

DESIGN AND DETAILING OF RETAINING WALL

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Retaining wall

Retaining walls are usually built to hold back soil mass. However, retaining walls can also be constructed for aesthetic landscaping purposes. Retaining walls are structures that are constructed to retain soil or any such materials which are unable to stand vertically by themselves. They are also provided to maintain the grounds at two different levels.

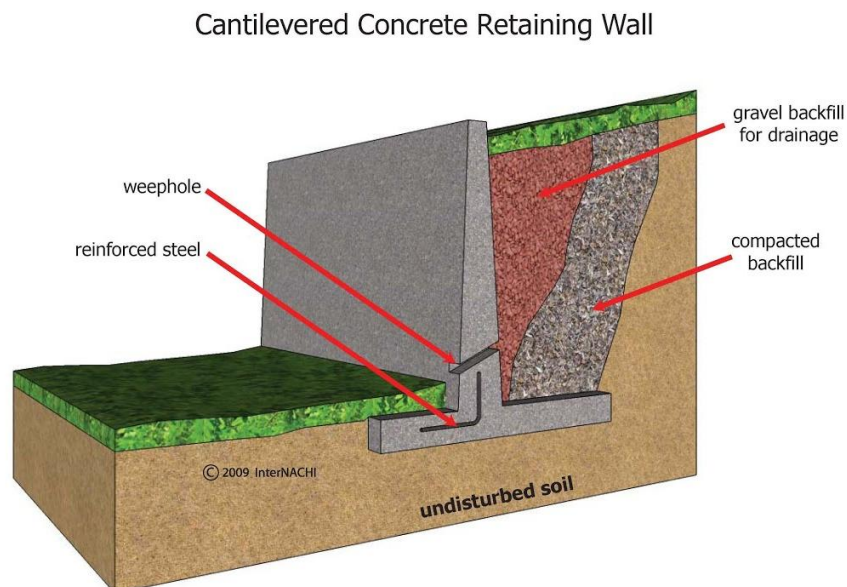


Figure 1: Cross section of cantilever retaining wall

Classification of retaining walls:

Following are the different types of retaining walls, which is based on the shape and the mode of resisting the pressure.

1. Gravity Wall-Masonry or Plain concrete

Gravity retaining walls are the walls which use their own weight to resist the lateral earth pressures. The main forces acting on gravity retaining walls are the vertical forces from the weight of the wall, the lateral earth pressure acting on the back face and the seismic loads. Since it's mostly about weight, these retaining walls allow for the widest amount of variety when it comes to materials. Gravity retaining Wall constructs of concrete, stone or brick masonry and are thicker in section. The geometry of these walls also helps them to maintain the stability.

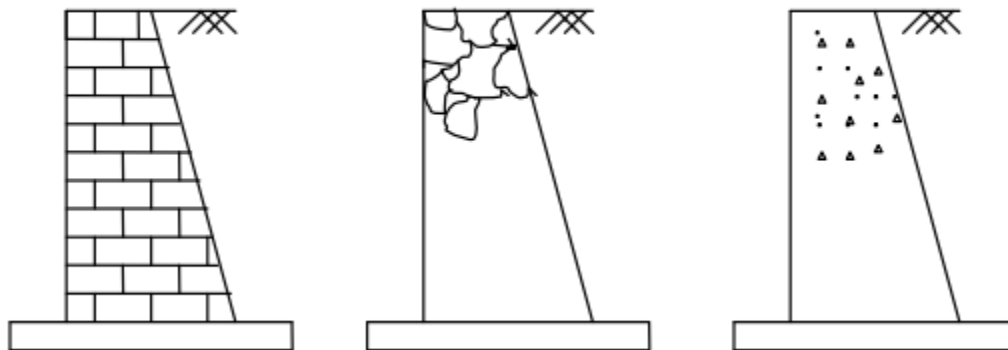


Figure 1: Types of gravity retaining walls

ϣ. Cantilever retaining wall-RCC (Inverted T and L)

Cantilever walls are built using reinforced concrete, with an L-shaped, or inverted T-shaped, foundation. The vertical stress behind the wall is transferred onto the foundation, preventing toppling due to lateral earth pressure from the same soil mass.

ϣ. Counterfort retaining wall-RCC

A counterfort retaining wall is a cantilever wall with counterforts attached to the inside face of the wall to further resist lateral thrust. Some common materials used for retaining walls are treated lumber, concrete block systems, poured concrete, stone, and brick.

ϣ. Buttress wall-RCC

A buttress wall is similar to a counterfort wall except that transverse walls are located on the side of the vertical wall opposite to the retained material and act as compression struts.

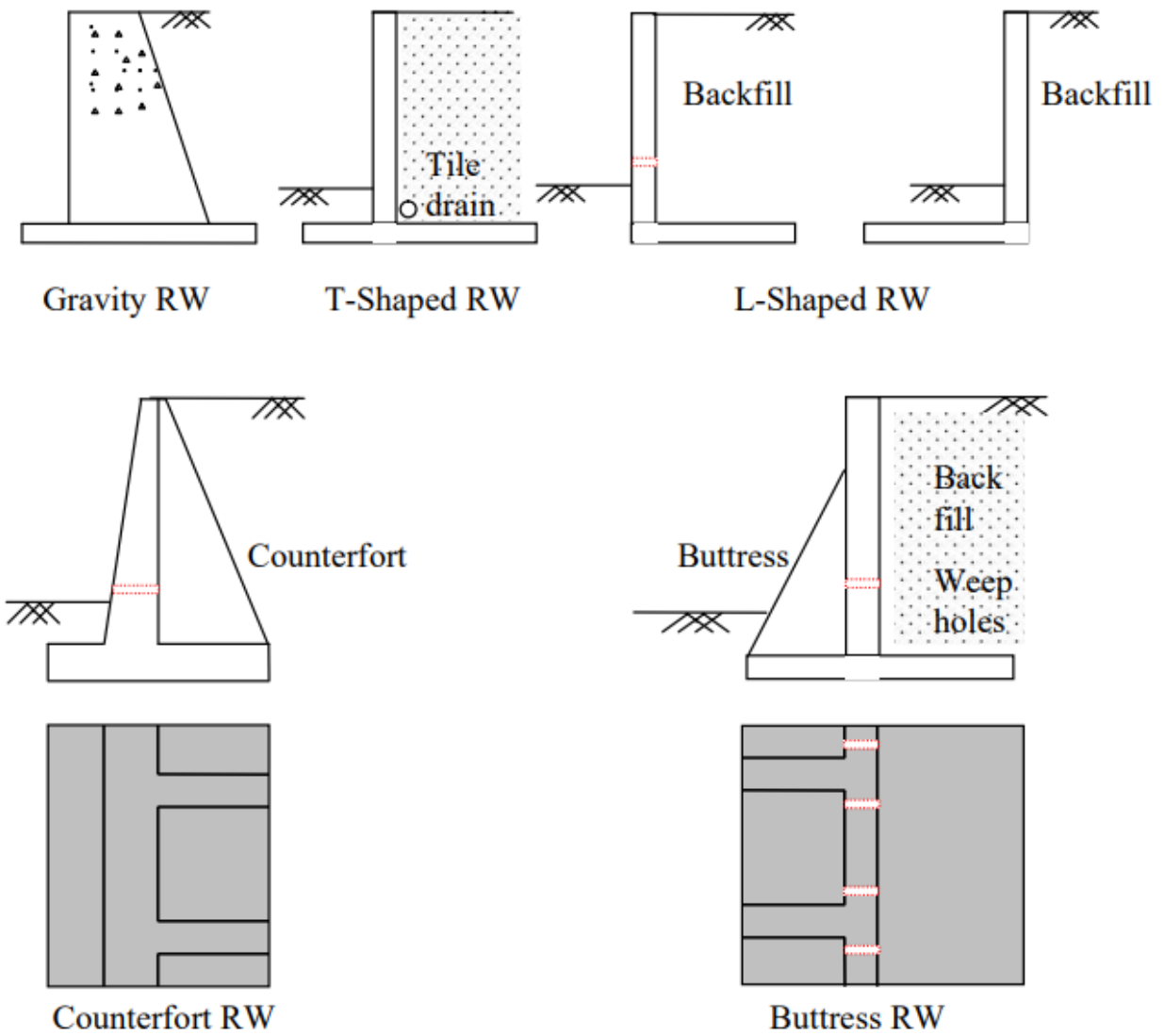


Figure 3: Types of retaining walls

Earth Pressure (P)

Earth pressure is the pressure exerted by the retaining material on the retaining wall. This pressure tends to deflect the wall outward. There are two types of earth pressure and they are:

Active earth pressure or earth pressure (P_a) and Passive earth pressure (P_p). Active earth pressure tends to deflect the wall away from the backfill. Earth pressure depends on type of backfill, the height of wall and the soil conditions.

Soil conditions: The different soil conditions are:

Dry leveled back fill

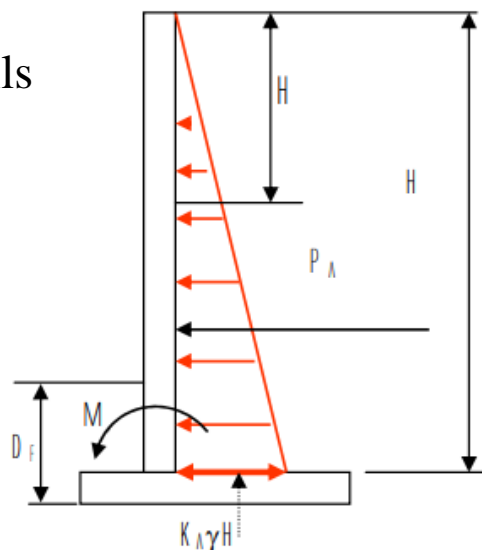
Moist leveled backfill

Submerged leveled backfill

Leveled backfill with uniform surcharge

Backfill with sloping surface

Analysis for dry back fills



Maximum pressure at any height, $p = k_a \gamma h$

Total pressure at any height from top, $P = 1/2 [k_a \gamma h] h = [k_a \gamma h^2]/2$

Bending moment at any height = $M = Pxh/3 = [k_a \gamma h^3]/6$

∴ Total pressure at bottom, $P_a = [k_a \gamma H^2]/2$

∴ Total Bending moment at bottom, $M = [k_a \gamma H^3]/6$

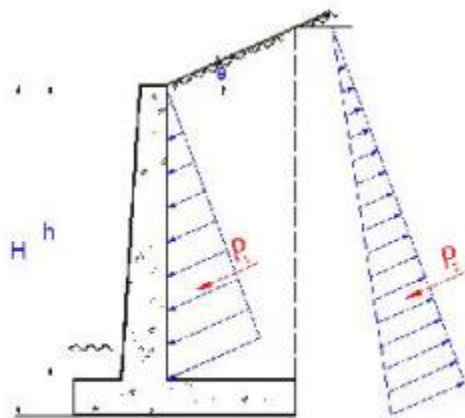
Where, $k_a =$ Coefficient of active earth pressure = $(1 - \sin \phi)/(1 + \sin \phi) = \tan^2 \phi$
= $1/k_p$, coefficient of passive earth pressure

$\phi =$ Angle of internal friction or angle of repose

$\gamma =$ Unit weight or density of backfill

If $\phi = 30^\circ$, $k_a = 1/3$ and $k_p = 3$. Thus k_a is 9 times k_p

Backfill with
sloping surface



SOIL PRESSURE DUE TO INCLINED SURCHARGE

$p_a = k_a \gamma H$ at the bottom and is parallel to inclined surface of backfill

$$k_a = \cos\theta \left[\frac{\cos\theta - \sqrt{\cos^2\theta - \cos^2\phi}}{\cos\theta + \sqrt{\cos^2\theta - \cos^2\phi}} \right]$$

Where θ = Angle of surcharge

\therefore Total pressure at bottom = $P_a = k_a \gamma H^2 / 2$

Stability requirements of RW:

Following conditions must be satisfied for stability of wall.

1. It should not overturn
2. It should not slide
3. It should not subside i.e Max. pressure at the toe should not exceed the safe bearing capacity of the soil under working condition.

Check against overturning

Factor of safety against overturning = $M_R / M_O \geq 1.00$ (= 1.4/1.4)

Where, M_R = Stabilizing moment or restoring moment

M_O = overturning moment

As per IS: 806-2000,

$$M_R > 1.2 M_{O, ch DL} + 1.4 M_{O, ch IL}$$

$$0.9 M_R \geq 1.4 M_{O, ch IL}$$

Check against Sliding

FOS = Resisting force to sliding/Horizontal force causing sliding

$$= \mu \Sigma W / P_a \geq 1.55 (=1.4/0.9)$$

As per IS: 406:2000

$$1.4 = \mu (0.9 \Sigma W) / P_a$$

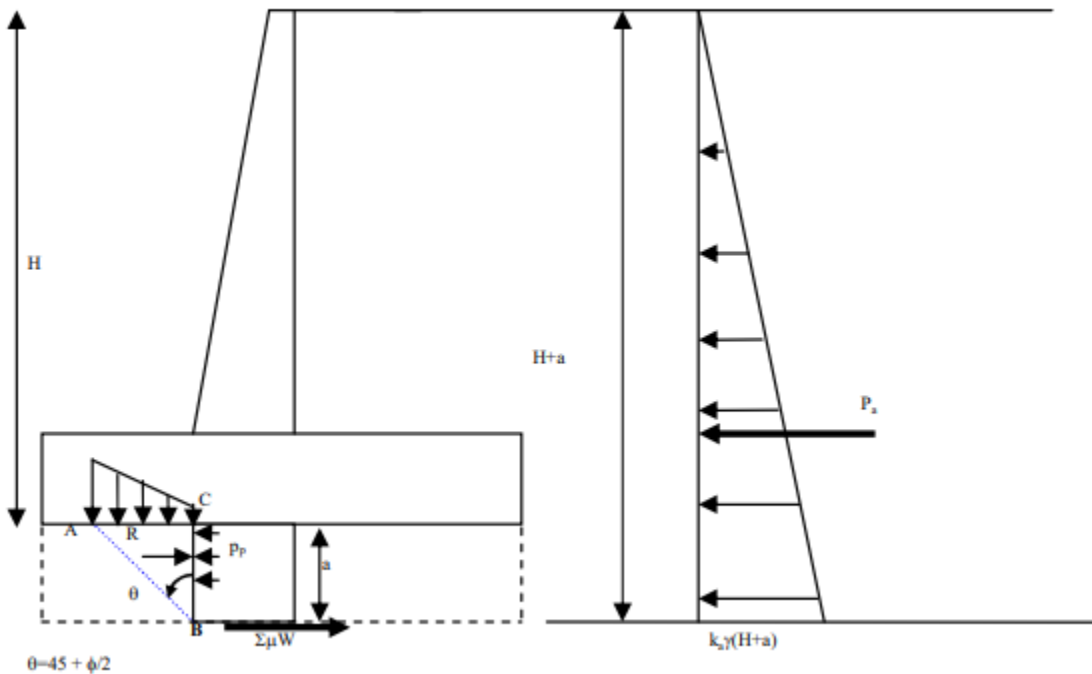
Design of Shear key:

If the wall is not safe against sliding, then a shear key is to be provided. It is provided either below the stem or at the end of heel. It should not be provided at the end of toe. If shear key is provided, then it should be designed taking the effect

of

passive

pressure.



In case the wall is unsafe against sliding

$$p_p = p \tan^2 (45 + \phi/2) = p k_p$$

where P_p = Unit passive pressure on soil above shearing plane AB if

ΣW = Total vertical force acting at the key base

ϕ = shearing angle of passive resistance

R = Total passive force = $p_p \times a$

P_A = Active horizontal pressure at key base for $H+a$

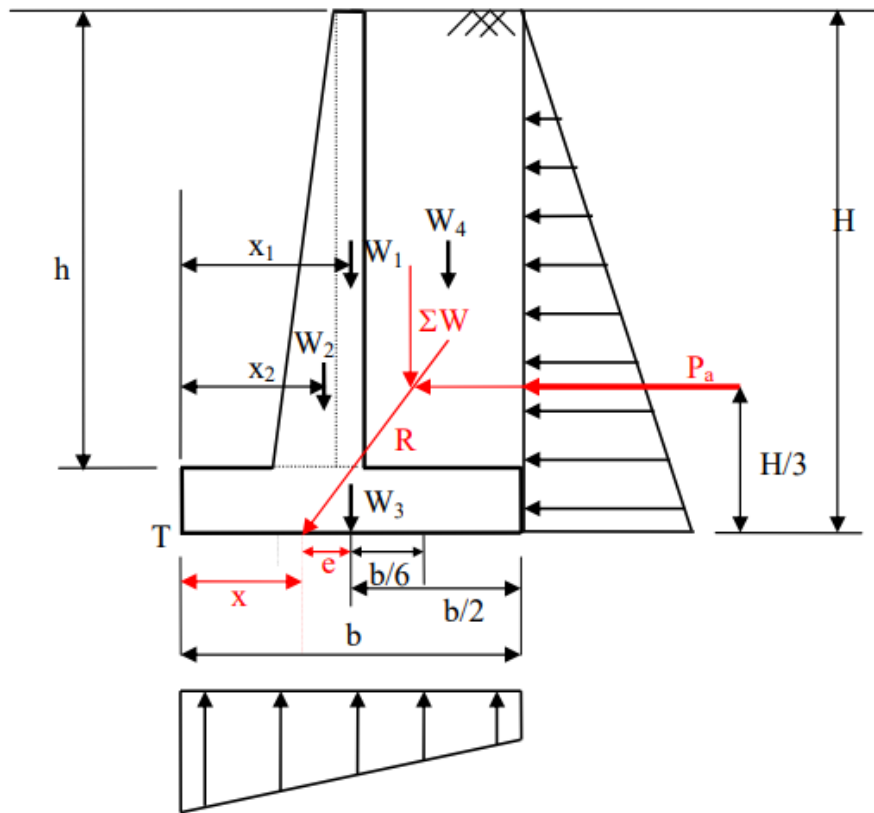
$\mu \Sigma W$ = Total frictional force under flat base

For equilibrium, $R + \mu \Sigma W = \text{FOS} \times P_A$

$$\text{FOS} = (R + \mu \Sigma W) / P_A \geq 1.55$$

Pressure below the wall

Consider the retaining wall as shown. All forces acting on the wall are shown. The moment of all forces at the end of toe is considered and the requirements of stability are to be established. For stability earth pressure at the end of the heel for the entire height of wall should be considered. The maximum and minimum pressure below the wall can be determined from the principles of static.



Pressure below the Retaining Wall

Let the resultant R due to ΣW and P_a lie at a distance x from the toe.

$X = \Sigma M / \Sigma W$, $\Sigma M =$ sum of all moments about toe.

Eccentricity of the load = $e = (b/2 - x)$

Minimum pressure at heel

$$P_{\min} = \frac{\Sigma W}{b} \left[1 - \frac{6e}{b} \right]$$

Maximum pressure at the toe

This should not be less than zero to avoid tension at the base. From this $e=b/3$, resultant should cut the base within the middle third. Otherwise the wall tends to separate from the base due to tension.

Maximum pressure at toe

$$P_{\max} = \frac{\sum W}{b} \left[1 + \frac{6e}{b} \right]$$

This should not be greater than SBC of soil to avoid the subsidence of wall.

Depth of foundation

Rankine's formula:
$$D_f = \frac{SBC}{\gamma} \left[\frac{1 - \sin \phi}{1 + \sin \phi} \right]^2 = \frac{SBC}{\gamma} k_a^2$$

Preliminary Proportioning (T shaped wall)

Following guidelines are to be followed for initial proportioning of wall without surcharge.

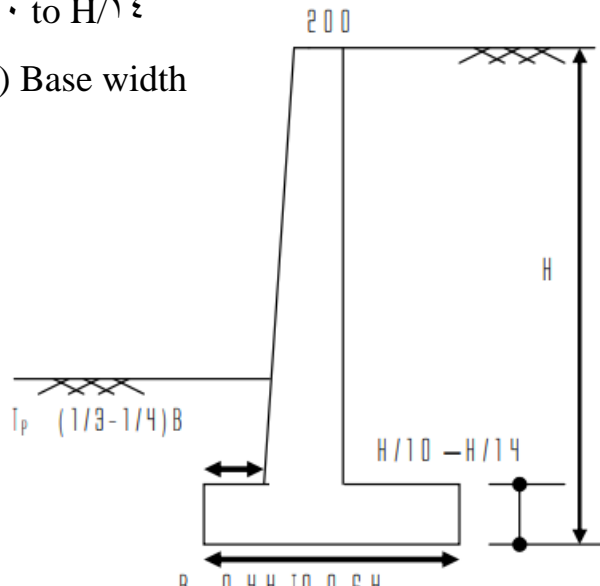
For surcharge and other cases, good text books should be followed.

Stem: Top width 200 mm to 300 mm

Base slab width $b = 0.5H$ to $0.7H$, and $0.7H$ to $0.9H$ for surcharged wall

Base slab thickness = $H/10$ to $H/12$

Toe projection = $(1/3 - 1/4) B$



Behavior or structural action and design

All the three elements namely stem, toe and heel acts as cantilever slabs and hence the design and detailing principles are same as that of conventional cantilever slabs.

Stem design: $M_u = \text{partial safety factor} \times (k_a \gamma H^3 / 6)$
Determine the depth d from $M_u = M_{u, \text{lim}} = Qbd^2$

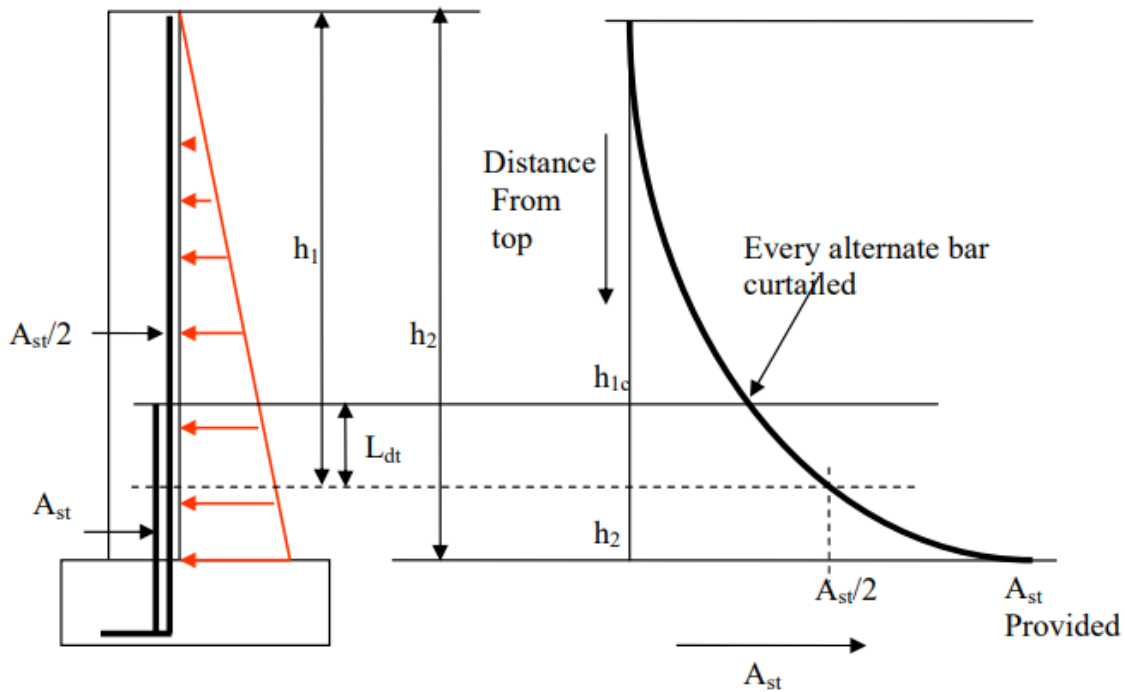
Determine the steel based on balanced or under reinforced design. Provide enough development length at the junction for all bars.

Curtailement of steel

Maximum steel is needed at the base where the BM is maximum. As the BM decreases towards the top, steel can be suitably curtailed at one or two levels. Usually steel is curtailed at one level where the steel quantity is about 50% or 60% of the base steel.

Effective depth is Proportional to h
Bending moment is proportional to h^3
 A_{st} is \propto to BM/Eff. depth and is \propto to h^2

$$\text{i.e. } \frac{A_{st1}}{A_{st2}} \approx \frac{h_1^2}{h_2^2}$$



Distribution steel: $\phi, 1\%$ Gross area for HYSD bars, $\phi, 1\%$ for Mild steel bars

Temperature steel: Provide this steel at the outer face which is same as the distribution steel.

Also provide suitable development lengths for all steel meeting at the junction. Provide suitable construction keys, drainage facilities, tile drains and weep holes as shown in the drawing. Sketch the drawings and detail as per the requirements.

Retaining wall Design

Design example-1

Design a cantilever retaining wall (T type) to retain earth for a height of 4m. the backfill is horizontal. The density of soil is 18 kN/m^3 . Safe bearing capacity of soil is 200 KN/m^2 . Take the co-efficient of friction between concrete and soil as 0.6. The angle of repose is 30° . Use M_{20} concrete and Fe_{25} steel.

Solution

Data: $h' = 4\text{m}$, $SBC = 200 \text{ kN/m}^2$, $\gamma = 18 \text{ kN/m}^3$, $\mu = 0.6$, $\phi = 30^\circ$

To fix the height of retaining wall, H

$$H = h' + D_f$$

To fix the height of retaining wall, H

$$H = h' + D$$

Depth of foundation

$$\text{Rankine's formula: } D_f = \frac{SBC}{\gamma} \left[\frac{1 - \sin \phi}{1 + \sin \phi} \right]^2 = \frac{SBC}{\gamma} k_a^2$$

1.73m say 1.8m , therefore $H = 5.8\text{m}$

Proportioning of wall

Thickness of base slab = $(1/10 \text{ to } 1/12) H$, 0.58m to 0.48m , say 0.5m

Width of base slab = $b = (0.8 \text{ to } 0.9) H$, 4.6m to 5.2m say 5m

Toe projection = $p_j = (1/3 \text{ to } 1/4)H$, 1 m to 1.5 m say 1.5 m

Provide 50 mm thickness for the stem at the base and 75 mm at the top

Design of stem

To find Maximum bending moment at the junction

$$P_h = 1/2 \times 1/3 \times 1.8 \times 5.0 = 15.0 \text{ KN}$$

$$M = P_h h/3 = 1.5 \times 1.8 \times 5.0/3 = 15.0 \text{ KN-m}$$

$$M_u = 1.0 \times M = 15.0 \text{ KN-m}$$

Taking 1 m length of wall,

$$M_u/bd^2 = 1.0 \times 15.0 < 2.76, \text{ URS (Here } d = 500 - \text{effective cover} = 500 - 50 = 450 \text{ mm).}$$

To find steel

$$P_t = 0.290\% < 0.96\%$$

$$A_{st} = 0.290 \times 1.0 \times 450/1.0 = 129.5 \text{ mm}^2$$

#12 @ 90 < 300 mm and τ_d ok

$$A_{st} \text{ provided} = 1266 \text{ mm}^2$$

Development length

$$L_d = 47 \phi_{bar} = 47 \times 12 = 564 \text{ mm}$$

Curtailement of bars

Curtailement 50% steel from top

$$(h_1/h)^2 = 1/2$$

$$(h_1/5.0)^2 = 1/2, h_1 = 3.54 \text{ m}$$

Actual point of cutoff = $3.36 - L_d = 3.36 - 4.7 \phi_{bar} = 3.36 - 1.06 \times 3 = 2.7 \text{ m}$ from top.

Spacing of bars = $180 \text{ mm c/c} < 300 \text{ mm}$ and $3d$ ok

Distribution steel

$$= 0.12\% GA = 0.12 \times 450 \times 1000 / 100 = 540 \text{ mm}^2$$

#10 @ $140 < 450 \text{ mm}$ and $3d$ ok

Secondary steel for stem at front (Temperature steel)

$$= 0.12\% GA = 0.12 \times 450 \times 1000 / 100 = 540 \text{ mm}^2$$

#10 @ $140 < 450 \text{ mm}$ and $3d$ ok

Check for shear

$$\text{Max. SF at Junction} = Ph = 77,68 \text{ kN}$$

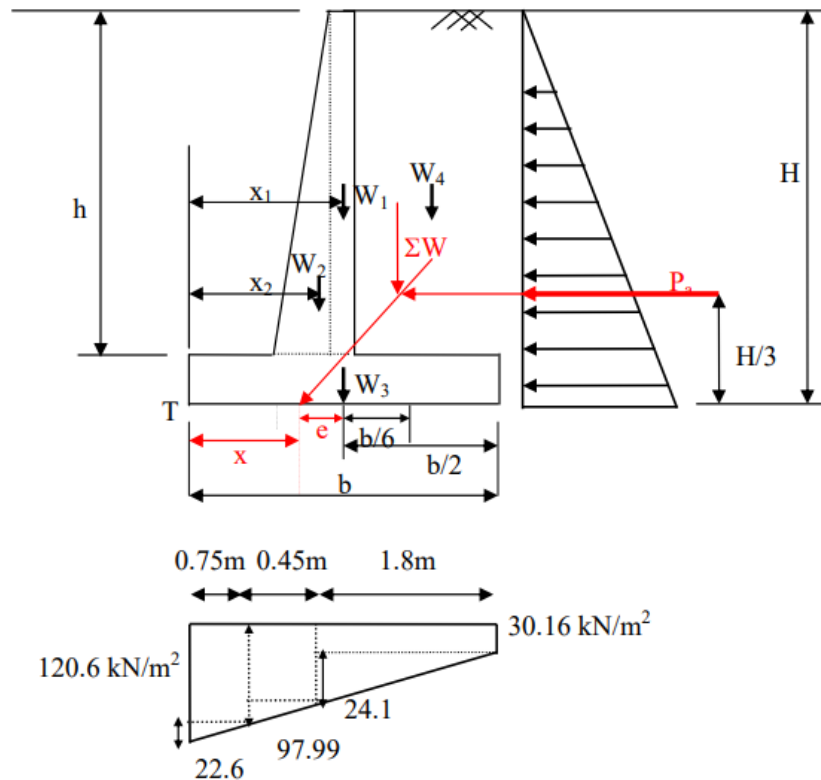
$$\text{Ultimate SF} = V_u = 1.0 \times 77,68 = 77,68 \text{ kN}$$

$$\text{Nominal shear stress} = \tau_v = V_u / bd = 77,68 \times 1000 / (1000 \times 450) = 0.17 \text{ MPa}$$

$$\text{To find } \tau_c : 100 A_{st} / bd = 0.32\%, \text{ From IS: } 456-2000, \tau_c = 0.38 \text{ MPa}$$

$\tau_v < \tau_c$ Hence safe in shear.

Stability analysis



Pressure below the Retaining Wall

Load	Magnitude, kN	Distance from A, m	Bending moment about A kN-m
Stem W1	$0.2 \times 4.75 \times 1 \times 25 = 23.75$	1.1	26.13
Stem W2	$\frac{1}{2} \times 0.25 \times 4.75 \times 1 \times 25 = 14.84$	$0.75 + \frac{2}{3} \times 0.25 = 0.316$	13.60
Base slab W3	$3.0 \times 0.45 \times 1 \times 25 = 33.75$	1.5	50.63
Back fill, W4	$1.8 \times 4.75 \times 1 \times 18 = 153.9$	2.1	323.20
total	$\Sigma W = 226.24$		$\Sigma M_R = 413.55$
Hori. earth pressure = P_H	$P_H = 0.333 \times 18 \times 5.2^2 / 2 = 81.04$ kN	$H/3 = 5.2/3$	$M_O = 140.05$

Stability checks:

Check for overturning:

$$FOS = \Sigma MR / M_O = 2.94 > 1.00 \text{ safe}$$

Check for Sliding:

$$FOS = \mu \Sigma W / P_H = 2.94 > 1.00 \text{ safe}$$

Check for subsidence:

Let the resultant cut the base at x from toe T,

$$x = \Sigma M / \Sigma W = 1.8 \text{ m} > b/3$$

$$e = b/3 - x = 0.3 \text{ m} < b/6$$

Pressure below the base slab

$$\text{Max. pressure} = P_{\max} = \frac{\Sigma W}{b} \left[1 + \frac{6e}{b} \right]$$

$$120.66 \text{ kN/m}^2 < \text{SBC, safe}$$

$$\text{Min. pressure} = P_{\min} = \frac{\Sigma W}{b} \left[1 - \frac{6e}{b} \right]$$

$$30.16 \text{ kN/m}^2 > \text{zero, No tension or separation, safe}$$

Design of Heel

To find the maximum bending moment

Load	Magnitude, kN	Distance from C, m	BM, M_C , kN-m
Backfill	153.9	0.9	138.51
Heel slab	$0.45 \times 1.8 \times 25 = 27.25$	0.9	18.23
Pressure distribution, rectangle	$30.16 \times 1.8 = 54.29$	0.9	-48.86
Pressure distribution, triangle	$\frac{1}{2} \times 24.1 \times 1.8 = 21.69$	$\frac{1}{3} \times 1.8$	-13.01
Total Load at junction	105.17	Total BM at junction	$\Sigma M_C = 94.86$

$$M_u = 1.0 \times 94.86 = 94.86 \text{ kNm}$$

$$M_u / b d^2 = 0.89 < 2.76, \text{ URS}$$

$$P_t = 0.264\% < 0.96\%$$

$$A_{st} = 0.264\% \times 1000 \times 400 / 100 = 106 \text{ mm}^2$$

$$\#16 @ 190 < 300 \text{ mm and } \checkmark \text{d ok}$$

$$A_{st} \text{ provided} = 106 \text{ mm}^2$$

Development length

$$L_d = \frac{\sigma_s}{4 \phi} \bar{\phi} = \frac{470}{4 \times 0.85} \times 16 = 276 \text{ mm}$$

Distribution steel

$$\text{Same, } \#10 @ 140 < 400 \text{ mm and } \checkmark \text{d ok}$$

Check for shear at junction (Tension)

Net downward force causing shear = 142,7 kN. Critical section for shear is at the face as it is subjected to tension.

Maximum shear = V = 100,17 kN, VU, max = 107,76 kN, $\tau_v = 0,39$ MPa

$p_t = 100 \times 100 / (1000 \times 400) = 0,25\%$

$\tau_{uc} = 0,37$ MPa

Allowable shear force = $0,37 \times 1000 \times 400 = 148$ kN, slightly less than VU, max. May be ok.

Design of toe

To find the maximum bending moment

Load	Magnitude, kN	Distance from C, m	BM, M_c , kN-m
Toe slab	$0.75 \times 0.45 \times 25 = 8.44$	0.75/2	-3.164
Pressure distribution, rectangle	$97.99 \times 0.75 = 73.49$	0.75/2	27.60
Pressure distribution, triangle	$\frac{1}{2} \times 22.6 \times 1 \times 0.75 = 8.48$	$\frac{2}{3} \times 1 = 0.75$	4.24
Total Load at junction	73.53	Total BM at junction	$\Sigma M = 28.67$ kNm

$M_u = 100 \times 28,67 = 2867$ kNm

$M_u / bd^2 = 0,27 < 2,76$, URS

$P_t = 0,25\%$. Very small, provide $0,12\%$ GA

$A_{st} = 0,12 \text{ mm}^2$

#10 @ 140 < 300 mm and \checkmark d ok

Development length:

$L_d = \frac{f_y}{4 \phi_{bar}} = \frac{470}{4} \times 10 = 1175$ mm

Check for shear:

Since the soil pressure introduces compression in the wall, the critical section is taken at a distance d from junction. Net shear force at the section =

$(120,6 + 100,17) / 2 \times 0,30 - 0,40 \times 0,30 \times 20 = 70,40$ kN

$V = 70.86 \text{ kN}$, $V_{U,max} = 70.86 \times 1.0 = 70.86 \text{ kN}$

$\tau_v = 70.86 \times 1000 / (1000 \times 400) = 0.177 \text{ MPa}$

$p_t = 0.2\%$

$\tau_{uc} = 0.37 \text{ MPa}$

$V_{allowable} = 0.37 \times 1000 \times 400 = 149.6 \text{ kN} > V_{U,max}$, ok

Construction joint

A key 20 mm wide x 50 mm deep with nominal steel

#10 @ 200, 600 mm length in two rows

Drainage:

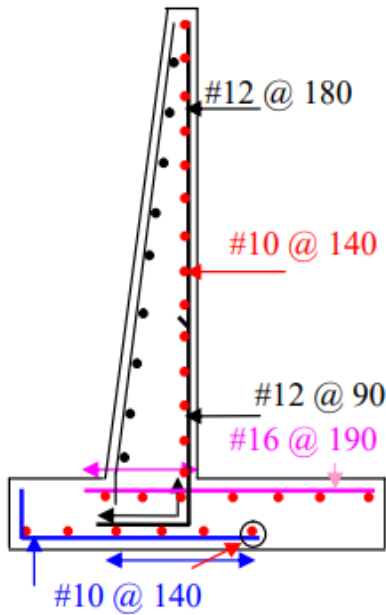
100 mm dia. pipes as weep holes at 3 m c/c at bottom.

Also provide 200 mm gravel blanket at the back of the stem for back drain

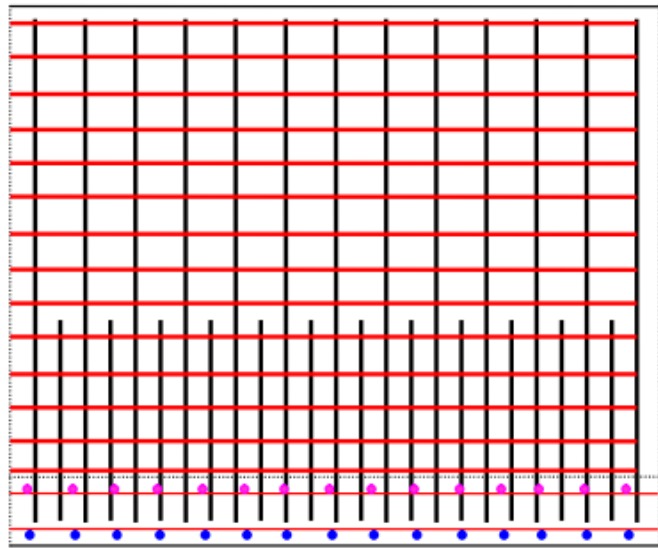
Sketch

Following section will be asked in the examination.

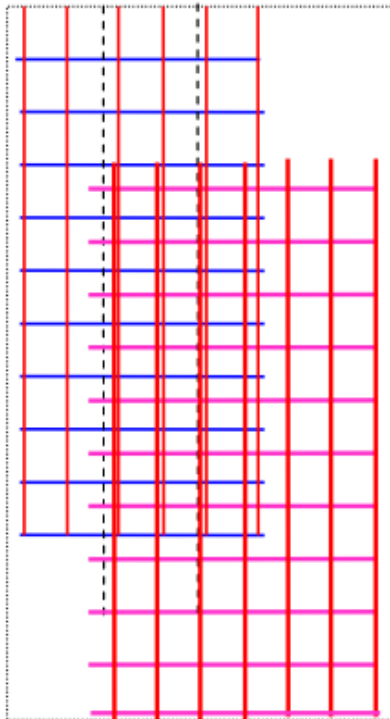
1. Cross section of wall
2. Longitudinal section of wall for about 3 m
3. Sectional plan of the base slab
4. Longitudinal section of stem near the base slab



Cross section of wall



Longitudinal section of wall



Sectional plan of base slab

Note

- ❖ Adopt a suitable scale such as 1:20
- ❖ Show all the details and do neat drawing
- ❖ Show the development length for all bars at the junction
- ❖ Name the different parts such as stem, toe, heel, backfill, weep holes, blanket, etc.,
- ❖ Show the dimensions of all parts
- ❖ Detail the steel in all the drawings
- ❖ Lines with double headed arrows represents the development lengths in the cross section

REFERENCES

[https://www.google.com/search?q=Buttress+wall-RCC&ei=rhuBYrTLMqGExc^Px^SkmAo&ved=ahUKEwi·\qHF\OH\AhUhQvEDHUcqCaMQ^dUDCA^&uact=°&oq=Buttress+wall-RCC&gs_lcp=Cgdnd^Mtd^1^EAMyFAgAEOoCELOCEIoDELcDENQDEOUCMhQIABDqAhC·AhCKAxC^AxDUAxDIajIUCAAQ^gIQtAIQigMQtwMQ^AMQ^QIyFAgAEOoCELOCEIoDELcDENQDEOUCMhQIABDqAhC·AhCKAxC^AxDUAxDIajIUCAAQ^gIQtAIQigMQtwMQ^AMQ^QIyFAgAEOoCELOCEIoDELcDENQDEOUCMhQIABDqAhC·AhCKAxC^AxDUAxDIajIUCAAQ^gIQtAIQigMQtwMQ^AMQ^QIyFAgAEOoCELOCEIoDELcDENQDEOUCMhQIABDqAhC·AhCKAxC^AxDUAxDIajIUCAAQ^gIQtAIQigMQtwMQ^AMQ^QIyFAgAEOoCELOCEIoDELcDENQDEOUCSgQIORgASgQIRhgAUABYgwlg^BJoAXABeACAAOCIAOCSAOCYAOCgAOGgAQKwAQrAAQE&sclient=gws-wiz](https://www.google.com/search?q=Buttress+wall-RCC&ei=rhuBYrTLMqGExc^Px^SkmAo&ved=ahUKEwi·\qHF\OH\AhUhQvEDHUcqCaMQ^dUDCA^&uact=°&oq=Buttress+wall-RCC&gs_lcp=Cgdnd^Mtd^1^EAMyFAgAEOoCELOCEIoDELcDENQDEOUCMhQIABDqAhC·AhCKAxC^AxDUAxDIajIUCAAQ^gIQtAIQigMQtwMQ^AMQ^QIyFAgAEOoCELOCEIoDELcDENQDEOUCMhQIABDqAhC·AhCKAxC^AxDUAxDIajIUCAAQ^gIQtAIQigMQtwMQ^AMQ^QIyFAgAEOoCELOCEIoDELcDENQDEOUCMhQIABDqAhC·AhCKAxC^AxDUAxDIajIUCAAQ^gIQtAIQigMQtwMQ^AMQ^QIyFAgAEOoCELOCEIoDELcDENQDEOUCSgQIORgASgQIRhgAUABYgwlg^BJoAXABeACAAOCIAOCSAOCYAOCgAOGgAQKwAQrAAQE&sclient=gws-wiz)

https://www.google.com/search?q=Counterfort+retaining+wall-RCC&ei=dBeBYtyCJOGSxc^P^ou^yAI&ved=ahUKEwjCjJvB^OH\AhVhSfEDHeKFDikQ^dUDCA^&uact=°&oq=Counterfort+retaining+wall-RCC&gs_lcp=Cgdnd^Mtd^1^EAMyBggAEBYQHjIGCAAQFhAeOhQIABDqAhC·AhCKAxC^AxDUAxDIAkoECEEYAEoECEYYAFAAWL^_YIxLaAFwAXgAgAGIAYgBiAGSAQMwLjGYAQCgAQQgAQKwAQrAAQE&sclient=gws-wiz

[https://www.google.com/search?q=Cantilever+retaining+wall-RCC+\(Inverted+T+and+L\)&oq=Cantilever+retaining+wall-RCC+\(Inverted+T+and+L\)&aqs=chrome..^i^o^v,^l^a^j·j^o^&sourceid=chrome&ie=UTF-^](https://www.google.com/search?q=Cantilever+retaining+wall-RCC+(Inverted+T+and+L)&oq=Cantilever+retaining+wall-RCC+(Inverted+T+and+L)&aqs=chrome..^i^o^v,^l^a^j·j^o^&sourceid=chrome&ie=UTF-^)

https://www.concretenetwork.com/concrete/poured_concrete_retaining_walls/four_types.htm

<http://www.constructioncivilengineering.com/reinforced-cement-concrete-retaining-wall.html>