# DESIGN AND DETAILING OF RETAINING WALLS

**(For class held from 2nd April 07)**

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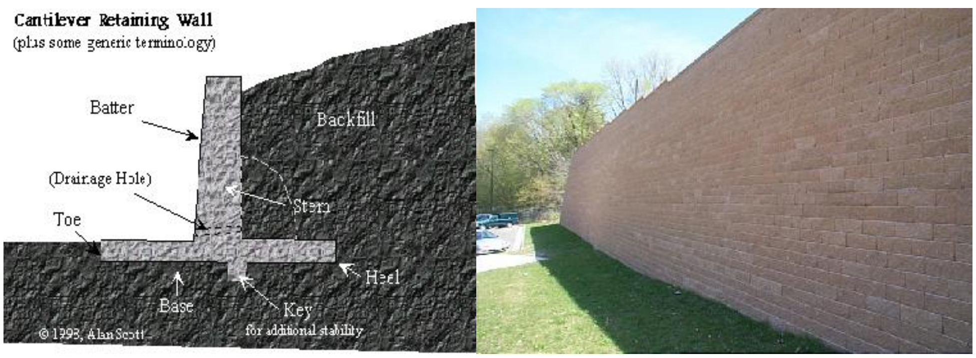
**Definition:** Retaining walls are usually built to hold back soil mass. However, retaining walls can also be constructed for aesthetic landscaping purposes. Retaining walls are structures that are constructed to retail soil or any such materials which are unable to stand vertically by themselves. They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




(a) (b)

Figure. Cross section of cantilever retaining wall (a) and the finished retaining wall (b)

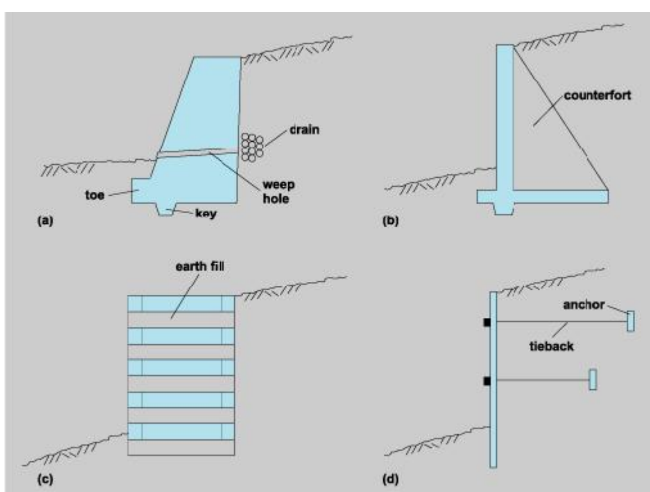



Figure. Types of retaining walls

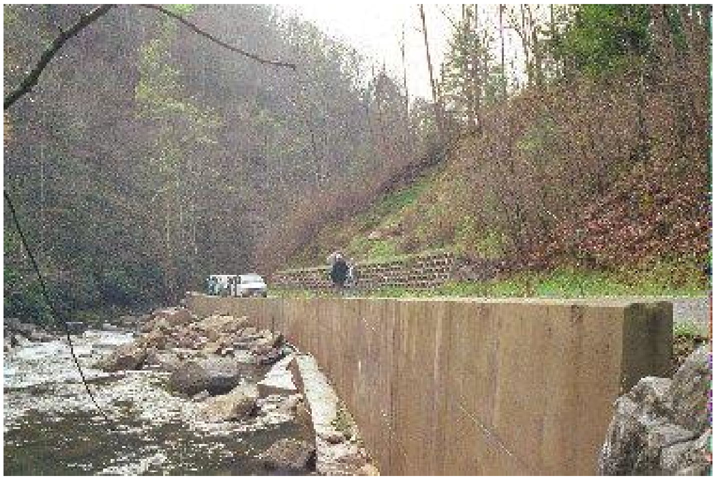


Figure. Photo of concrete retaining wall

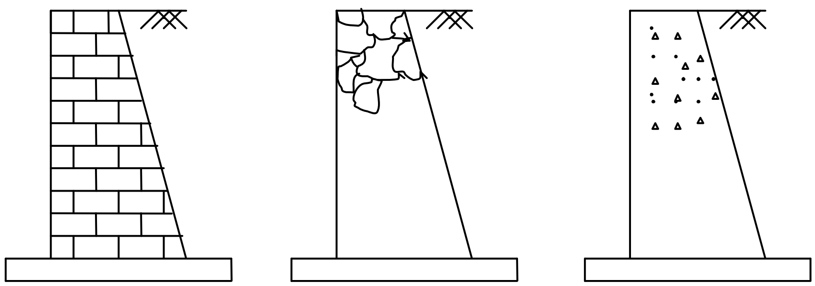


Figure. Types of gravity retaining walls

**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
2. Cantilever retaining wall-RCC
   (Inverted T and L)
3. Counterfort retaining wall-RCC
4. Buttress wall-RCC

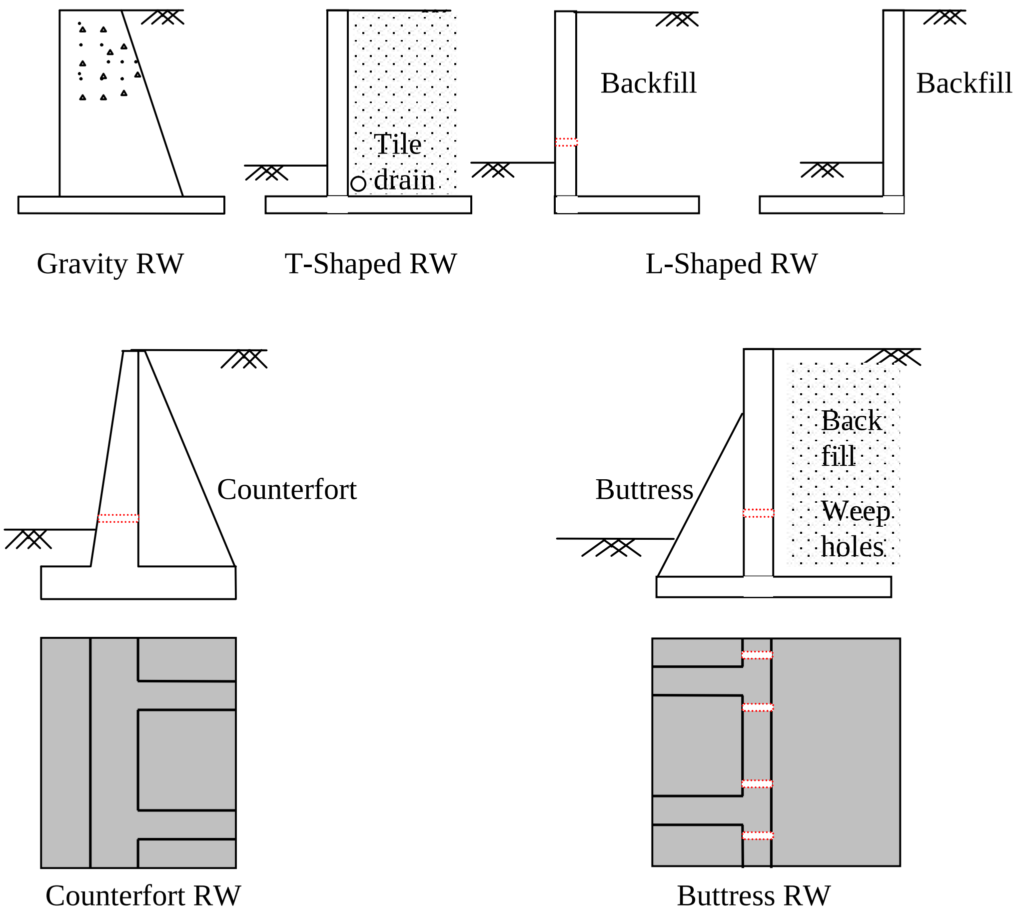


Figure. Types of retaining walls

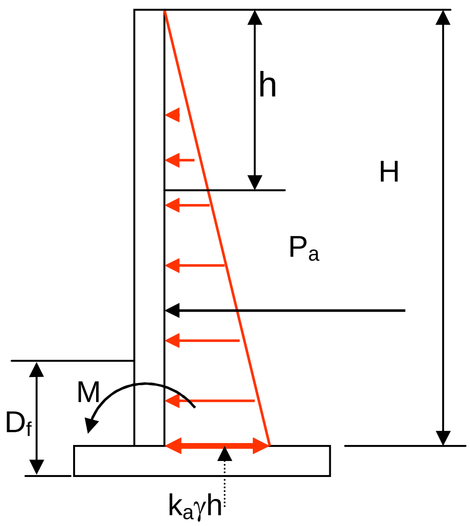
**Earth Pressure (P)**

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**

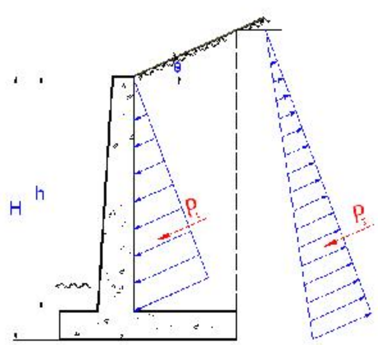



Maximum pressure at any height, $p=k_a\gamma h$
Total pressure at any height from top, $P=1/2[k_a\gamma h]h = [k_a\gamma h^2]/2$
Bending moment at any height = $M=Pxh/3= [k_a\gamma h^3]/6$

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

∴ 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 = $M_R$ / $M_O \geq 1.55$ (=1.4/0.9)

Where, $M_R$ =Stabilising moment or restoring moment

$M_O$ =overturning moment

As per IS:456-2000,

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

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

**Check against Sliding**

FOS = Resisting force to sliding/Horizontal force causing sliding

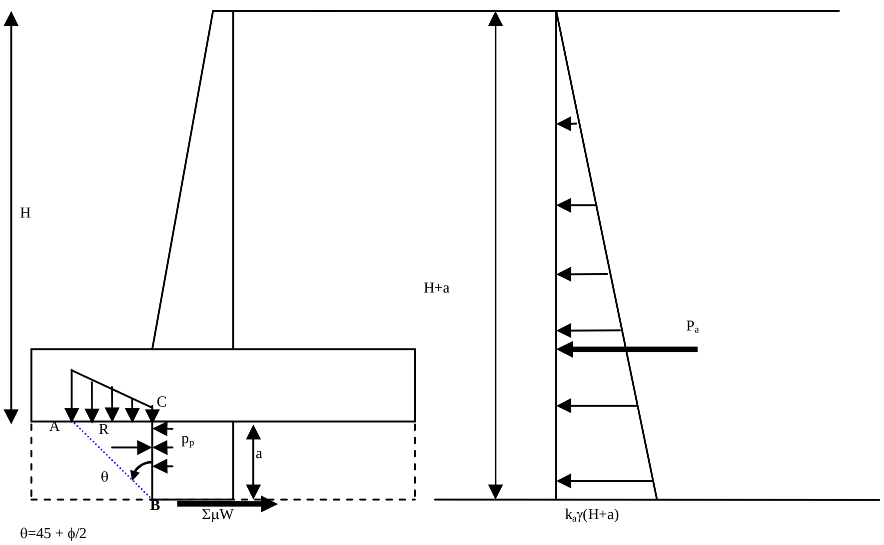
= $\mu\sum W/P_a \geq 1.55$ (=1.4/0.9)

As per IS:456:2000

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

**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 $p_p$= Unit passive pressure on soil above shearing plane AB

If

$\sum W$= Total vertical force acting at the key base

$\phi$= shearing angle of passive resistance

R= Total passive force = $p_p$ x a

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

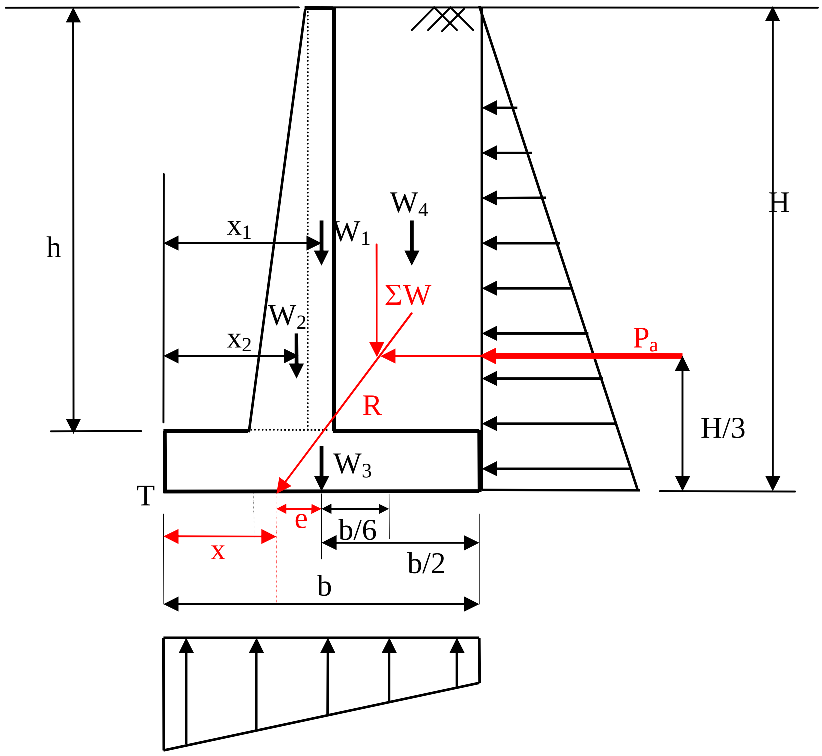
$\mu\sum W$=Total frictional force under flat base

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

Maximum pressure at the toe

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

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

This should not be less than zero to avoid tension at the base. From this e=b/6, 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.

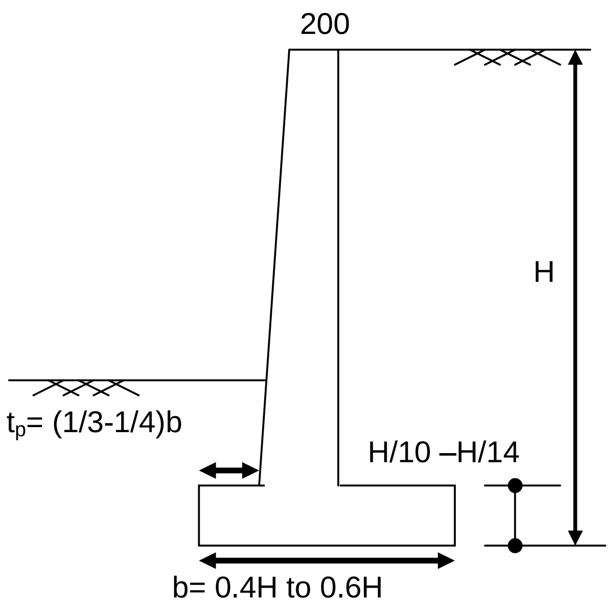
**Depth of foundation**

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

Stem: Top width 200 mm to 400 mm
Base slab width b= 0.4H to 0.6H, and 0.6H to 0.75H for surcharged wall
Base slab thickness= H/10 to H/14
Toe projection= (1/3-1/4) Base width




**Behaviour 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.

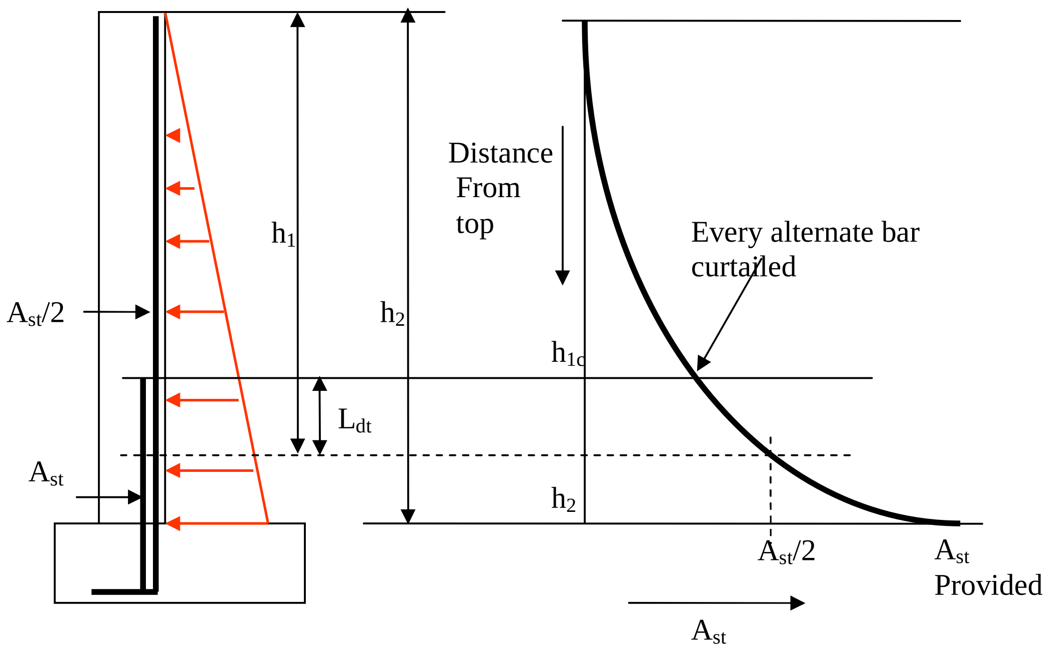
Stem design: $M_u$=partial safety factor x ($k_a \gamma H^3/6$)
Determine the depth d from $M_u = M_{u,\,lim} = Qbd^2$
Determine the steel based on balanced or under reinforced design. Provide enough development length at the junction for all bars.

**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 50% or 67% of the base steel.

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

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




Distribution steel: 0.12% Gross area for HYSD bars, 0.15% 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 18kN/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 degrees. Use M20 concrete and Fe415 steel.

### Solution

Data: $h' = 4$m, SBC= 200 kN/m$^2$, $\gamma$= 18 kN/m$^3$, $\mu$=0.6, $\varphi$=30°

To fix the height of retaining wall, H
$H = h' + D_f$

Depth of foundation

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

1.23m say 1.2m , therefore H= 5.2m

Proportioning of wall
Thickness of base slab= (1/10 to 1/14) H, 0.52m to 0.43m, say 450 mm
Width of base slab=b = (0.5 to 0.6) H, 2.6m to 3.12m say 3m
Toe projection= pj= (1/3 to ¼)H, 1m to 0.75m say 0.75m
Provide 450 mm thickness for the stem at the base and 200 mm at the top

**Design of stem**

**To find Maximum bending moment at the junction**

$P_h$= ½ x 1/3 x 18 x $4.75^2$=67.68 kN
M= $P_h$ h/3 = 0.333 x 18 x $4.75^3$/6 = 107.1 kN-m
$M_u$= 1.5 x M = 160.6 kN-m

Taking 1m length of wall,
$M_u/bd^2$= 1.004 < 2.76, URS (Here d=450- effective cover=450-50=400 mm)

**To find steel**
$P_t$=0.295% <0.96%
$A_{st}$= 0.295x1000x400/100 = 1180 $mm^2$
#12 @ 90 < 300 mm and 3d ok
$A_{st}$ provided= 1266$mm^2$

**Development length**
$L_d$=47 $\varphi_{bar}$ =47 x 12 = 564 mm

**Curtailment of bars**
Curtail 50% steel from top
$(h_1/h)^2 = ½$

$(h_1/4.75)^2 = ½$, $h_1$ = 3.36m
Actual point of cutoff= 3.36-$L_d$ =3.36-47 $\varphi_{bar}$ = 3.36-0.564 = 2.74m from top.

Spacing of bars = 180 mm c/c < 300 mm and 3d ok

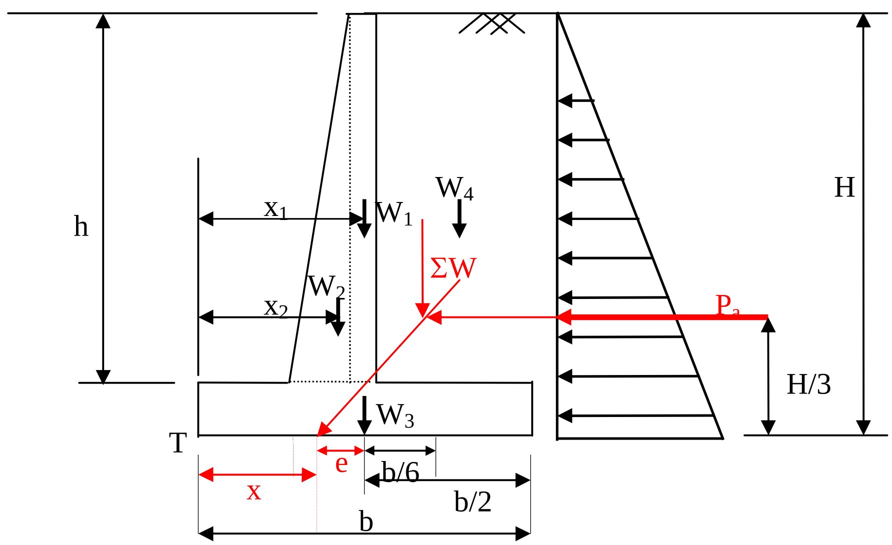
**Distribution steel**
= 0.12% GA = 0.12x450 x 1000/100 = 540 $mm^2$
#10 @ 140 < 450 mm and 5d ok

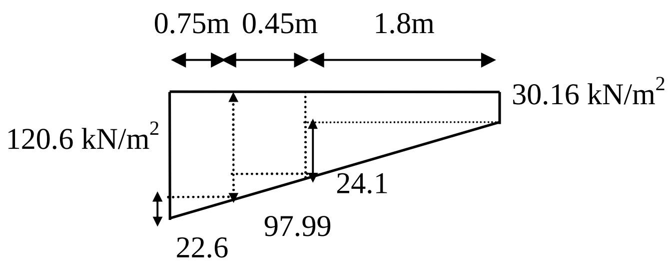
**Secondary steel for stem at front (Temperature steel)**
0.12% GA = 0.12x450 x 1000/100 = 540 $mm^2$
#10 @ 140 < 450 mm and 5d ok

**Check for shear**

Max. SF at Junction = $P_h$=67.68 kN
Ultimate SF= $V_u$=1.5 x 67.68 = 101.52 kN
Nominal shear stress =$\tau_v$=$V_u$/bd = 101.52 x 1000 / 1000x400 = 0.25 MPa
To find $\tau_c$ : 100$A_{st}$/bd = 0.32%, From IS:456-2000, $\tau_c$= 0.38 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 | 0.2x4.75x1x25 = 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** | | **$\Sigma M_R$=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 = $\Sigma M_R / M_O$= 2.94 >1.55 safe

Check for Sliding:
FOS = $\mu\ \Sigma W / P_H$= 2.94 >1.55 safe

Check for subsidence:
Let the resultant cut the base at x from toe T,
x= ΣM/ ΣW= 1.20 m > b/3
e= b/2 –x = 3/2 – 1.2 = 0.3m < b/6

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** | **$\Sigma M_C$=94.86** |

$M_u$= 1.5 x 94.86 =142.3 kNm
$M_u/bd^2$= 0.89 < 2.76, URS
$P_t$=0.264% < 0.96%
$A_{st}$= 0.264x1000x400/100 = 1056 mm$^2$
#16@ 190 < 300 mm and 3d ok
$A_{st}$ provided= 1058mm$^2$

**Development length**
$L_d$=47 $\varphi_{bar}$ =47 x 16 = 752mm

**Distribution steel**

Same, #10 @ 140 < 450 mm and 5d ok

**Check for shear at junction (Tension)**

Net downward force causing shear = 142.3kN. Critical section for shear is at the face as it is subjected to tension.

Maximum shear =V=105.17 kN, $V_U$, max= 157.76 kN, $\tau_v$ =0.39 MPa

$p_t$=100x1058/(1000x400)=0.27%

$\tau_{uc}$ =0.37 MPa

Allowable shear force= 0.37x 1000 x 400 =148kN, slightly less than $V_U$, 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** |

$M_u$= 1.5 x 28.67 =43 kNm

$M_u/bd^2$= 0.27< 2.76, URS

$P_t$=0.085%  Very small, provide 0.12%GA

$A_{st}$= 540 $mm^2$

#10 @ 140 < 300 mm and 3d ok

**Development length:**

$L_d$=47 $\varphi_{bar}$ =47 x 10 = 470 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+110.04)/2 x 0.35 -0.45x0.35x25=75.45kN

V=75.46  kN, $V_U$,max=75.45x1.5=113.18 kN

$\tau_{v=}$113.17x1000/(1000x400)=0.28 MPa

$p_t$=0.25%

$\tau_{uc}$ =0.37 MPa

V,allowable = 0.37x 1000 x 400 =148 kN > $V_U$,max, ok

**Construction joint**

A key 200 mm wide x 50 mm deep with nominal steel

#10 @ 250, 600 mm length in two rows

**Drainage:**

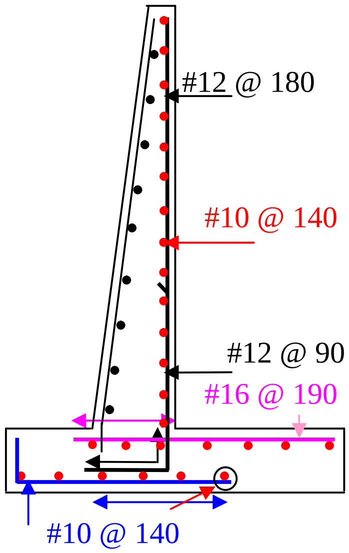
100 mm dia. pipes as weep holes at 3m c/c at bottom

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

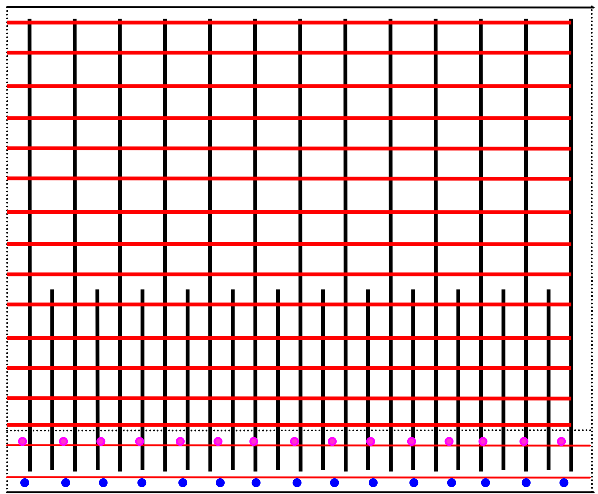
**Sketch**

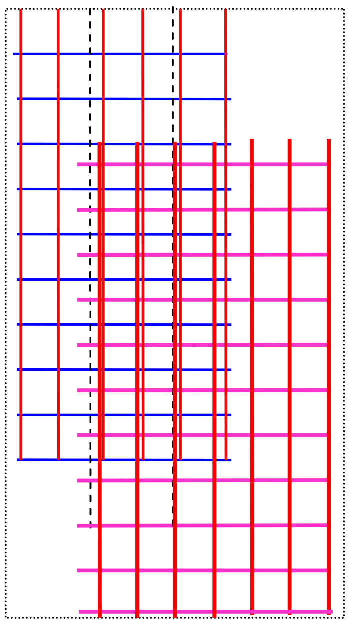
Following section will be asked in the examination.

1. Cross section of wall
2. Longitudinal section of wall for about 2m
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

END

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