Que 5.2. Determine the plan dimensions of a RCC footing for a column subjected to a characteristics load of 1000 kN and moment about the major axis $M_x = 180$ kN-m the size of the column is 300 mm × 750 mm. the safe bearing capacity of the soil is 200 kN/m².

AKTU 2017-18, Marks 10

Answer

Given : Characteristics load = 1000 kN. Moment, M_x = 180 kN-m.
Size of the column = 300 mm × 750 mm,
Safe bearing capacity = 200 kN/m².
To Find : Plan dimensions.

1. Ultimate load = 1.5 × 1000 = 1500 kN
   Approximate weight of footing
   $$= \frac{10}{100} \times 1500 = 150 \text{ kN}$$
   Total load = 1500 + 150 = 1650 kN
2. Moment = 180 kN-m = 180 × 10³ N-m
3. $$\text{Eccentricity, } e = \frac{180 \times 10^6}{1650 \times 10^3} = 0.0111 \text{ m} \approx 11 \text{ mm}$$
4. $$\text{Area of footing} = \frac{\text{Total load}}{\text{Safe bearing capacity}} = \frac{1650 \times 10^3}{200 \times 10^3} = 8.25 \text{ m}^2$$
5. Provide side of foundation = 3.5 m × 2.5 m
6. The footing will be provided so that the centre of gravity of column load will coincide with the centre of gravity of footing area. Footing is placed symmetrical with respect to X-X axis of column projection of the footing beyond the column face will be
   1750 − 11 − 375 = 1364 mm.
   and 1750 + 11 − 375 = 1386 mm respectively.

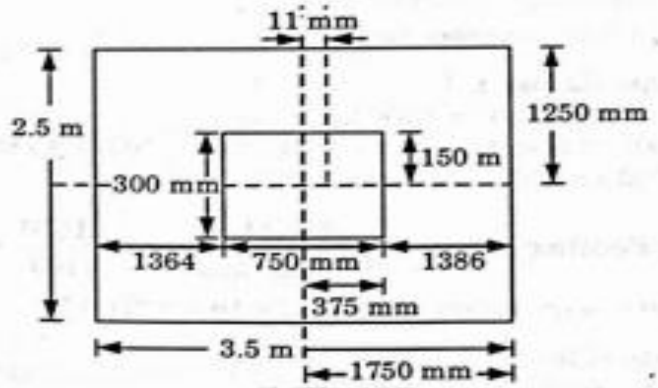

Fig. 5.2.1.

7. Net upward pressure intensity $= \frac{1500}{3.5 \times 2.5} = 171.43$ kN/m²

8. **Depth of Footing :**

i. BM at the critical section, $M_{ux} = 3.5 \times 1.386 \times 171.43 \times \frac{1.386}{2}$

$$M_{ux} = 576.3 \text{ kN-m}$$

ii. Equating $M_{u,lim}$ to M_{ux}

$$M_{u,lim} = 0.138 f_{ck} bd^2$$
$$576.3 \times 10^6 = 0.138 \times 20 \times 750 \times d^2$$
$$d = 527 \text{ mm}$$

iii. BM of section along $Y - Y$

$$M_{uy} = 171.43 \times 2.5 \times 1.1 \times (1.1/2) = 259.29 \text{ kN-m}$$

iv. Required depth, $d = \sqrt{\frac{259.29 \times 10^6}{0.138 \times 20 \times 300}} = 559.6$ mm

9. Provide effective depth of footing is 600 mm and 650 mm overall depth.

10. Provided plan dimension of footing 3.5 m × 2.5 m and depth 600 mm.

Que 5.3. **Design a square spread footing to carry an axial load of 1500 kN from a 400 mm square tied column containing 20 mm bars as the main reinforcement. The bearing capacity of soil is 100 kN/m². Consider base of footing at 1.2 m below the ground level. The unit weight of soil is 20 kN/m³. Use M20 grade concrete and Fe415 grade steel.**

AKTU 2013-14, Marks 10

Answer

Given : Axial load (W) = 1500 kN
Bearing capacity of soil = 100 kN/m²
Depth of base of footing = 1.0 m, Unit weight of soil (γ) = 20 kN/m³
$f_{ck} = 20$ N/mm², $f_y = 415$ N/mm²
To Find : Design square footing.

1. **Load Calculation :**

$$W_c = 1500 \text{ kN}$$

Self weight of footing = 10% × of W_c = (10 / 100) × 1500 = 150 kN
Total weight = 1500 + 150 = 1650 kN

2. **Area of Footing :** Area $= \frac{\text{Total load}}{\text{Bearing capacity}} = \frac{1650}{100} = 16.5$ m²

Weight of soil on footing = 20 × 1.2 × 16.5 = 396 kN

ii. Size of footing $= \sqrt{16.5} = 4.06$ m

Provide 4.5 m size of square footing.

3. Depth of Footing by One Way Shear Criterion :

i. Net upward pressure,

$$p = \frac{1500}{4.5^2} = 74.074 \text{ kN/m}^2$$

ii. Critical section is at distance '*d*' away from the face of the column

Shear force, $V_u = 1.5 \times 74.074 \times 4.5 \left[\left(\frac{4.5-0.4}{2}\right) - d\right]$

$= 500(2.05 - d)$ ...(5.3.1)

iii. Assuming 0.2% steel, $\tau_c = 0.32$ N/mm²

iv. Shear force resisted by the section $= \tau_c \times bd = 0.32 \times 10^3 \times 4.5 \times d$

$= 1440\,d$ ...(5.3.2)

v. Equating eq. (5.3.1) and eq. (5.3.2), we get

$500(2.05 - d) = 1440\,d$

$d = 0.529$ m ...(5.3.3)

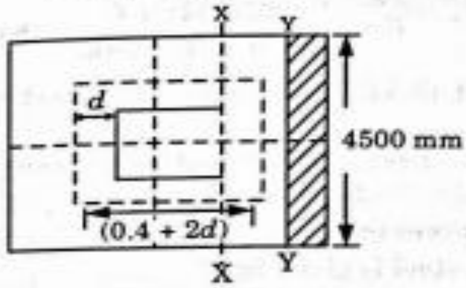

Fig. 5.3.1.

4. Depth of Footing by Two Way Shear Criterion :

i. Critical section is taken at a distance *d*/2 away from the face of column

ii. Perimeter of critical section $= 4(0.4 + d) = 1.6 + 4d$

iii. Shear force at critical section $= 1.5 \times 74.074\,(4.5^2 - (0.4 + d)^2)$

$= 111.11\,(20.25 - (0.4 + d)^2)$

$2250 = 111.11(0.4 + d)^2$ ...(5.3.4)

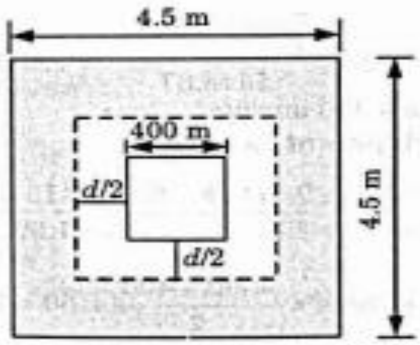

Fig. 5.3.2.

iv. Shear force resisted by the critical section maximum allowable shear

$$\text{stress} = 0.25\sqrt{f_{ck}} = 0.25\sqrt{20}$$
$$= 1.118 \text{ kN/mm}^2 = 1118 \text{ N/mm}^2$$

v. Shear force resisted $= 1118(1.6 + 4d)d = 1788.8 + 4472d$ ...(5.3.5)

vi. Equating the eq. (5.3.3) and eq. (5.3.5), we get

$$2250 - 111.11(0.4 + d)^2 = 1788.8\,d + 4472\,d^2$$
$$d = 0.522 \text{ m}$$ ...(5.3.6)

5. **Depth of Footing by Bending Moment Criterion :**

i. Bending moment about an axis X-X pass through the face of column as shown in Fig. 5.3.1.

ii. BM at critical section, M_u

$$= 1.5 \times 74.074 \times 4.5 \times \frac{(4.5 - 0.4)^2}{8} = 1050.62 \text{ kN-m}$$

iii. The effective depth required,

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

or $$d = \sqrt{\frac{1050.62 \times 10^6}{0.138 \times 20 \times 4500}} = 290.85 \text{ mm}$$ ...(5.3.7)

From eq. (5.3.3), (5.3.6) and (5.3.7) the highest value of d obtained is 0.529 m

iv. Provide 550 mm effective depth and 600 mm overall depth. Increased depth is taken due to shear considerations.

6. **Area of Reinforcement :**

i. Area of tension steel is given by,

$$M = 0.87\, f_y A_t \left(d - \frac{f_y A_t}{f_{ck} b}\right)$$

$$1050.62 \times 10^6 = 0.87 \times 415 \times A_t \left(550 - \frac{415 \times A_t}{20 \times 4500}\right)$$

$$A_{st} = 5548.87 \text{ mm}^2$$

ii. Use 16 mm ϕ bars,

Spacing, $$S = \frac{\frac{\pi}{4}(16)^2 \times 4500}{5548.87} = 163.06 \text{ mm}$$

Use 16 mm ϕ bars @ 160 mm c/c.

7. **Check for Development Length :**

$$L_d = \frac{0.87 f_y\, \phi}{4\tau_{bd}} = \frac{0.87 \times 415 \times 16}{4 \times 1.92} = 752.19 \text{ mm}$$

Available length of bars $= \frac{4500 - 400}{2} - 50 = 2000 \text{ mm} > 752.19 \text{ mm}$

then safe

8. **Reinforcement Details :**

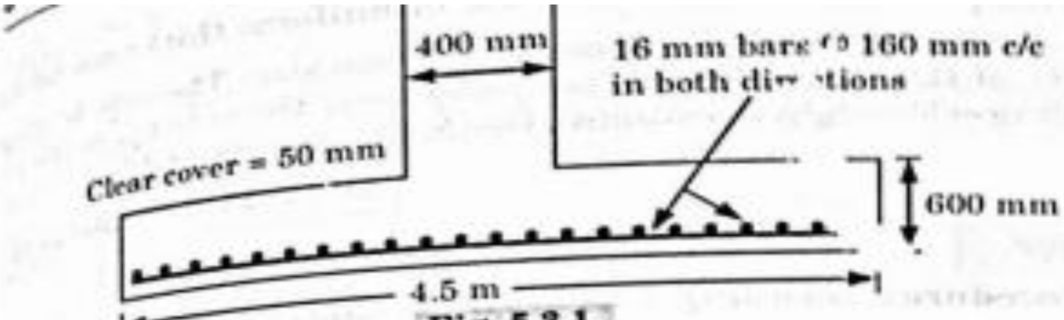

Fig. 5.3.1.

Que 5.4. A square column 450 mm × 450 mm supports an axial load 1600 kN. Design a square footing for the column. The safe bearing capacity of the soil in 250 kN/m². Use M25 concrete and Fe415 grade steel.

AKTU 2014-15, Marks 10

Answer

Procedure : Same as Q. 5.3, Page 5–5A, Unit-5.

1. Provide size of footing is 2.7 m × 2.7 m
2. Net soil pressure, $p = 329.22$ kN/m²
3. Bending moment, BM = 562.5 kN-m
4. **Required Depth of Footing :**
   i. By one way action, $d = 0.537$ m
   ii. By two way action, $d = 0.465$ m
   iii. By bending moment, $d = 0.24$ m

   Provide 560 mm effective depth and 610 mm overall depth.
5. **Reinforcement :**
   i. Required, $A_{st} = 2873$ mm²
   ii. Provide 12 mm ϕ bar @ 100 mm c/c (Actual provide 3054 mm²)
6. **Development Length :**
   i. Required, $L_d = 483.6$ mm
   ii. Provided development length = 1075 mm
7. **Detailed Reinforcement :**

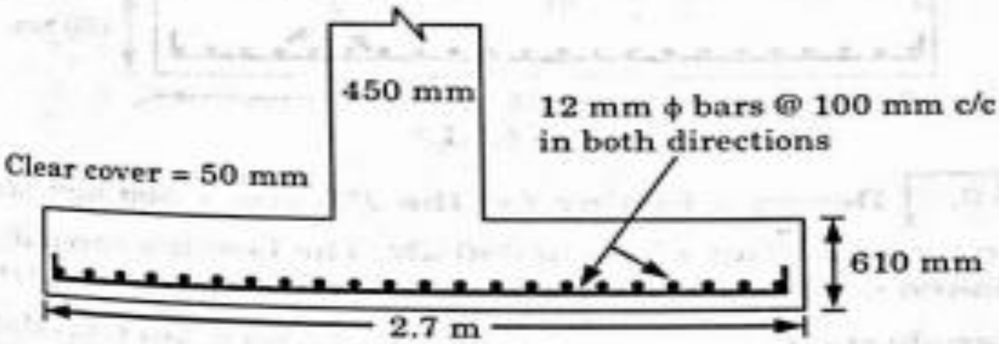

Fig. 5.4.1.

Que 5.6. **Design a footing for the 250 mm × 500 mm size RCC column transmitting a load of 300 kN. The bearing capacity of soil to be taken as 90 kN/m² at 1.0 m below GL. Use M20 concrete and Fe415 grade steel.** **AKTU 2014-15, Marks 10**

Given : Size of column = 250 mm × 500 mm.
Load, W_c = 300 kN, Bearing capacity, q_a = 90 kN/m²
To Find : Design a footing.

1. **Loads :**
   i. Column load, W_c = 300 kN
   ii. Weight of footings, W_f = 10% of W_c = 30 kN
   iii. Total load = 300 + 30 = 330 kN
2. **Area of Footing :**
   i. Area of footing, $A = \frac{W_c + W_f}{q_a} = \frac{330}{90} = 3.67\ m^2$
   ii. Considering length to width ratio of footing is same as that of column, *i.e.*, 2.
   iii.
   $$y = 2x$$
   $$\text{Area of footing} = x \times y = x \times 2x$$
   $$3.67 = 2x^2$$
   $$x = 1.35\ m \approx 1.36\ m$$
   $$y = 2.72\ m$$
3. Soil pressure due to column load only,
   $$p = \frac{300}{2.72 \times 1.36} = 81.09\ kN/m^2$$
4. Factored soil pressure = 1.5 × 81.09 = 121.65 kN/m²
5. **Calculation of Depth of Footing :**
   i. **By One Way Shear Criteria :**
      a. Critical section is at d from face to column.
      b. SF in longer direction $= 121.65 \times 2.72 \times \left(\frac{1.36 - 0.250}{2} - d\right)$
      $$= 183.64 - 330.88\ d$$
      c. Shear force in shorter direction
      $$= 121.65 \times 1.36 \times \left(\frac{2.72 - 0.500}{2} - d\right)$$
      $$= 183.64 - 165.44\ d \quad ...(5.6.1)$$
      d. Shear force resisted by the concrete
      $$= \tau_c\, xd$$
      (Assume 0.2 % steel, τ_c = 0.32 N/mm²)
      $$= \frac{0.32}{10^3} \times 10^6 \times 1.36\ d = 435.2\ d \quad ...(5.6.2)$$
      e. Now, equating the eq. (5.6.1) and (5.6.2), we get
      $$183.64 - 165.44d = 435.2\ d$$
      $$d = 0.306\ m \quad ...(5.6.3)$$

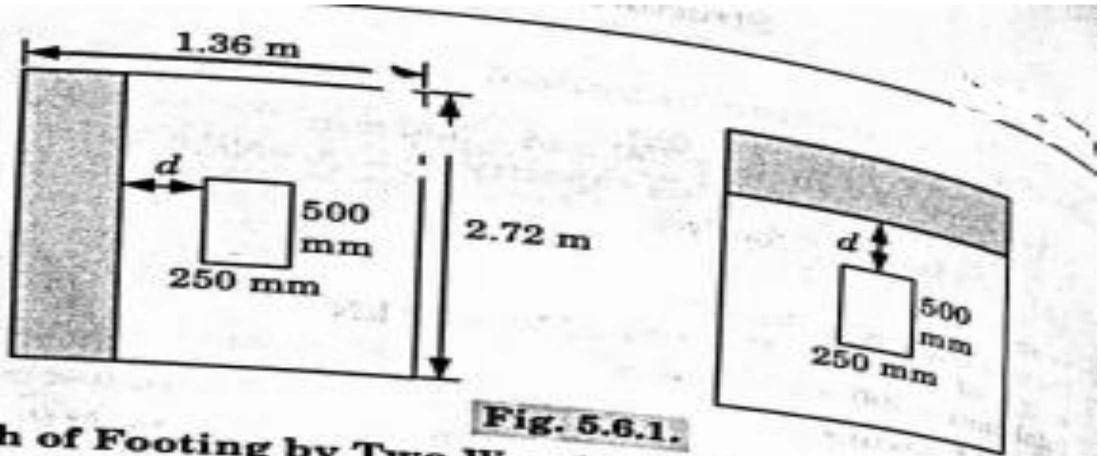

Fig. 5.6.1.

ii. Depth of Footing by Two Way Shear Criteria :

a. Critical section will occur at $d/2$ from face of column.

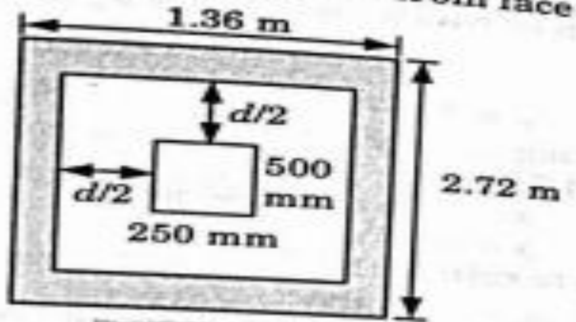

Fig. 5.6.2.

b. Shear force at critical section due to shaded area

$= 121.65 \times [2.72 \times 1.36 - (0.250 + d) \times (0.500 + d)]$

$= 450 - 121.65\,(0.125 + 0.75\,d + d^2)$

$= 434.80 - 91.23\,d - 121.65\,d^2$ ...(5.6.4)

c. Punching shear resisted by section $= \tau_c \times A$

where, $\tau_c = 0.25\sqrt{f_{ck}} = 0.25\sqrt{20} = 1.12\ \text{N/mm}^2$

$A = [(0.25 + d) + (0.500 + d)] \times d$

$= (0.75 + 2d) \times d = 0.75d + 2d^2$

d. Shear force resisted $= 1.12 \times \dfrac{10^6}{10^3} \times (0.75\,d + 2d^2)$

$= 840\,d + 2240\,d^2$ ...(5.6.5)

Equating both eq. (5.6.4) and eq. (5.6.5), we get

$434.80 - 91.23\,d - 121.65\,d^2 = 840\,d + 2240\,d^2$

$2361.65\,d^2 + 931.23\,d - 434.80 = 0$

$d = 0.275$ m ...(5.6.6)

iii. Depth of Footing by Bending Moment Criteria :

a. Critical section is at the face of the column.

b. Bending moment in longer direction

$= 121.65 \times 1.36 \times 1.11 \times 1.11 / 2 = 101.92$ kN-m

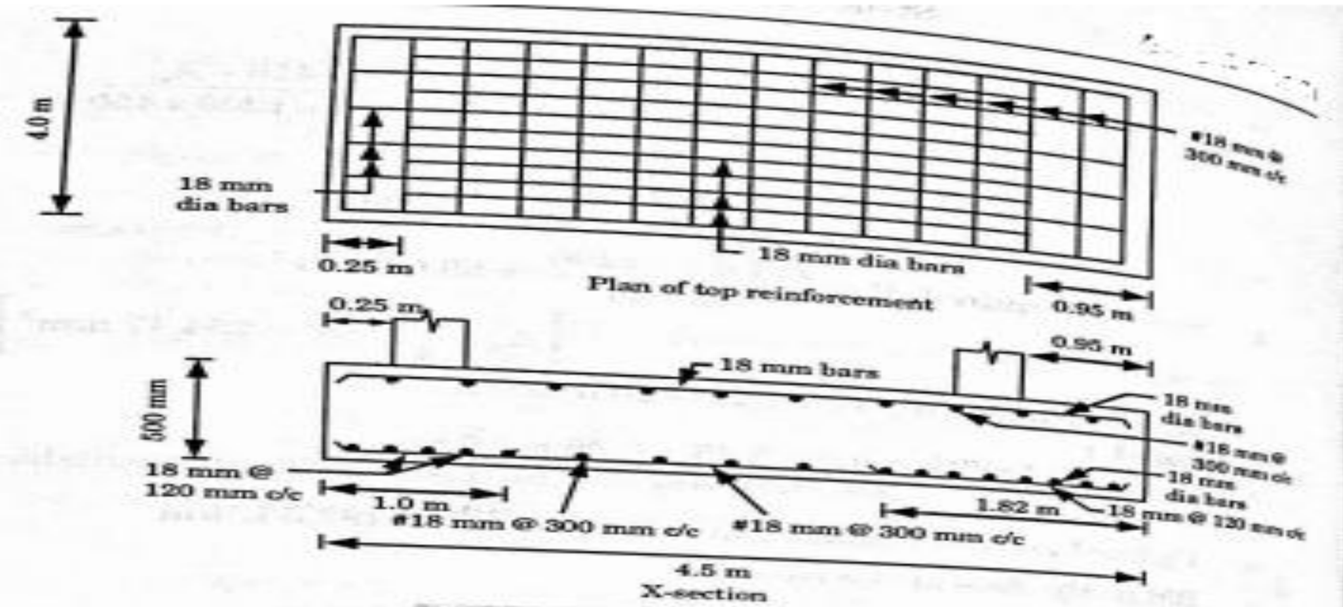

Fig. 5.10.3. Plan of reinforcement.

Desgin a cantilever retaining wall to retain earth embankment 4 m high above GL. The density of earth is 18 kN/m^3 and its angle of repose is 30°. The embankment is horizontal at its top. The safe bearing capacity of the soil may be taken as 200 kN/m^2 and the co-efficient of friction between the soil and concrete is 0.5. Adopt M20 grade of concrete and Fe 415 HYSD bars.

AKTU 2015-16, Marks 10

Answer

Given : Height of embankment = 4 m
Density of earth = 18 kN/m^3, Angle of repose = 30°
Bearing capacity of soil = 200 kN/m^2, Coefficient of friction = 0.5
To Find : Design of retaining wall.

1. Wall Proportions :

i. Thickness of the stem at the top = 200 mm

ii. Maximum bending moment per metre run of the wall,

$$M = k_p \frac{\gamma h^3}{6}$$

$$k_p = \frac{1-\sin\phi}{1+\sin\phi} = \frac{1-\sin 30^\circ}{1+\sin 30^\circ} = \frac{1}{3}$$

$$M = \frac{1}{3} \times 18 \times \frac{(4)^3}{6} = 64 \text{ kN-m}$$

iii. Equating the moments of resistance to the maximum bending moment,

$$0.138 f_{ck} bd^2 = 1.5 \times 64 \times 10^6$$

$$d = 186.5 \text{ mm}$$

Effective cover to reinforcement = 40 mm

iv. Total thickness of stem required = 190 + 40 = 230 mm

Provide a thickness of 350 mm at bottom of the stem.

v. The base slab thickness also will be 350 mm.

vi. Total height of wall, $H = 4 + 0.350 = 4.35$ m

vii. Width of base slab, $b = 0.5H$ to $0.6H = 2.175$ to 2.61 m

Provide a base width of 2.50 m.

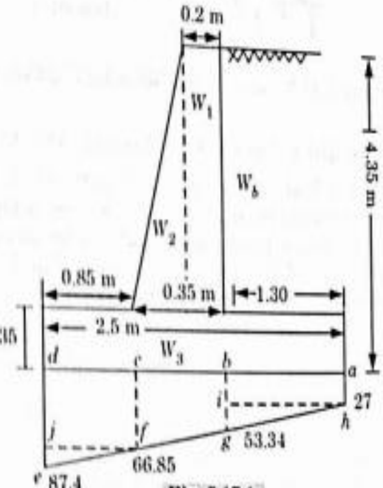

Fig. 5.17.1.

viii. **Toe Projection :** This may be made about one-third the base width.

$$\text{Toe width} = \frac{2.50}{3} = 0.83 \approx 0.85 \text{ m}$$

Structural Behavior of Footing & Retaining Wall

2. Stability Calculations for One Metre Length of Wall :

Load due to	Magnitude (kN)	Distance from a (m)	Moment about a (kN-m)
$W_1 = 0.20 \times 4 \times 25$	20	1.40	28
$W_2 = \frac{0.15 \times 4}{2} \times 25$	7.5	1.55	11.625
$W_3 = 2.5 \times 0.35 \times 25$	21.875	1.25	27.35
$W_b = 1.3 \times 4 \times 18$	93.6	0.65	60.84
Moment of lateral pressure $= k_p \frac{\gamma H^3}{6} = \frac{1}{3} \times 18 \times \frac{(4.35)^3}{6}$			82.32
Total	142.975		210.135

3. Distance from the point of application of the resultant force from the heel end a.

$$\bar{x} = \frac{\text{Bending moment}}{\text{total load}} = \frac{210.135}{142.975}$$

$$\bar{x} = 1.47 \text{ m}$$

4. Eccentricity,

$$e = \bar{x} - \frac{b}{2} = 1.47 - \frac{2.5}{2} = 0.22 \text{ m}$$

But $\frac{b}{6} = \frac{2.5}{6} = 0.41$ m

$\therefore$ $e < b/6$

5. Extreme pressure intensity at the base,

$$P = \frac{W}{b}\left(1 \pm \frac{6e}{b}\right) = \frac{142.975}{2.5}\left(1 \pm \frac{6 \times 0.22}{2.5}\right)$$

$$p_{max} = 87.4 \text{ kN/m}^2$$

$$p_{min} = 27 \text{ N/m}^2$$

Safe bearing capacity = 200 kN/m²

6. **Design of Stem :**

i. Maximum bending moment for the stem

Ultimate moment, $M_u = 1.5 \times 64 = 96$ kN-m

ii. Effective depth, $d = 350 - 40 = 310$ mm

iii. Area of steel,

$$= 50\left[\frac{1-\sqrt{1-\frac{4.6 M_u}{f_{ck} bd^2}}}{f_y / f_{ck}}\right]$$

$$= 50\left[\frac{1-\sqrt{1-\frac{4.6\times 96\times 10^6}{20\times 1000\times 310^2}}}{415/20}\right] = 0.295\ \%$$

$$A_{st} = \frac{0.295}{100}\times 1000\times 310 = 914.5\ mm^2$$

iv. Spacing for 16 mm diameter bars, $\left[A_s = \frac{3.14}{4}\times 16^2 = 201\ mm^2\right]$

Spacing, $S = \frac{201\times 1000}{914.5} = 219.8\ mm \approx 200\ mm\ c/c$

Provide 16 mm ϕ @ 200 mm c/c distance.

v. Distribution steel, $A_{st} = \frac{0.12}{100}\times 350\times 1000 = 420\ mm^2$

vi. Spacing for 8 mm diameter bars,

Spacing, $S = \frac{50\times 1000}{420} = 119.05\ mm \approx 110\ mm\ c/c$

If the distribution steel is provided near both faces, then the spacing will be @ 220 mm c/c near each face.

7. Design of Toe Slab :

i. The bending moment for 1 meter wide strip of the toe slab can be calculate as :

Load due to	Magnitude (kN)	Distance from c (m)	Moment about c (kN-m)
Upward pressure [*cdjf*] 66.85 × 1 × 0.85	56.82	0.425	24.15
$ejf = \frac{1}{2}\times 0.85\times 20.53$	8.73	0.57	4.98
Total			29.13
Deduct for self weight of the toe slab 0.85 × 0.35 × 25	7.44	0.425	3.16
Bending moment for toe slab			25.97

For base slab effective cover = 60 mm

i. Maximum bending moment for a 1 meter wide strip of the toe slab.

$M = 25.97$ kN-m

ii. Area of steel, $A_{st} = \frac{M_u}{bd^2} = \frac{1.5\times 25.97\times 10^6}{1000\times 290^2} = 0.4632$

$$p_t = 50\left[\frac{1-\sqrt{\frac{1-4.6\times 0.4632}{20}}}{415/20}\right] = 0.132\ \%$$

Minimum % of steel when Fe 415 is used = 0.2 %

$$A_{st} = \frac{0.2}{100}\times 1000\times 290 = 580\ mm^2$$

v. Spacing of 12 mm ϕ bars, $S = \frac{113\times 1000}{580} = 195$ mm c/c

Provide 12 mm ϕ bars @ 190 mm c/c

8. Design of the Heel Slab :

i. The BM calculations for 1 meter wide strip of the heel slab are given in the table :

Load due to	Magnitude (kN)	Distance from b (m)	Moment about b (kN-m)
Weight of the backing 1.3 × 4 × 18	93.6	0.65	60.84
Weight of the heel slab 1.30 × 0.35 × 25	11.375	0.65	7.4
			68.24
Deduct for upward pressure *abih*, 27 × 1.30 × 1	35.1	0.65	22.815
$igh = \frac{1}{2}\times 1.30\times 31.4$	20.4	0.433	8.84
			31.655
BM for heal slab			36.585

i. Maximum bending moment,

$M = 36.585$ kN-m

ii. Steel required, $A_{st} = \frac{M_u}{bd^2} = \frac{1.5\times 36.58\times 10^6}{1000\times 290^2} = 0.6525\ mm^2$

$$p_t = 50\left[\frac{1-(46\times 6525/20)}{415/20}\right] = 0.108\ \%$$

Minimum % of steel = 0.2 %

$$A_{st} = \frac{0.2}{100} \times 1000 \times 290 = 580 \text{ mm}^2$$

iv. Spacing of 12 mm diameter bars, $\left[A_\phi = \frac{3.14}{4} \times 12^2 = 113 \text{ mm}^2\right]$

Spacing, $S = \frac{113 \times 1000}{580} = 195$ mm c/c

Provide 12 mm ϕ bars @ 190 mm c/c

9. Check for Sliding :

i. Total horizontal soil pressure force per meter run of the wall,

$$P_h = k_p \frac{\gamma H^2}{2} = \frac{1}{3} \times 18 \times \frac{(4.35)^2}{2} = 56.77 \text{ kN}$$

ii. Limiting friction = $\mu W = 0.5 \times 142.975 = 71.49$ kN

iii. Factor of safety against sliding

$$= \frac{\mu W}{P_h} = \frac{71.49}{56.77} = 1.26 < 1.55$$

Hence, we have to provide a shear key to increase the resistance against sliding.

10. Check for Overturning :

$$F = \frac{\Sigma M_R}{M_0} = \frac{210.635}{82.82} = 2.54 > 1.55$$

Hence Safe.

11. Design a Shear Key :

i. Safe horizontal pressure force = $1.55\, P_h = 1.55 \times 56.77 = 88$ kN

ii. Maximum available force = 71.49 kN

iii. Unbalance horizontal force = $88 - 71.49 = 16.51$ kN

iv. Safe horizontal soil reaction = 0.7 × Safe bearing capacity = $0.7 \times 200 = 140$ kN/m²

v. Let the height of the key be y

$$140 \times 1000 \times y = 16.51 \times 10^3$$

$$y = 0.118 \text{ m}$$

vi. Minimum height of key = 300 mm

vii. Maximum BM = $16.15 \times \frac{0.3}{2} = 2.48$ kN-m

viii. Ultimate BM = $1.5 \times 2.48 = 3.72$ kN-m

$$0.138 f_{ck}\, bd^2 = 3.72 \times 10^6$$

$$d = 36.71 \text{ mm}$$

ix. Minimum thickness of key = 200 mm

Provide 300 × 200 mm shear key.

Consider the Fig. 5.14.1 showing a cantilever retaining wall subjected to a lateral force P_{ah}.

1. **Stem :**

i. The vertical wall or stem acts like a cantilever subjected to a triangular loading as shown in Fig. 5.14.1 with maximum pressure developed at the base. The base of the stem is subjected to maximum bending moment ($M_B = k_a \gamma h^3/6$).

ii. The stem of the retaining wall deflects as shown in the Fig. 5.14.1, developing tension on the face *AB*, retaining the earth.

2. **Heel Slab :**

i. The heel slab is subjected to an upward soil pressure and a downward pressure due to the weight of the backfill supported on heel as shown in Fig. 5.14.1.

ii. The resultant pressure is calculated by subtracting these two and is downward as the pressure due to weight of backfill is more than the upward soil pressure. This causes tension on the top face *i.e.*, *BC*.

3. **Toe Slab :**

i. The toe slab is also subjected to an upward soil pressure and a downward pressure due to the weight of the front fill supported on toe slab as shown in Fig. 5.14.1.