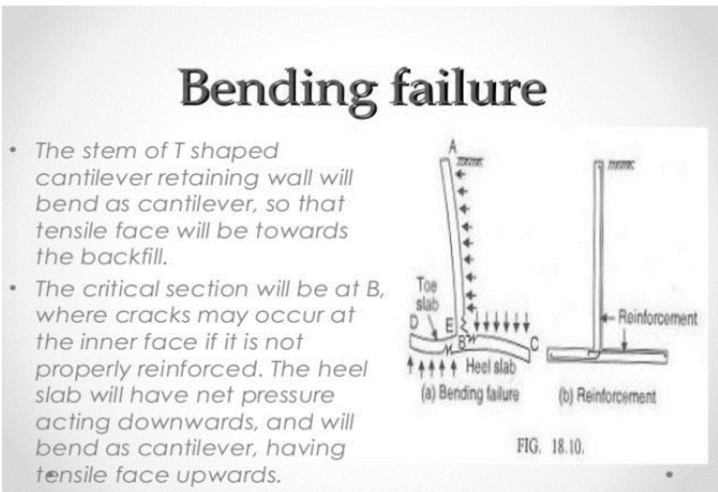
Minimum F.o.s =2 for overturning.

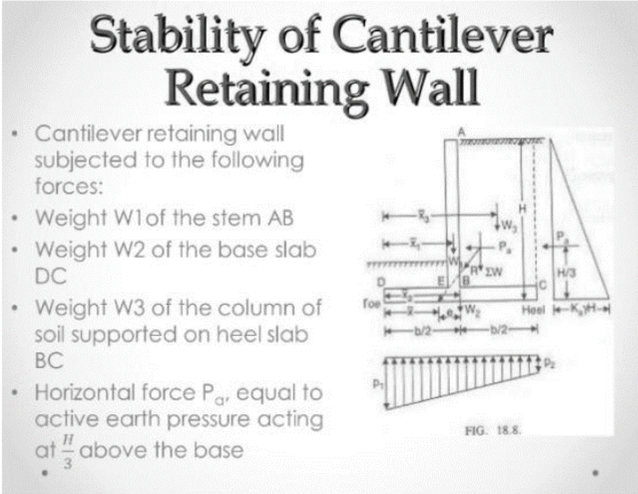
b) **Check for *sliding* along its base:**
The horizontal force tends to slide the wall away from the fill. The tendency to resist this is achieved by the friction at the base. The FOS adopted for sliding is 1.5.

Shear Key:

If the wall is found unsafe against sliding. Shear key has to be provided. This shear key develops a passive pressure which resists the sliding if the wall.







Design a Cantilever retaining wall to retain earth embakment of 3m height from the ground level.SBC of soil (q_0) = 100 KN/m^{2}Angle of repose of soil (Φ) = 30^{o}Unit weight of Soil (γ) = 18 KN/m^3.Friction coefficient between counterfort and soil μ = 0.5. Use M20 grade concrete and Fe 415 Steel

Solution :
Step 1 : Minimum Depth of foundation

$Y_{min} = \frac{q0}{\gamma}((1-\sin\Phi)/(1+\sin\Phi))^2$

$Y_{min} = 100/18\ ((1\text{-}\sin 30)/(1+\sin 30))^2$

$= 0.62$ m

∴ Provide a minimum depth of foundation as 0.7 m

∴ Total height of retaining structure $= 3 + 0.7$

$= 3.7\ m$

Step 2 : Width of base slab

$b = 0.6H$

$= 0.6 \times 3.7$

$= 2.22\ m$

∴ Provide width of base slab as 2.3 m

Step 3 : Width of toe slab
Width of toe slab = αb

$$\alpha = 1 - (\frac{q0}{2.2\ \gamma H})$$

$= 1\text{-}(100/(2.2 \times 18 \times 3.7)$

$\alpha = 0.317$

∴ ∝b= 0.317x 2.3

= 0.729 m

∴ Provide the toe slab as 0.7 m

Assume thickness of stem as 200 mm and thickness of base slab as 300 mm

Note : Last two assumptions are made from the reference of cantilever retaining wall.

Heightof the stem (H1) =Total height (H) – Thickness of base slab

$$H1 = 3.7 - 0.3$$

$$H1 = 3.4m$$

Check for stability

Let us assume

W1 = weight of stem / m length

W2 = weight of base slab / m length

W3 = weight of soil on heel slab / m length

Weights	Force (KN / m length)	Distance from D to location of force (m)	Moment of Resistance (M_R) KN- m
W1	0.2 x 1x 3.4 x 25 = 17	$(0.7 + 0.1 + (\frac{0.2}{2})) = 0.9$	17 x 0.9 = 15.3
W2	(1/2) x 0.1x 3.4 x1x25 = 4.25	$(0.7 + ((\frac{2}{3}) 0.1)) = 0.77$	4.25 x 0.77 =3.273
W3	2.3 x 0.3 x 1 x 25 = 17.25	$(2.3 /2) = 1.15$	17.25 x 1.15 = 19.83
W4	1.3 x3.4 x1 x18 =79.56	$(0.7 + 0.3 + (\frac{1.3}{2})) = 1.65$	79.56 x1.65 = 131.274
	∑W = 118.06		**∑ M_R = 169.684**

∴ Total resisting moment ∑ M_R = 169.684 KN.m

Horizontal earth pressure, $P_H = K_a\alpha\left(\frac{H^2}{2}\right)$

= 0.333 x 18 x $(3.7^2/2)$

$P_H = 41.029\ KN$

Overturning moment (M_o) = P_H x $\left(\frac{H}{3}\right)$

(Moment about at Point B)

= 41.029 x (3.7/3)

M_o = 50.602 KN.m

Factor of safety against overturning

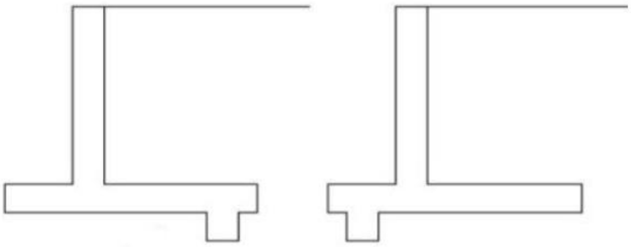
= (∑ M_R)/ M0 = 3.353 > 2

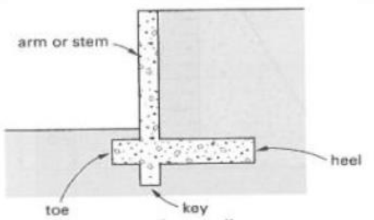
∴ Safe in overturning

Resisting force = ∑µ.W = 0.5 x 118.06 = 59.06KN

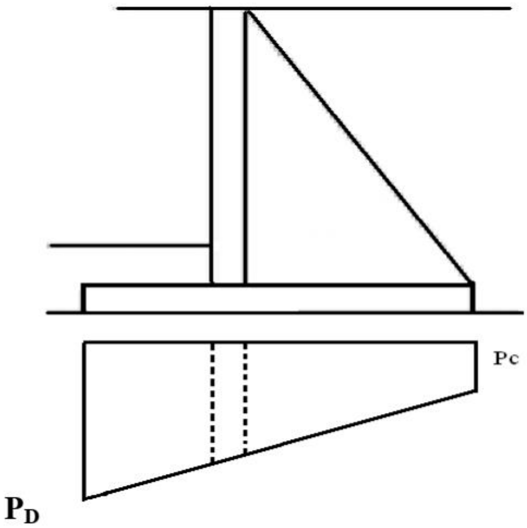
Factor of safety against sliding = $\sum \mu . W / PH = 1.439 < 1.5$

$\therefore$ It's not safe against sliding, therefore need to provide shear Key.





Different locations of shear key in retaining wall



Pressure distribution at base

Net moment = M = 169.684-50.602 = 119.082KN.m.

Let x be the distance from the toe where the resultant R acts,

$x = M / \sum W = 1$ m

Eccentricity = $e = b/2 - x = 2.3/2 - 1 = 0.383 < b/6$

Maximum pressure at toe

$P_D = \sum W / b\ (1+(6e/b))$

$= 118.06/2.3\ (1+ 6 \times .15/2.3)$

$= 71.416\ kN/m^2$

Minimum Pressure at heel

$P_B = \sum W / b\ (1 - (6e/b))$

$= 31.245\ kN/m^2$

Design of Heel Slab:

Forces in the heel slab are:

i) Downward weight of soil/ backfill on heel slab
ii) Downward weight of heel slab
iii) Upward soil reaction , along the length of heel slab

Self weight of heel Slab = 0.2 x 25 = 5 kN/m^2 (↓)

Self weight of backfill in 1m strip at point C = 3.5 x 18 = 63 kN/m^2 (↓)

Net pressure at point B $= P_B - W_1 - W_2$

= 53.95-63-5

= 14.05 KN/m^2

Net pressure at point C $= P_c - W_1 - W_2$

= 31.245-63-5

= 36.755 KN/m^2

Calculation of total downward shear forces in heel slab

Total shear force (rectangular portion) = 1.3 x 14.05 x 1

F_1= 18.265 KN

Total shear force (triangular portion) = (1/2) x 22.705 x 1.3 x1

F_2= 14.758 KN

Position of Resultant (R) from point B = 0.747 m from point B

Total downward force on heel slab (F) = $F_{1+} F_2$

= 33.023KN

Factored Load on heel slab = 1.5 x 33.023

V_u= 49.535 kN/m^2

Maximum Negative moment in heel Slab

Moment at point B, (M) = 49.535 x 0.747

$= 37.002 \times 10^6$ N-mm

$M = 0.138\, f_{ck}\, bd^2$

$37.002 \times 10^6 = 0.138 \times 20 \times 1000 \times d^2$

$d = 116$ mm

Effective depth calculation in heel slab based on shear

$\tau_c = \frac{V_u}{b\, d}$ Note $\tau_v = \tau_c$

For under reinforced section assume $p_t = 0.5\%$, From table 19 of IS 456:2000, for M_{20} grade concrete $\tau_c = 0.48 N/mm^2$

$\therefore d = 103$ mm

Assume a clear cover of 60mm and 12 mm diameter

Effective depth for 400 mm depth = 200 – 60 - (12/2)

= 134 mm

∴ Provide a total depth of heel slab of 400 mm and effective depth of 334 mm

A_{st} calculation moments in heel slab

Calculation for reinforcement at support (A_{st})

$$M = 0.87\, f_y\, A_{st}\, d\, \frac{(1 - f_y\, A_{st})}{(fck\, b\, d)}$$

$= 889.066\ mm^2$

Assume 12 mm Ø bar

$$\text{Spacing of a bar} = \pi \frac{x\,((12)^2/4)}{889.066} \times 1000$$

= 127.21 mm

=120 mm

$$A_{st\ provi} = \pi \frac{x\,((12)^2/4)}{120} \times 1000$$

∴ Provide 12 mm Ø bar with 120 mm c/c, $A_{st\ provi} = 942.478\ mm^2$

Calculation of minimum reinforcement

$A_{st} = 0.12\%\ bd$

$= (0.12/100) \times 1000 \times 400$

$A_{st} = 480\ mm^2$

Assume 8 mm Ø bar

$$\therefore \text{Spacing between distribution bars} = \pi \frac{x\,((8)^2/4)}{480} \times 1000$$

= 100 mm

∴ Provide 8 mm Ø bar with 100 mm c/c on both top and bottom of heel slab

Design of a stem

Initially we assumed a total depth of a base slab as 300mm, But after the design we provide the total depth of base slab as 200mm.

If the total depth of a base slab is reduced as from 300m to 200mm means then the height of a stem will get increases.

Now the height of a stem (H_1) = 3.7- 0.2

= 3.5 m

Maximum moment in Stem at point B, $M = K_a\alpha\left(\frac{H^2}{2}\right)\left(\frac{H}{3}\right)$

$= 42.832KN.m$

Factored Moment, $M_u = 1.5 \times 42.832 \times 10^6$

$= 64.248$ KN.m

Effective depth based on moment

$$M = 0.87\, f_y\, A_{st}\, d\, \frac{(1 - f_y\, A_{st})}{(fck\ b\ d)}$$

$d = 153$ mm

Effective depth based on shear

Shear force in stem $V = ½(k_a.\gamma.H_1)H$

$V = 36.713KN$

Factored Load $V_u = 55.07KN$

Effective depth calculation based on shear

$\tau_c = \frac{V_u}{b\ d}$ Note $\tau_v = \tau_c$

For under reinforced section assume p_t = 0.5%, From table 19 of IS 456:2000, for M_{20} grade concrete $\tau_c = 0.48N/mm^2$

$\therefore d = 115$ mm

Total depth of stem = 153+ 60+(12/2)

Provide a total depth of 300 mm and 200m at the top

A_{st} calculation in stem

$$M = 0.87\, f_y\, A_{st}\, d\, \frac{(1 - f_y\, A_{st})}{(fck\ b\ d)}$$

$A_{st} = 821.145\ mm^2$

Assume 12 mm dia bar

Spacing of a bar = $\pi \frac{x((12)^2/4)}{821.145}$ x 1000

= 137.731 mm

=130 mm

$A_{st\ provi} = \pi \frac{x((12)^2/4)}{130}$ x 1000

∴ Provide 12 mm Ø bar with 130 mm c/c, $A_{st\ provi}$ = 869.979 mm^2

Percentade of steel $P_t = (A_{st})/ bd \times 100$

= 0.372%

Based on Pt calculate τ_c form table 19 of IS 456:2000

$$\tau_v = \frac{V_u}{b\,d}$$

= 0.235 N/mm^2

$\tau_v < \tau_c$

Hence safe in shear

Calculation of minimum reinforcement

A_{st} = 0.12% bd

= (0.12/100) x 1000 x 300

A_{st} =360 mm^2

Assume 8 mm Ø bar

∴ Spacing between distribution bars = $\pi \frac{x((8)^2/4)}{360}$ x 1000

= 140 mm

∴ Provide 8 mm Ø bar with 140 mm c/c on both top and bottom of heel slab

Design of toe Slab:

Forces in toes slab

In the portion of toe slab design , two forces are considered,

i) Upward soil pressure along toe slab

ii) Downward weight of toe slab

Self weight of toe Slab = 0.3 x 25 = 7.5 kN/m^2 (↓)

Net pressure at point D = 71.416 - 7.5

= 63.916 KN/m^2

Net pressure at point E = 59.19-7.5

= 51.69 KN/m^2

Total resultant shear force in toe slab

Total pressure on toe slab = (h/2)(a+b)

= (0.7/2) (63.916+51.69)

= 40.462KN/m

Factored shear force per 'm' width on toe slab (F_T) = 1.5x 40.462x 1

= 60.639KN

Position of resultant shear force on toe slab = 0.362m from E

Maximum bending moment at toe:

At point E , bemding moment is maximum in toe slab

∴ moment at e , M = 60.693 x 0.362x10^6

= 21.97 x 10^6 N.mm

Calculation of effective depth based on moment

$M = 0.138\ f_{ck}\ bd^2$

$21.97 \times 10^6 = 0.138 \times 20 \times 1000 \times d^2$

d = 90 mm

Calculation of effective depth based on shear

$$\tau_v = \frac{V_u}{b\,d}$$

Note $\tau_v = \tau_c$

Cslculate Percentade of steel $P_t = (A_{st})/\ bd \times 100$

P_t = 0.957%

From table 19 of IS 456:2000, for M_{20} grade concrete τ_c = 0.48N/mm^2

Effective depth is calculate d =127 mm

Total depth of toe slab (D) = 127 +60+ (12/2)

D= 193mm

∴ Provide total depth of toe slab as 200mm

Effective depth of toe slab (d) = 200 -60- (12/2)

d = 134mm

∴ Provide total depth of toe slab as 200mm and effective depth of 134mm

Calculation of A_{st} in toe slab

$$M = 0.87\ f_y\ A_{st}\ d\ \frac{(1 - f_y\ A_{st})}{(fck\ b\ d)}$$

$$A_{st} = 492.189\ mm^2$$

Assume 12 mm dia bar

$$\text{Spacing of a bar} = \pi\ \frac{x\ (\ (12)^{\ 2} / 4)}{492.189}\ x\ 1000$$

$$= 230\ mm$$

$$A_{st\ provi} = \pi\ \frac{x\ (\ (12)^{\ 2} / 4)}{200}\ x\ 1000$$

∴ Provide 12 mm Ø bar with 200 mm c/c, $A_{st\ provi} = 565.486\ mm^2$

Percentade of steel $P_t = (A_{st}) /\ bd\ x100$

$P_t = 0.422\%$

From table 19 of IS 456:2000, for M_{20} grade concrete $\tau_c = 0.46 N/mm^2$

$\tau_v = \frac{V_u}{b\ d}$

$\tau_v = 0.452 < 0.46\ N/mm^2$

Hence safe in shear.

Calculation of minimum reinforcement

$A_{st} = 0.12\%\ bd$

$= (0.12/100)\ x\ 1000\ x\ 200$

$A_{st} = 240\ mm^{\ 2}$

Assume 8 mm Ø bar

∴ Spacing between distribution bars $= \pi\ \frac{x\ (\ (8)^{\ 2} / 4)}{240}\ x\ 1000$

$= 210\ mm$

∴ Provide 8 mm Ø bar with 210 mm c/c .

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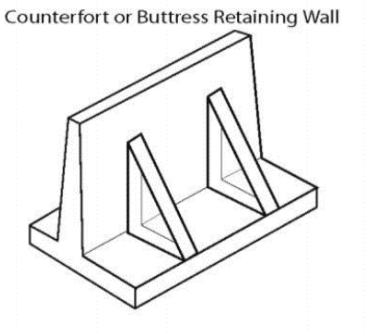
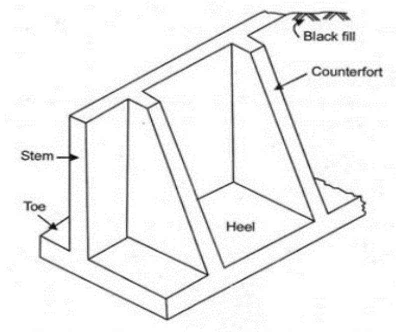
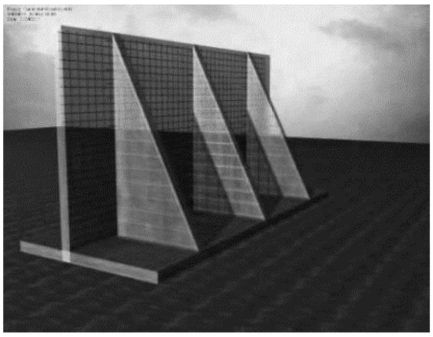
Design of Counter fort Retaining Wall

In Case of Cantilever retaining wall the bending moment in the vertical stem varies as h^{3}, where h is the height of the stem. The Height of the stem plays a very important role. When the height of the stem increases beyond 6m, the thickness of the stem can be increased which leads to an uneconomical design. Hence a counter fort to the retaining wall is provided to reduce the thickness of the stem. This Counterfort supports both the vertical stem as well as heel slab, sometimes counterforts are also provided over toe slabs up to the ground level.





Counterfort retaining walls



Moment about a point B = R x h/3

$$M = \tfrac{1}{2}(k_a.\gamma.h)h.(h/3)$$

$$M = \tfrac{1}{2}(k_a.\gamma.(h^3/3))$$

$$M \alpha h^3$$

Design of Stem:

The stem of the Counterfort retaining wall acts as a continuous slab supported on counterforts. Due to the varying earth pressure over the height of the stem, the stem slab deflects outwards and hence main reinforcement are provided along the length of the retaining wall at an outer face of the stem between counter fort and at an inner face of the rear counter fort. The reaction of the stem is taken by the counterforts to which it is firmly anchored.

Note: In Counterfort Retaining wall, if stem slab will act as a continuous slab, the negative moment will occur at counterfort and positive moment will occur in between counterfort.

The - ve bending Moment in the stem of Counterfort = $(wl^2)/12$

The + ve bending Moment in between Counterfort = $(wl^2)/16$

Lecture 08

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