DESIGN AND DETAILING OF RETAINING WALL

List of content

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 retail 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.

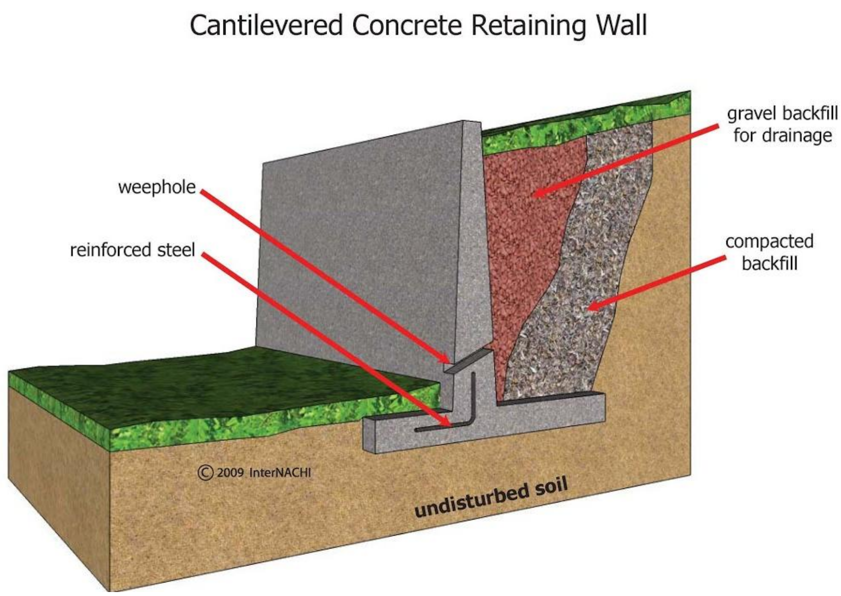


Figure١: Cross section of cantilever retaining wall

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.

١. 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.

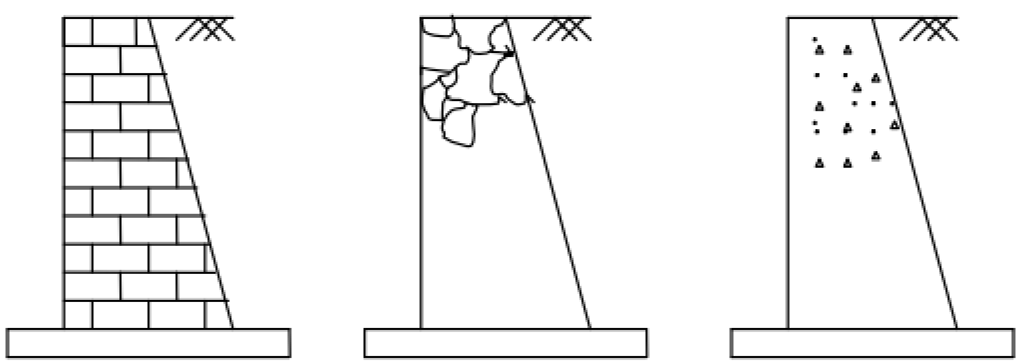


Figure ٢: Types of gravity retaining walls

٢. 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.

٣. 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.

٤. 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.

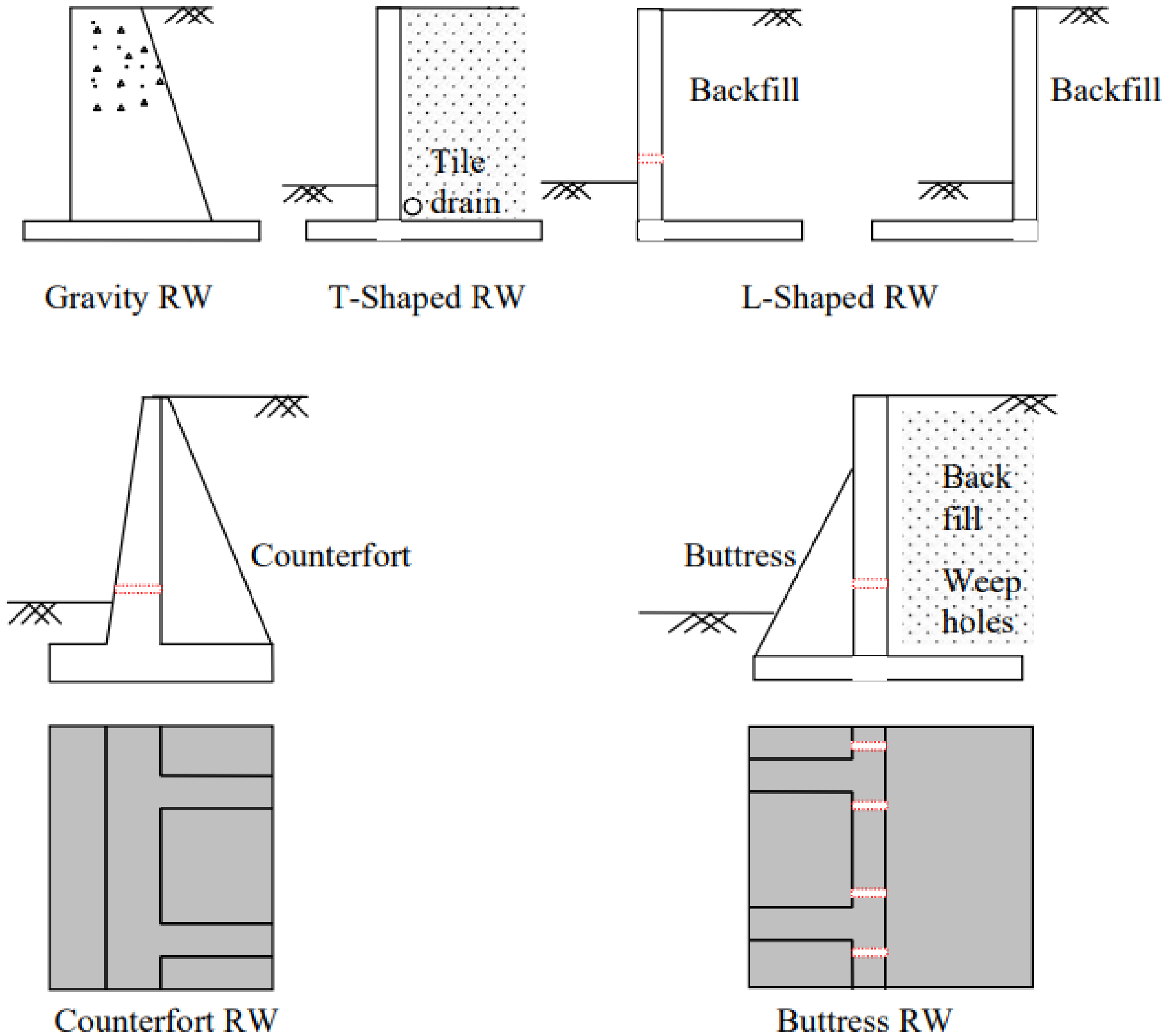


Figure ٣: Types of retaining walls

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 (Pa) and Passive earth pressure (Pp). 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

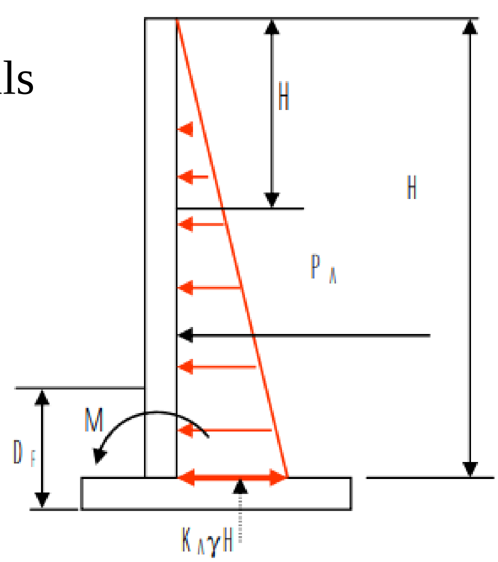
Moist leveled backfill

Submerged leveled backfill

Leveled backfill with uniform surcharge

Backfill with sloping surface

Analysis for dry back fills

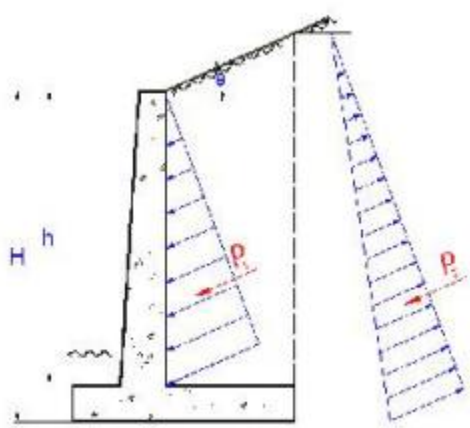


Maximum pressure at any height, $p=k_a\gamma h$
Total pressure at any height from top, $P=1/2[k_a\gamma h]h = [k_a\gamma h^2]/2$
Bending moment at any height = $M=Pxh/3= [k_a\gamma h^3]/6$

$\therefore$ Total pressure at bottom, $P_a= [k_a\gamma H^2]/2$
$\therefore$ 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
ϕ= Angle of internal friction or angle of repose
γ=Unit weigh or density of backfill

If $\phi= 30°$, $k_a=1/3$ 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.

١. It should not overturn

٢. It should not slide

٣. 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 = MR / MO $\geq$ ١,٥٥ (=١,٤/٠,٩)

Where, MR =Stabilizing moment or restoring moment

MO =overturning moment

As per IS:٤٥٦-٢٠٠٠,

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

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

Check against Sliding

FOS = Resisting force to sliding/Horizontal force causing sliding

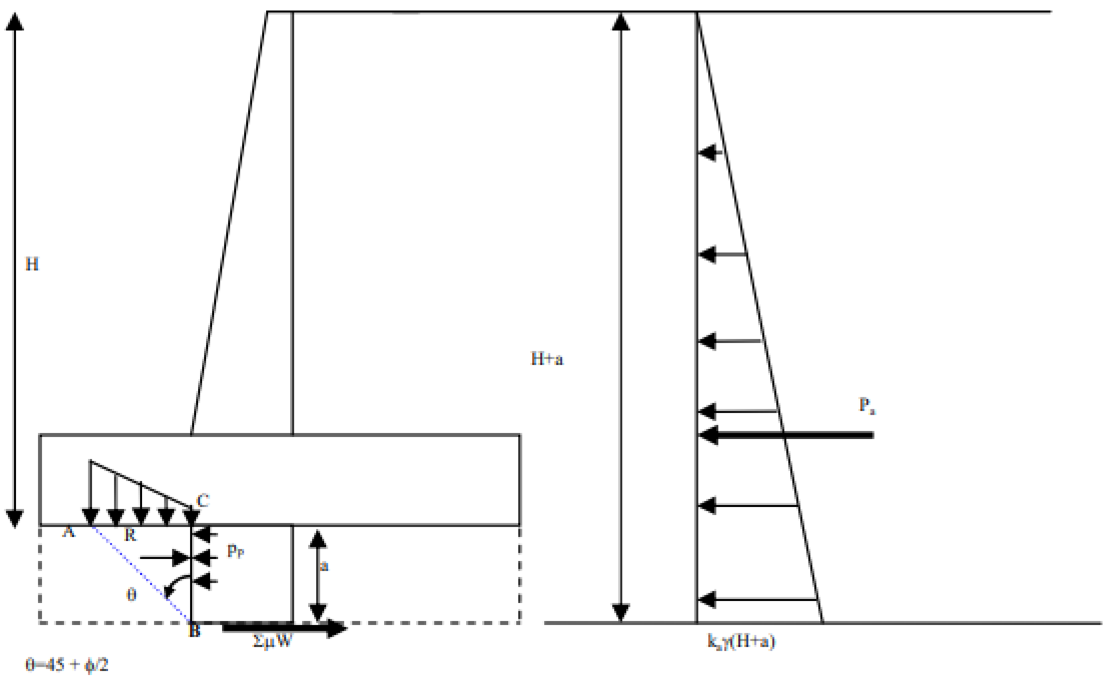
$= \mu\sum W/P_a \geq 1.55\ (=1.4/0.9)$

As per IS:٤٥٦:٢٠٠٠

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

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 Pp= Unit passive pressure on soil above shearing plane AB if

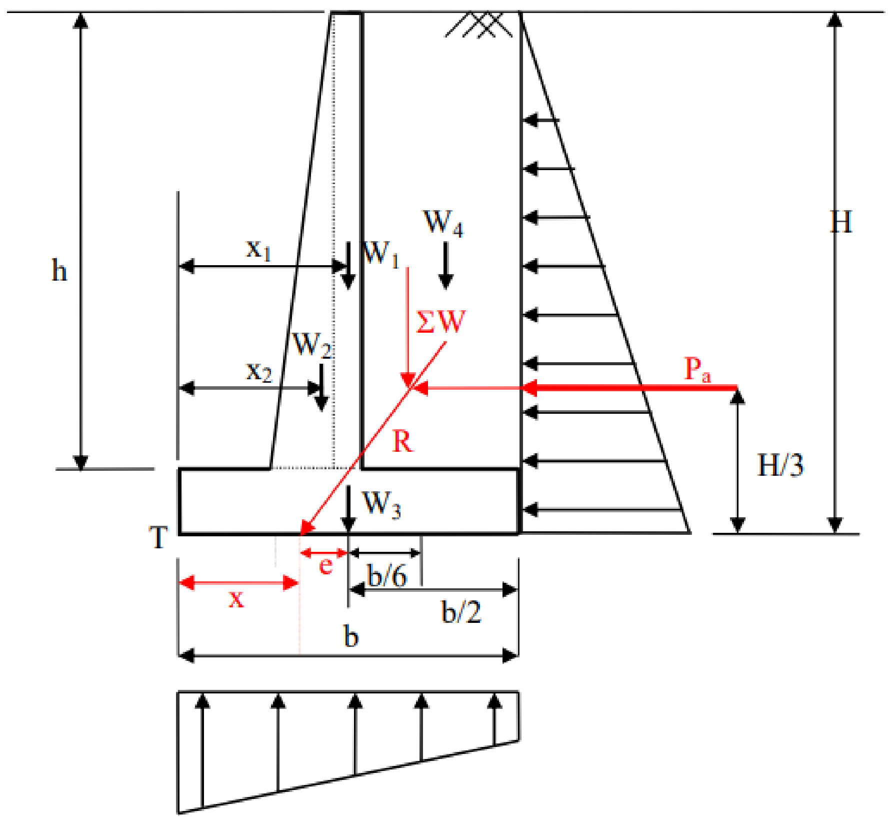
$\sum W$= Total vertical force acting at the key base
ϕ= shearing angle of passive resistance
R= Total passive force = p_p x a
P_A=Active horizontal pressure at key base for H+a
$\mu \sum W$=Total frictional force under flat base

For equilibrium, $R + \mu \sum W = FOS \times P_A$

$FOS = (R + \mu \sum W)/ P_A \geq 1.55$

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 $\sum W$ and P_a lie at a distance x from the toe.
X = $\sum M/\sum W$, $\sum M$ = sum of all moments about toe.
Eccentricity of the load = e = (b/2-x)
Minimum pressure at heel

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

Maximum pressure at the toe

This should not be less than zero to avoid tension at the base. From this e=b/٦, 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

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

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

Depth of foundation

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

Preliminary Proportioning (T shaped wall)

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

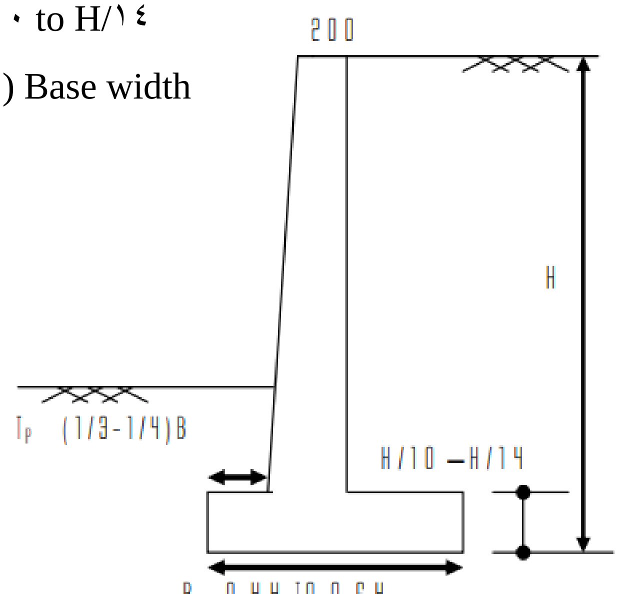
For surcharge and other cases, good text books should be followed.

Stem: Top width ٢٠٠ mm to ٤٠٠ mm

Base slab width b= ٠,٤H to ٠,٦H, and ٠,٦H to ٠,٧٥H for surcharged wall

Base slab thickness= H/١٠ to H/١٤

Toe projection= (١/٣-١/٤) Base width



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

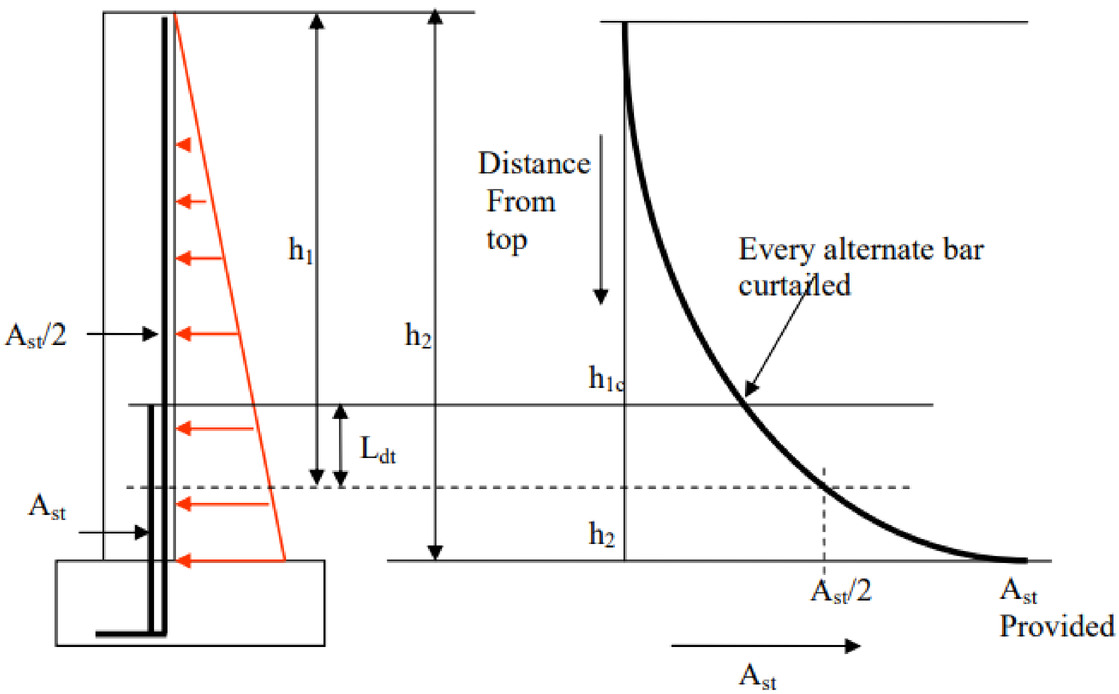
Determine the steel based on balanced or under reinforced design. Provide enough development length at the junction for all bars.

Curtailment 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 ٥٠٪ or ٦٧% of the base steel.

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

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



Distribution steel: ٠,١٢٪ Gross area for HYSD bars, ٠,١٥٪ 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-١

Design a cantilever retaining wall (T type) to retain earth for a height of ٤m. the backfill is horizontal. The density of soil is ١٨kN/m٣ . Safe bearing capacity of soil is ٢٠٠ KN/m٢. Take the co-efficient of friction between concrete and soil as ٠,٦. The angle of repose is ٣٠ degrees. Use M٢٠ concrete and Fe٤١٥ steel.

Solution

Data: h' = 4m, SBC= 200 kN/m^2, γ= 18 kN/m^3, μ=0.6, φ=30°

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

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

١,٢٣m say ١,٢m, therefore H= ٥,٢m

Proportioning of wall

Thickness of base slab= (١/١٠ to ١/١٤) H, ٠,٥٢m to ٠,٤٣m, say ٤٥٠ mm

Width of base slab=b = (٠,٥ to ٠,٦) H, ٢,٦m to ٣,١٢m say ٣m

Toe projection= pj= (١/٣ to ¼)H, ١m to ٠,٧٥m say ٠.٧٥m

Provide ٤٥٠ mm thickness for the stem at the base and ٢٠٠ mm at the top

Design of stem

To find Maximum bending moment at the junction

Ph= ½ x ١/٣ x ١٨ x ٤,٧٥٢=٦٧,٦٨ KN

M= Ph h/٣ = ٠,٣٣٣ x ١٨ x ٤,٧٥٣/٦ = ١٠٧,١ KN-m

Mu= ١,٥ x M = ١٦٠,٦ KN-m

Taking ١m length of wall,

Mu/bd^{٢}= ١,٠٠٤ < ٢,٧٦, URS (Here d=٤٥٠- effective cover=٤٥٠-٥٠=٤٠٠ mm).

To find steel

Pt=٠,٢٩٥٪ <٠,٩٦٪

Ast= ٠,٢٩٥x١٠٠٠x٤٠٠/١٠٠ = ١١٨٠ mm٢

#١٢ @ ٩٠ < ٣٠٠ mm and ٣d ok

Ast provided= ١٢٦٦mm٢

Development length

Ld=٤٧ φbar =٤٧ x ١٢ = ٥٦٤ mm

Curtailment of bars

Curtail ٥٠٪ steel from top

(h١/h)٢ = ½

(h١/٤,٧٥)٢ = ½, h١ = ٣,٣٦m

Actual point of cutoff= ٣,٣٦-Ld =٣,٣٦-٤٧ φbar = ٣,٣٦-٠,٥٦٤ = ٢,٧٤m from top.

Spacing of bars = ١٨٠ mm c/c < ٣٠٠ mm and ٣d ok

Distribution steel

= ٠,١٢٪ GA = ٠,١٢x٤٥٠ x ١٠٠٠/١٠٠ = ٥٤٠ mm٢

#١٠ @ ١٤٠ < ٤٥٠ mm and ٥d ok

Secondary steel for stem at front (Temperature steel)

٠,١٢٪ GA = ٠,١٢x٤٥٠ x ١٠٠٠/١٠٠ = ٥٤٠ mm٢

#١٠ @ ١٤٠ < ٤٥٠ mm and ٥d ok

Check for shear

Max. SF at Junction = Ph=٦٧,٦٨ kN

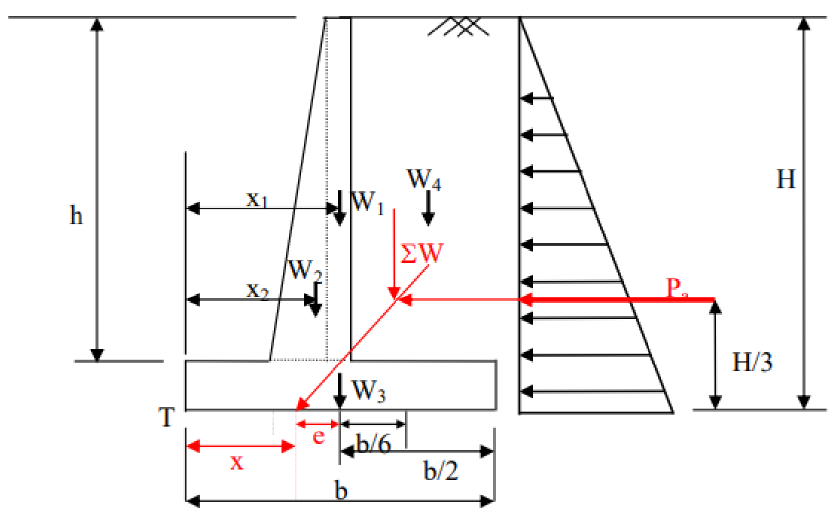
Ultimate SF= Vu=١,٥ x ٦٧,٦٨ = ١٠١,٥٢ kN

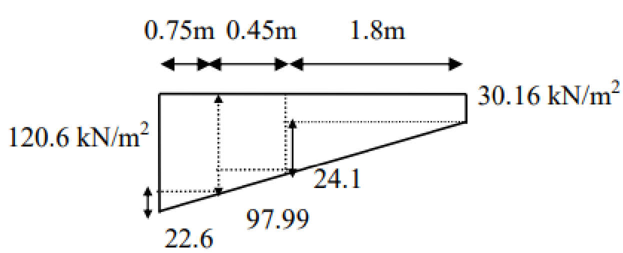
Nominal shear stress =τv=Vu/bd = ١٠١,٥٢ x ١٠٠٠ / ١٠٠٠x٤٠٠ = ٠,٢٥ MPa

To find τc : ١٠٠Ast/bd = ٠,٣٢٪, From IS:٤٥٦-٢٠٠٠, τc= ٠,٣٨ MPa

τv< τc 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	0.2x4.75x1x25 = 23.75	1.1	26.13
Stem W2	½ x0.25x4.75x1x25 = 14.84	0.75 + 2/3x0.25=0.316	13.60
Base slab W3	3.0x0.45x1x25 = 33.75	1.5	50.63
Back fill, W4	1.8x4.75x1x18 = 153.9	2.1	323.20
total	**ΣW= 226.24**		**ΣM_R=413.55**
Hori. earth pressure =P_H	P_H =0.333x18x5.2^2/2 =81.04 kN	H/3 =5.2/3	**M_O=140.05**

Stability checks:

Check for overturning:

FOS = ΣMR/ MO= ٢,٩٤ >١,٥٥ safe

Check for Sliding:

FOS = μ ΣW/ PH= ٢,٩٤ >١,٥٥ safe

Check for subsidence:

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

x= ΣM/ ΣW= ١,٢٠ m > b/٣

e= b/٢ –x = ٣/٢ – ١,٢ = ٠,٣m < b/٦

Pressure below the base slab

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

120.66 kN/m^2 < SBC, safe

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

30.16 kN/m^2 > zero, No tension or separation, safe

Design of Heel

To fine 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	0.45x1.8x25 = 27.25	0.9	18.23
Pressure distribution, rectangle	30.16 x 1.8 =54.29	0.9	-48.86
Pressure distribution, triangle	½ x 24.1 x1.8=21.69	1/3x1.8	-13.01
Total Load at junction	**105.17**	**Total BM at junction**	**ΣM_C=94.86**

Mu= ١,٥ x ٩٤,٨٦ =١٤٢,٣ kNm

Mu/bd٢= ٠,٨٩ < ٢,٧٦, URS

Pt=٠,٢٦٤٪ < ٠,٩٦٪

Ast= ٠,٢٦٤x١٠٠٠x٤٠٠/١٠٠ = ١٠٥٦ mm٢

#١٦@ ١٩٠ < ٣٠٠ mm and ٣d ok

Ast provided= ١٠٥٨mm٢

Development length

Ld=٤٧ φbar =٤٧ x ١٦ = ٧٥٢m

Distribution steel

Same, #١٠ @ ١٤٠ < ٤٥٠ mm and ٥d ok

Check for shear at junction (Tension)

Net downward force causing shear = ١٤٢,٣kN. Critical section for shear is at the face as it is subjected to tension.

Maximum shear =V=١٠٥,١٧ KN, VU, max= ١٥٧,٧٦ kN, τv =٠,٣٩ MPa

pt=١٠٠x١٠٥٨/(١٠٠٠x٤٠٠) =٠,٢٧٪

τuc =٠,٣٧ MPa

Allowable shear force= ٠,٣٧x ١٠٠٠ x ٤٠٠ =١٤٨kN, 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	0.75x0.45x25=8.44	0.75/2	-3.164
Pressure distribution, rectangle	97.99x0.75=73.49	0.75/2	27.60
Pressure distribution, triangle	½ x22.6 x1x0.75=8.48	2/3x1=0.75	4.24
Total Load at junction	**73.53**	**Total BM at junction**	**ΣM=28.67kNm**

Mu= ١,٥ x ٢٨,٦٧ =٤٣ kNm

Mu/bd٢= ٠,٢٧< ٢,٧٦, URS

Pt=٠,٠٨٥٪ Very small, provide ٠,١٢٪GA

Ast= ٥٤٠ mm٢

#١٠ @ ١٤٠ < ٣٠٠ mm and ٣d ok

Development length:

Ld=٤٧ φbar =٤٧ x ١٠ = ٤٧٠ 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= (١٢٠,٦+١١٠,٠٤)/٢ x ٠,٣٥ -٠,٤٥x٠,٣٥x٢٥=٧٥,٤٥kN

V=٧٥,٤٦ kN, VU,max=٧٥,٤٥x١,٥=١١٣,١٨ kN

τv=١١٣,١٧x١٠٠٠/(١٠٠٠x٤٠٠)=٠,٢٨ MPa

pt=٠,٢٥٪

τuc =٠,٣٧ MPa

V,allowable = ٠,٣٧x ١٠٠٠ x ٤٠٠ =١٤٨ kN > VU,max, ok

Construction joint

A key ٢٠٠ mm wide x ٥٠ mm deep with nominal steel

#١٠ @ ٢٥٠, ٦٠٠ mm length in two rows

Drainage:

١٠٠ mm dia. pipes as weep holes at ٣m c/c at bottom.

Also provide ٢٠٠ mm gravel blanket at the back of the stem for back drain

Sketch

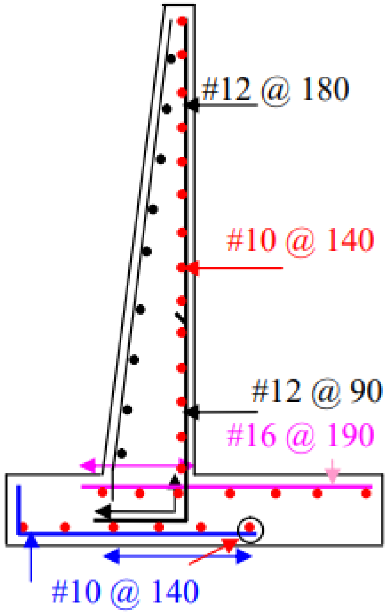
Following section will be asked in the examination.

١. Cross section of wall

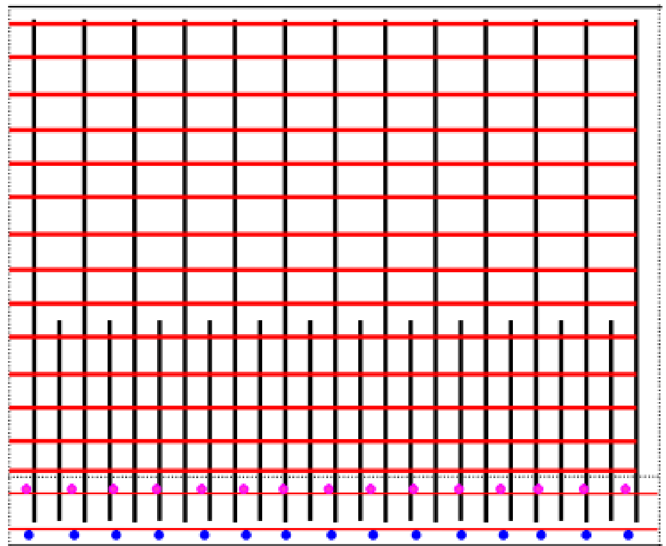
٢. Longitudinal section of wall for about ٢m

٣. Sectional plan of the base slab

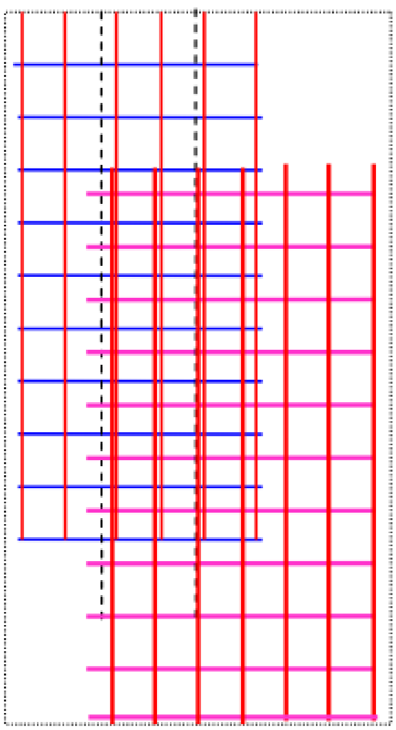
٤. Longitudinal section of stem near the base slab



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

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