Example (11.1):

Design an isolated footing to support an interior column 25 *cm* × 60 *cm* in cross section that carries a dead load of 60 *tons*, a live load of 40 *tons*, a dead load moment of 15 *t.m*, and a live load moment of 10 *t.m* (service loads and moments). Use $f'_c = 250\, kg/cm^2$, $f_y = 4200\, kg/cm^2$, $q_{all}\,(gross) = 2.0\, kg/cm^2$, $\gamma_{soil} = 1.7\, t/m^3$, and $D_f = 2.0\, m$.

Note that there is no restriction on foundation projections on any side of the footing.

Solution:

1- Select a trial footing depth:

Assume that the footing is 50 *cm* thick.

2- Establish the required base area of the footing:

$$q_{all}\,(net) = 20 - 1.5\,(1.7) - 0.5\,(2.5) = 16.2\, t\,/\,m^2$$

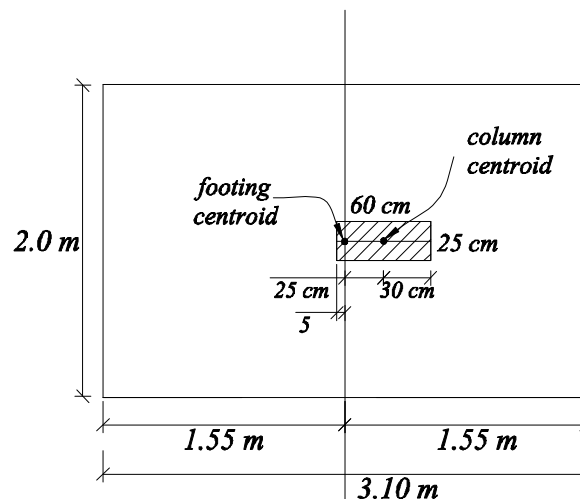Eccentricity $e = \dfrac{M}{P} = \dfrac{15+10}{60+40} = 0.25\, m$

Figure 11.10.a

Approximate footing area is given as:

$$A_{req} = \frac{P}{q_{all}\,(net)} = \frac{60+40}{16.2} = 6.17\, m^2$$

Try 3.10 *m* × 2.0 *m* × 0.5 *m* footing

In order to have uniform soil pressure under the footing, the footing is to be positioned in such a way to balance the given moment through shifting the centroid of the footing 0.25 *m* away from the centroid of the column as shown in Figures 11.10.a and 11.10.b.

3- Evaluate the net factored soil pressure:

$$P_u = 1.20(60) + 1.60(40) = 136 \ tons$$

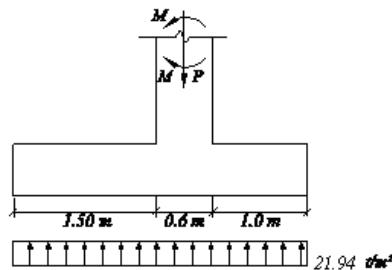$$q_u(net) = \frac{P_u}{LB} = \frac{136}{(3.1)(2.0)} = 21.94 \ t/m^2 \ , \text{ as shown in Figure 11.10.b.}$$

Figure 11.10.b

4- Check footing thickness for punching shear:

Average effective depth $d = 50 - 7.5 - 1.6 = 40.9 \ cm$

The factored shear force

$$V_u = (21.94)[(3.1)(2.0) - 1.009(0.659)] = 121.44 \ tons$$

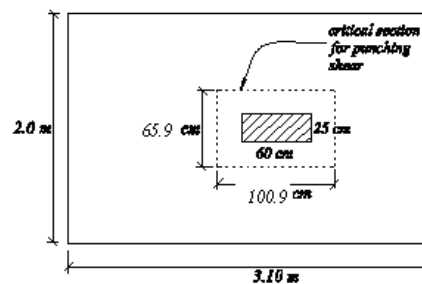$$b_0 = 2(60 + 25 + 40.9 + 40.9) = 333.6 \ cm$$

ΦV_c is the smallest of:

Figure 11.10.c: Critical section for punching shear

$$F\,V_c = 0.53\,F\,\sqrt{f'_c}\left(1+\frac{2}{b}\right)l\,b_0\,d$$

$$= 0.53\,(0.75)\sqrt{250}\left(1+\frac{2}{60/25}\right)(333.6)(40.9)/1000 = 157.22\ tons$$

$$F\,V_c = 1\,F\,\sqrt{f'_c}\,b_0\,d$$

$$= 0.75\,\sqrt{250}\,(333.6)(40.9)/1000 = 161.80\ tons$$

$$F\,V_c = 0.27\,F\left(\frac{a_s\,d}{b_0}+2\right)l\,\sqrt{f'_c}\,b_0\,d$$

$$= 0.27\,(0.75)\left(\frac{40\,(40.9)}{333.6}+2\right)\sqrt{250}\,(333.6)(40.9)/1000 = 301.61\ tons$$

$$F\,V_c = 157.22\ tons \quad > 121.44\ tons$$

i.e. footing thickness is adequate for resisting punching shear.

5- Check footing thickness for beam shear in each direction:

a- In the short direction:

The critical section for beam shear is given in Figure 11.10.d.

$$F\,V_c = 0.75\,(0.53)\sqrt{250}\,(200)(40.9)/1000 = 51.41\ tons$$

Maximum factored shear force V_u is located at distance d from faces of column,

$$V_u = (21.94)(2.0)(1.091) = 47.87\ tons < 51.41\ tons$$

b- In the long direction:

The critical section for beam shear is given in Figure 11.10.e.

$$F\,V_c = 0.75\,(0.53)\sqrt{250}\,(310)(40.9)/1000 = 79.69\ tons$$

Maximum factored shear force V_u is located at distance d from faces of column,

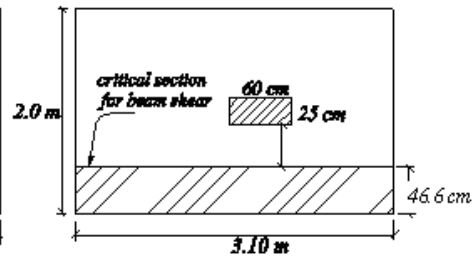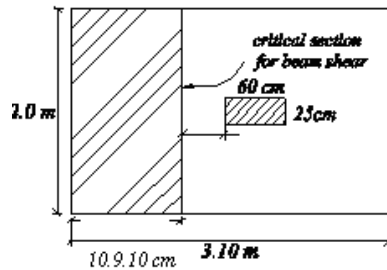$$V_u = (21.94)(3.1)(0.466) = 31.69\ tons < 79.69\ tons$$

Figure 11.10.d: Critical section for beam shear (short direction)   **Figure 11.10.e: Critical section for beam shear (long direction)**

6- Compute the area of flexural reinforcement in each direction:

a- Reinforcement in long direction:

$$M_u = (21.94)(2.0)\frac{(1.5)^2}{2} = 49.37 \ t.m$$

$$r = \frac{0.85(250)}{4200}\left[1 - \sqrt{1 - \frac{2.353(10)^5(49.37)}{(0.90)(200)(40.9)^2(250)}}\right] = 0.004067$$

$A_s = 0.004067\,(200)(40.9) = 33.27\,cm^2$, use *14 f 18 mm* in the long direction.

b- Reinforcement in short direction:

$$M_u = (24.52)(3.1)\frac{(0.875)^2}{2} = 26.04 \ t.m$$

$$r = \frac{0.85(250)}{4200}\left[1 - \sqrt{1 - \frac{2.353(10)^5(26.04)}{(0.90)(310)(40.9)^2(250)}}\right] = 0.001346$$

$A_s = 0.0018(310)(50) = 27.9\,cm^2$

central band reinforcement $= \left(\dfrac{2}{1+b}\right)A_s$

$$= \left(\frac{2}{1+310/200}\right)(27.9) = 21.88\,cm^2$$

Use *15 f 14 mm* in the central band

For the side bands, $A_s = (27.9 - 21.88) = 6.02\,cm^2$

Use $2\,f\,14\,mm$ in the right side band, and $3\,f\,14\,mm$ in the left side band.

7- Check for bearing strength of column and footing concrete:

For column,

$F\,P_n = 0.65(0.85)(250)(25)(60)/1000 = 207.18\ tons \quad > 136\ tons$

i.e. use minimum dowel reinforcement, $A_s = 0.005(25)(60) = 7.5\ cm^2$

The column is to be designed for axial force plus bending moment.

8- Check for anchorage of the reinforcement:

a. *Reinforcement in long direction* ($f\,18\,mm$):

$y_t = y_e = 1 = 1$ *and* $y_s = 0.8$

c_b is the smaller of:

$7.5 + 0.9 = 8.4\ cm$, or $\dfrac{200 - 15 - 1.8}{14(2)} = 6.54\ cm$, i.e., $c_b = 6.54\ cm$

$\dfrac{c_b + K_{tr}}{d_b} = \dfrac{6.54 + 0}{1.8} = 3.63 > 2.5$, *take it equal to* 2.5

$l_d = \dfrac{0.8(1.8)(4200)}{3.5\,(2.5)\sqrt{250}} = 43.71\ cm$

Available length = $100.0 - 7.5 = 92.5\ cm > 43.71\ cm$

b. *Reinforcement in short direction* ($f\,14\,mm$):

$y_t = y_e = 1 = 1$ *and* $y_s = 0.8$

c_b is the smaller of:

$7.5 + 0.7 = 8.2\ cm$, or $\dfrac{200 - 15 - 1.4}{14(2)} = 6.56\ cm$, i.e., $c_b = 6.56\ cm$

$\dfrac{c_b + K_{tr}}{d_b} = \dfrac{6.56 + 0}{1.4} = 4.69 > 2.5$, *take it equal to* 2.5

$l_d = \dfrac{0.8(1.4)(4200)}{3.5\,(2.5)\sqrt{250}} = 34.0\ cm$

Available length = $87.5 - 7.5 = 80.0\ cm > 34.0\ cm$

9- Prepare neat design drawings, showing footing dimensions and provided reinforcement:
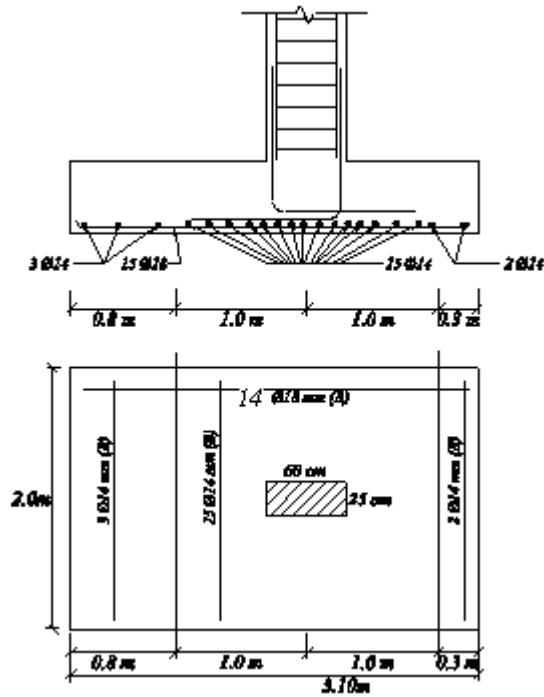
Design drawings are shown in Figure 11.10.f.

Figure 11.10.f: Design drawings

Example (11.2):

Design an isolated edge footing to support an edge column 70 *cm* × 25 *cm* in cross section and carries a dead load of 25 *tons* and a live load of 20 *tons*.

Use $f_c' = 250 \, kg / cm^2$, $f_y = 4200 \, kg / cm^2$, $q_{all} \, (gross) = 2.5 \, kg / cm^2$, $g_{soil} = 1.7 \, t / m^3$,   and
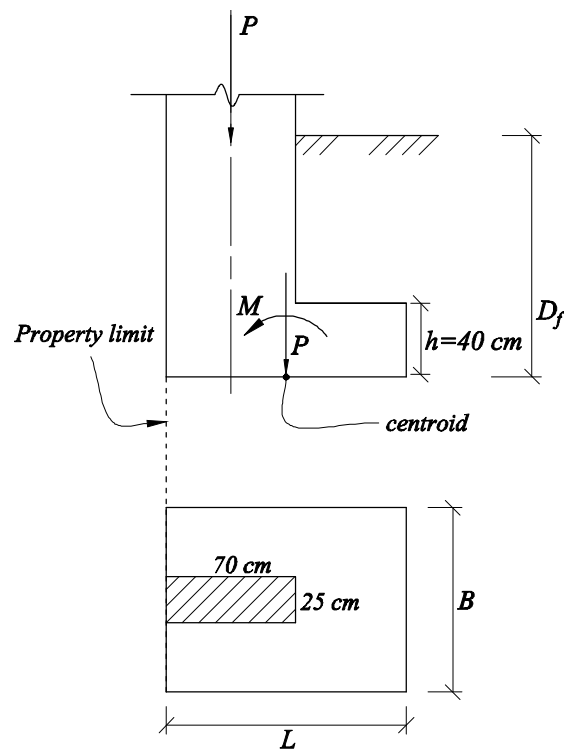
$D_f = 1.5 \, m$.

Figure 11.11.a: Footing dimensions

Solution:

1- Select a trial footing depth:

Assume that the footing is 40 *cm* thick, shown in Figure 11.11.a.

2- Establish the required base area of the footing:

$q_{all} \, (net) = 25 - 1.1(1.7) - 0.4(2.5) = 22.13 \, t/m^2$

Try 1.3 *m* × 3.0 *m* × 0.4 *m* footing

$$q_{all} \, (net) = \frac{25 + 20}{1.3(3)} \pm \frac{6(25 + 20)(0.3)}{3(1.3)^2}$$

$q_{max} = 11.54 + 15.97 = 27.51 \ t/m^2 \quad > 22.13 \ t/m^2$ (compressive)

$q_{min} = 11.54 - 15.97 = -4.43 \ t/m^2$ (tensile), as shown in Figure 11.11.b.

Try $1.0 \ m \times 4.0 \ m \times 0.4 \ m$ footing

$$q_{all} \ (net) = \frac{25 + 20}{1.0(4)} \pm \frac{6(25 + 20)(0.15)}{4(1.0)^2}$$

$q_{max} = 11.25 + 10.125 = 21.375 \ t / m^2 \quad < 22.13 \ t / m^2$ (compressive)

$q_{min} = 11.25 - 10.125 = 1.125 \ t / m^2$ (compressive), as shown in Figure 11.11.c.

Use $1.0 \ m \times 4.0 \ m \times 0.4 \ m$ footing
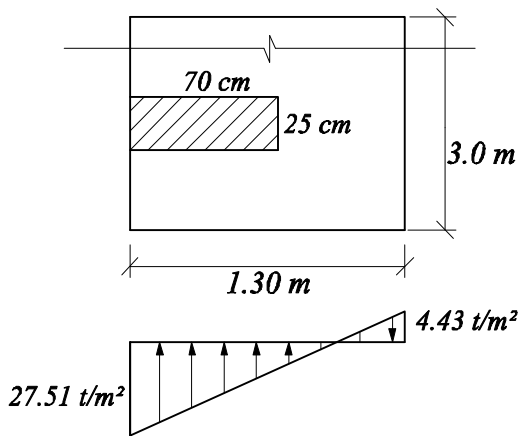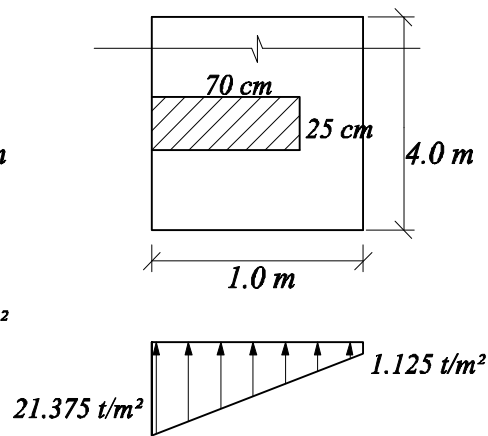

Figure 11.11.b: Net soil pressure   **Figure 11.11.c: Net soil pressure**

3- Evaluate the net factored soil pressure:

$P_u = 1.20(25) + 1.60(20) = 62 \ tons$

$$q_u \ (net) = \frac{62}{1.0(4)} \pm \frac{6(62)(0.15)}{4(1.0)^2}$$

$q_{u \ max} = 15.50 + 13.95 = 29.45 \ t/m^2$

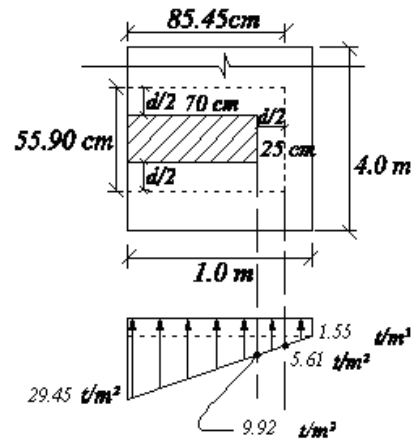$q_{u \ min} = 15.50 - 13.95 = 1.55 \ t/m^2$, shown in Figure 11.11.d.

Figure 11.11.d: Critical section for punching shear and factored soil pressure

4- Check footing thickness for punching shear:

Average effective depth $d = 40 - 7.5 - 1.6 = 30.9\ cm$

The factored shear force

$$V_u = 62 - \left(\frac{5.61 + 29.45}{2}\right)(0.8545)(0.559) = 53.72\ tons$$

$$b_0 = 2(85.45) + 25.0 + 30.9 = 226.8\ cm$$

ΦV_c is the smallest of:

$$F\ V_c = 0.53\ F\ \sqrt{f'_c}\left(1 + \frac{2}{b}\right)1\ b_0\ d$$

$$= 0.53\,(0.75)\,\sqrt{250}\left(1 + \frac{2}{70/25}\right)(226.8)(30.9)/1000 = 75.51\ tons$$

$$F\ V_c = 1\ F\sqrt{f'_c}\ b_0\ d$$

$$= 0.75\,\sqrt{250}\,(226.8)(30.9)/1000 = 83.11\ tons$$

$$F\ V_c = 0.27\ F\left(\frac{a_s\ d}{b_0} + 2\right)1\ \sqrt{f'_c}\ b_0\ d$$

$$= 0.27\,(0.75)\left(\frac{30\,(30.9)}{226.8} + 2\right)\sqrt{250}\,(226.8)(30.9)/1000 = 136.59\ tons$$

$$F\,V_c = 75.51\ tons\quad > 53.72\ tons$$

i.e. footing thickness is adequate for resisting punching shear.

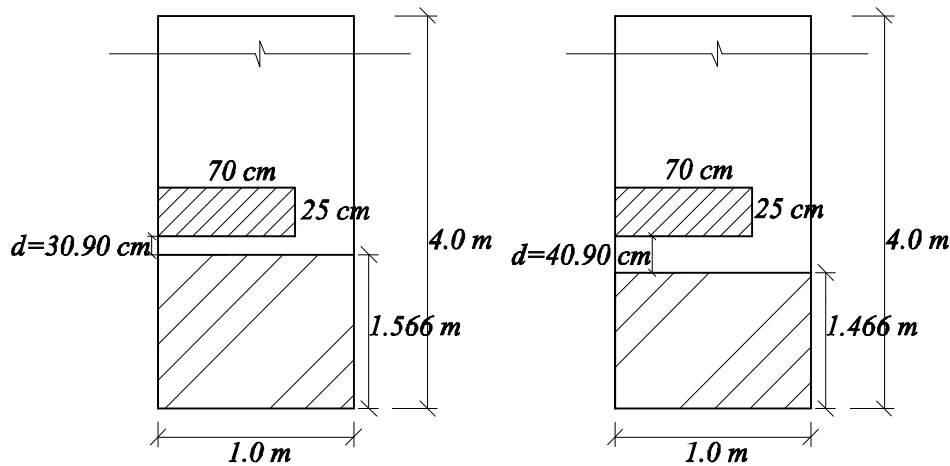## 5- Check footing thickness for beam shear in each direction:

Figure 11.11.e: Critical section for beam shear (short direction)   **Figure 11.11.f: Critical section for beam shear (short direction)**

a- In the short direction:

The critical section for beam shear is shown in Figure 11.11.e.

$$FV_c = 0.75(0.53)\sqrt{250}(100)(30.9)/1000 = 19.42 \text{ tons}$$

Maximum factored shear force V_u is located at distance d from faces of column. The factored shear force

$$V_u = \left(\frac{1.55 + 29.45}{2}\right)(1.0)(1.566) = 24.27 \text{ tons} \quad > 19.42 \text{ tons}$$

Increase footing thickness to 50 *cm* and check for beam shear. The critical section for beam shear is shown in Figure 11.11.f.

$$FV_c = 0.75(0.53)\sqrt{250}(100)(40.9)/1000 = 25.71 \text{ tons}$$

The factored shear force

$$V_u = \left(\frac{1.55 + 29.45}{2}\right)(1.0)(1.466) = 22.72 \text{ tons} \quad < 25.71 \text{ tons}$$

i.e. footing thickness is adequate for resisting shear.

6- Compute the area of flexural reinforcement in each direction:

a- Reinforcement in short direction:

$$M_u = 4\left[(1.55)(0.3)^2 / 2\right] + 4\left[\left(\frac{9.92 - 1.55}{2}\right)(0.3)(0.1)\right] = 0.78 \ t.m$$

$$A_s = 0.0018(400)(50) = 36.0 \ cm^2$$

Central band reinforcement $= \left(\dfrac{2}{1+b}\right)A_s$

$$= \left(\frac{2}{1+400/100}\right)(36) = 14.40 \ cm^2$$

Use $13\,f\,12\ mm$ in the central band

For the side bands, $A_s = (36 - 14.40) = 21.60 \ cm^2$

Use $10\,f\,12\ mm$ in each of the side bands

b- Reinforcement in long direction:

$$M_u = \left[\left(\frac{1.55 + 29.45}{2}\right)(1.0/2)(1.875)^2\right] = 27.25 \ t.m$$

$$r = \frac{0.85(250)}{4200}\left[1 - \sqrt{1 - \frac{2.353(10)^5(27.25)}{0.9\,(100)(40.9)^2(250)}}\right] = 0.0045107$$

$A_s = 0.0045107(100)(40.9) = 18.45\,cm^2$, use $10\,f\,16\ mm$ in the long direction

7- Check for bearing strength of column and footing concrete:

For column,

$$F\,P_n = 0.65(0.85)(250)(25)(70)/\,1000 = 241.72 \ tons \quad > 62 \ tons$$

i.e. use minimum dowel reinforcement, $A_s = 0.005(25)(70) = 8.75 \ cm^2$

8- Check for anchorage of the reinforcement:

a- Reinforcement in long direction ($f\,16\ mm$):

$y_t = y_e = 1 = 1$ and $y_s = 0.8$

c_b is the smaller of:

$7.5 + 0.8 = 8.3 \ cm$, or $\dfrac{100 - 15 - 1.6}{10(2)} = 4.17 \ cm$, i.e., $c_b = 4.17 \ cm$

$$\frac{c_b + K_{tr}}{d_b} = \frac{4.17 + 0}{1.6} = 2.61 > 2.5, \text{ take it equal to 2.5}$$

$$l_d = \frac{1.6(0.8)(4200)}{3.5(2.5)\sqrt{250}} = 38.86 \text{ cm}$$

Available length $= 187.5 - 7.5 = 180.0$ cm > 38.86 cm

  b- Reinforcement in short direction (∮ 12 mm):

$$y_t = y_e = 1 = 1 \text{ and } y_s = 0.8$$

c_b is the smaller of:

$$7.5 + 0.6 = 8.1 \, cm, \text{ or } \frac{400 - 15 - 1.2}{31 \, (2)} = 6.19 \, cm, \text{ i.e., } c_b = 6.19 \, cm$$

$$\frac{c_b + K_{tr}}{d_b} = \frac{6.19 + 0}{1.2} = 5.16 > 2.5, \text{ take it equal to 2.5}$$

$$l_d = \frac{1.2(0.8)(4200)}{3.5(2.5)\sqrt{250}} = 29.14 \text{ cm}$$

Available length $= 30.0 - 7.5 = 22.5$ cm < 29.14 cm

Hook all bars at their ends to provide additional anchorage length.

9- Prepare neat design drawings showing footing dimensions and provided reinforcement:

Design drawings are shown in Figure 11.11.g.

As seen in this example, the design leads to a footing that is long and narrow. Either combined or strap footing is a better solution for this eccentric case.
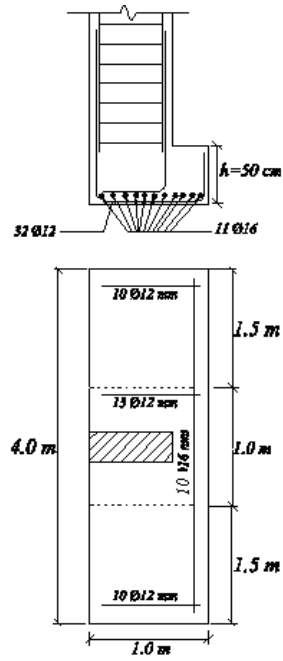
Figure 11.11.g: Design drawings

Design of Wall Footings

When a wall carries a uniformly distributed line load, wall sections along the length of the wall behave equally. Consequently, the design of the footing can be based on a strip 1-m wide along the length of the wall. Design of wall footings is summarized in the following steps.

1- Select a trial footing depth:

According to *ACI Code 15.7*, depth of footing above reinforcement is not to be less than 15 *cm* for footings on soil. **Establish the required base width of the footing:**

Width of footing is established by dividing the total service load by the allowable net soil pressure.

2- Evaluate the net factored soil pressure.

3- Check footing thickness for beam shear in the transverse direction:

The critical section for beam shear is located at distance *d* from the face of the wall.

4- Compute the area of flexural reinforcement:

If a footing carries a concrete wall, *ACI Code 15.4.2* specifies that the critical section for moment be taken at the face of the wall. Main reinforcement is provided in the short direction while shrinkage reinforcement is provided in the long direction of the footing.

5- Check for bearing strength of wall and footing concrete.

6- Check for anchorage of the reinforcement:

Both, flexural and dowel reinforcement lengths are checked for anchorage to prevent bond failure of the dowels in the footing and to prevent failure of the lap splice between the dowels and the wall reinforcing bars.

7- Prepare neat design drawings showing footing dimensions and provided reinforcement.

Example (11.3):

Design a footing to support a reinforced concrete wall 20 *cm* thick as shown in خطأ! لم يتم العثور على المرجع.a. The wall supports a service dead load of 10 *t/m* and a service live load of 7.5 *t/m* in addition to its own weight.

Use $f_c' = 300 \, kg/cm^2$, $f_y = 4200 \, kg/cm^2$, $q_{all} \, (gross) = 1.8 \, kg/cm^2$, $g_{soil} = 1.7 \, t/m^3$, and $D_f = 2.0 \, m$.
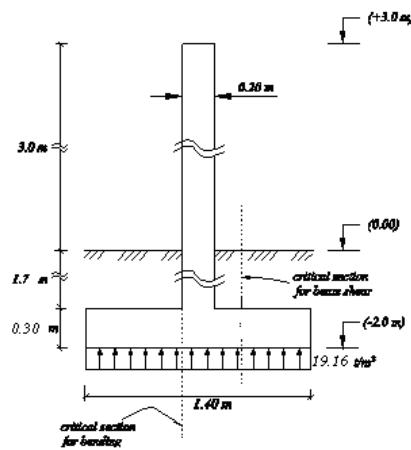

Figure 11.12.a: Footing dimensions

Solution:

1- Select a trial footing depth:

Assume that the footing is 30 *cm* thick.

2- Establish the required base width of the footing:

For a strip 1-*m* wide along the wall,

$q_{all} \, (net) = 18 - 1.7 \, (1.7) - 0.3 \, (2.5) = 14.36 \, t/m^2$

Total service load /m = 10 + 7.5 + 0.20 (1.7 + 3) (2.5) = 19.85 *tons*

$A_{req} = \dfrac{19.85}{14.36} = 1.38 \, m^2$

Use $B = 1.4 \, m$.

3- Evaluate the net factored soil pressure:

$q_u \, (net) = \dfrac{1.2(10) + 1.6(7.5) + 1.2(0.2)(4.7)(2.5)}{1.4(1.0)} = \dfrac{26.82}{1.4} = 19.16 \, t/m^2$

4- Check footing thickness for beam shear:

Effective depth $d = 30 - 7.5 - 0.70 = 21.8\ cm$

$F\,V_c = 0.75(0.53)\sqrt{300}\,(100)(21.8)/1000 = 15.0\ tons$

Maximum factored shear force V_u is located at distance d from the face of wall,

$V_u = (19.16)(1.0)\left[\left(\dfrac{1.4-0.2}{2}\right)-0.218\right] = 7.32\ tons < 15.0\ tons$

i.e. provided footing thickness is adequate for resisting beam shear.

5- Compute the area of flexural reinforcement:

a- Flexural reinforcement

$M_u = 19.16\dfrac{(0.6)^2}{2} = 3.45\ t.m$

$r = \dfrac{0.85(300)}{4200}\left[1-\sqrt{1-\dfrac{2.353(10)^5\,(3.45)}{0.9\,(100)\,(21.8)^2\,(300)}}\right] = 0.00195$

$A_s = 0.00195(100)21.8 = 4.25\ cm^2$

$A_{s,min} = 0.0018(100)30 = 5.40\ cm^2$

use $f\,12\ mm$ @ 205 cm

b- Shrinkage reinforcement:

$A_s = 0.0018(140)(25) = 6.30\ cm^2$, use $8f\,10\ mm$

6- Check for bearing strength of wall and footing concrete:

$F\,P_n = 0.65(0.85)(300)(20)(100)/1000 = 331.5\ tons\ > 26.82\ tons$

i.e, use minimum dowel reinforcement, $A_s = 0.005(20)(100) = 10.0\ cm^2$

7- Check for anchorage of the reinforcement:

a- Flexural reinforcement ($f\,12\ mm$):

$y_t = y_e = 1 = 1$ and $y_s = 0.8$

C is the smaller of:

$7.5 + 0.6 = 8.1\ cm$, or $\dfrac{15}{2} = 7.5\ cm$, i.e., $c_b = 7.5\ cm$

$$\frac{c_b + K_{tr}}{d_b} = \frac{7.5 + 0}{1.2} = 6.25 > 2.5, \textit{ take it equal to 2.5}$$

$$l_d = \frac{1.2(0.8)(4200)}{3.5(2.5)\sqrt{300}} = 26.60 \text{ cm}$$

Available development length = 60.0 – 7.5 = 52.5 *cm* > 26.60 cm   O.K

  b*- *Dowel reinforcement (f 10 mm):

To calculate required development length for f 10 *mm* bars,

$$l_d = \frac{0.075(1.0)(4200)}{\sqrt{300}} = 18.18 \text{ cm}, \textit{ or}$$

$$l_d \geq 0.0044(1.0)(4200) = 18.48 \text{ cm}, \textit{ or}$$

$$l_d \geq 20.0 \text{ cm}$$

Available length = 30 - 7.5 - 1.2 -1 = 20.30 *cm* > 20 *cm*   O.K

  c*- *Reinforcement splices:

To calculate splice length for f 10 *mm* bars,

$$l_{splice} \geq 0.0073(1.0)(4200) = 30.66 \text{ cm}$$

8- Prepare neat design drawings, showing footing dimensions and provided reinforcement:
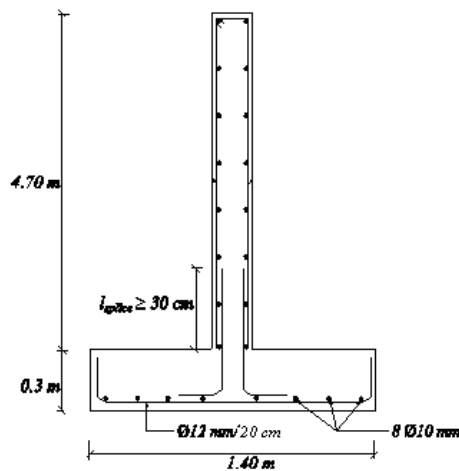
Design drawings are shown in Figure 11.12.b.

Figure 11.12.b: Design drawings

Example (11.1):

Design an isolated footing to support an interior column 25 *cm* × 60 *cm* in cross section that carries a dead load of 60 *tons*, a live load of 40 *tons*, a dead load moment of 15 *t.m*, and a live load moment of 10 *t.m* (service loads and moments). Use $f'_c = 250\,kg/cm^2$, $f_y = 4200\,kg/cm^2$, $q_{all}\,(gross) = 2.0\,kg/cm^2$, $\gamma_{soil} = 1.7\,t/m^3$, and $D_f = 2.0\,m$.

Note that there is no restriction on foundation projections on any side of the footing.

Solution:

1- Select a trial footing depth:

Assume that the footing is 50 *cm* thick.

2- Establish the required base area of the footing:

$$q_{all}\,(net) = 20 - 1.5\,(1.7) - 0.5\,(2.5) = 16.2\,t/m^2$$
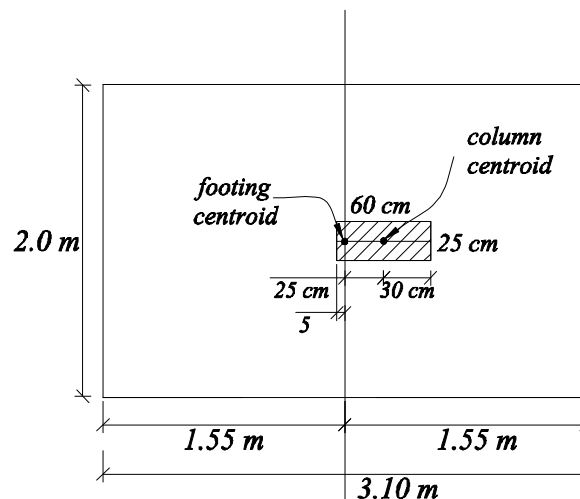
Eccentricity $e = \dfrac{M}{P} = \dfrac{15+10}{60+40} = 0.25\,m$

Figure 11.10.a

Approximate footing area is given as:

$$A_{req} = \frac{P}{q_{all}\,(net)} = \frac{60+40}{16.2} = 6.17\,m^2$$

Try 3.10 *m* × 2.0 *m* × 0.5 *m* footing

In order to have uniform soil pressure under the footing, the footing is to be positioned in such a way to balance the given moment through shifting the centroid of the footing 0.25 *m* away from the centroid of the column as shown in Figures 11.10.a and 11.10.b.

3- Evaluate the net factored soil pressure:

$$P_u = 1.20(60) + 1.60(40) = 136 \ tons$$

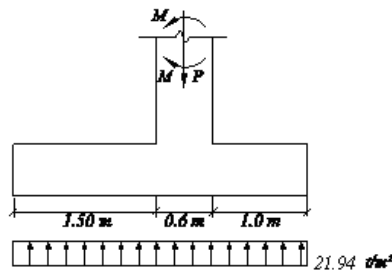$$q_u\,(net) = \frac{P_u}{LB} = \frac{136}{(3.1)(2.0)} = 21.94 \ t/m^2 \ , \text{ as shown in Figure 11.10.b.}$$

Figure 11.10.b

4- Check footing thickness for punching shear:

Average effective depth $d = 50 - 7.5 - 1.6 = 40.9 \ cm$

The factored shear force

$$V_u = (21.94)[(3.1)(2.0) - 1.009(0.659)] = 121.44 \ tons$$

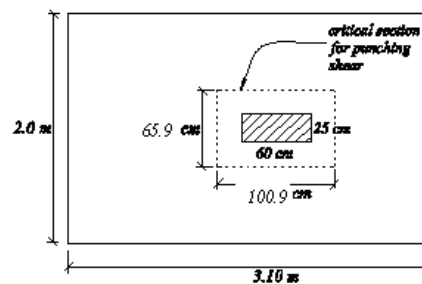$$b_0 = 2(60 + 25 + 40.9 + 40.9) = 333.6 \ cm$$

ΦV_c is the smallest of:

Figure 11.10.c: Critical section for punching shear

$$F\,V_c = 0.53\,F\,\sqrt{f'_c}\left(1+\frac{2}{b}\right)1\;b_0\;d$$

$$= 0.53\,(0.75)\sqrt{250}\left(1+\frac{2}{60/25}\right)(333.6)(40.9)/1000 = 157.22\;\;tons$$

$$F\,V_c = 1\,F\sqrt{f'_c}\;b_0\;d$$

$$= 0.75\sqrt{250}\,(333.6)(40.9)/1000 = 161.80\;tons$$

$$F\,V_c = 0.27\,F\left(\frac{a_s\,d}{b_0}+2\right)1\;\sqrt{f'_c}\;b_0\;d$$

$$= 0.27\,(0.75)\left(\frac{40\,(40.9)}{333.6}+2\right)\sqrt{250}\,(333.6)(40.9)/1000 = 301.61\;\;tons$$

$$F\,V_c = 157.22\;tons\quad > 121.44\;tons$$

i.e. footing thickness is adequate for resisting punching shear.

5- Check footing thickness for beam shear in each direction:

a- In the short direction:

The critical section for beam shear is given in Figure 11.10.d.

$$F\,V_c = 0.75\,(0.53)\sqrt{250}\,(200)(40.9)/1000 = 51.41\;tons$$

Maximum factored shear force V_u is located at distance d from faces of column,
$$V_u = (21.94)(2.0)(1.091) = 47.87\;tons < 51.41\;tons$$

b- In the long direction:

The critical section for beam shear is given in Figure 11.10.e.

$$F\,V_c = 0.75\,(0.53)\sqrt{250}\,(310)(40.9)/1000 = 79.69\;tons$$

Maximum factored shear force V_u is located at distance d from faces of column,
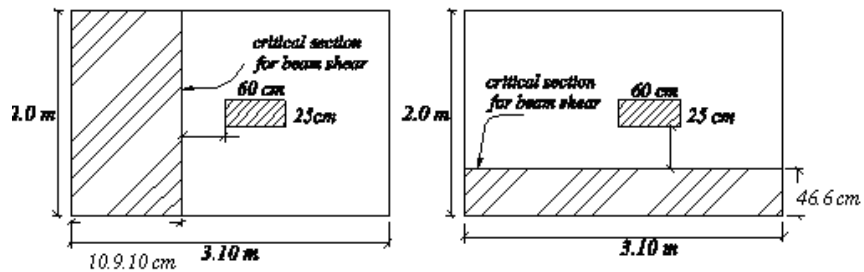$$V_u = (21.94)(3.1)(0.466) = 31.69\;tons < 79.69\;tons$$

Figure 11.10.d: Critical section for beam shear (short direction)   **Figure 11.10.e: Critical section for beam shear (long direction)**

6- Compute the area of flexural reinforcement in each direction:

  a- Reinforcement in long direction:

$$M_u = (21.94)(2.0)\frac{(1.5)^2}{2} = 49.37 \ t.m$$

$$r = \frac{0.85(250)}{4200}\left[1 - \sqrt{1 - \frac{2.353(10)^5(49.37)}{(0.90)(200)(40.9)^2(250)}}\right] = 0.004067$$

$A_s = 0.004067 \ (200)(40.9) = 33.27 \ cm^2$, use *14 f 18 mm* in the long direction.

  b- Reinforcement in short direction:

$$M_u = (24.52)(3.1)\frac{(0.875)^2}{2} = 26.04 \ t.m$$

$$r = \frac{0.85(250)}{4200}\left[1 - \sqrt{1 - \frac{2.353(10)^5(26.04)}{(0.90)(310)(40.9)^2(250)}}\right] = 0.001346$$

$A_s = 0.0018(310)(50) = 27.9 \ cm^2$

central band reinforcement $= \left(\dfrac{2}{1+b}\right)A_s$

$$= \left(\frac{2}{1+310/200}\right)(27.9) = 21.88 \ cm^2$$

Use *15 f 14 mm* in the central band

For the side bands, $A_s = (27.9 - 21.88) = 6.02 \ cm^2$

Use $2\,f\,14\;mm$ in the right side band, and $3\,f\,14\;mm$ in the left side band.

7- Check for bearing strength of column and footing concrete:

For column,

$$F\,P_n=0.65(0.85)(250)(25)(60)/1000=207.18\;tons \quad >136\;tons$$

i.e. use minimum dowel reinforcement, $A_s=0.005(25)(60)=7.5\;cm^2$

The column is to be designed for axial force plus bending moment.

8- Check for anchorage of the reinforcement:

a. Reinforcement in long direction ($f\,18\;mm$):

$$y_t=y_e=1=1\;and\;y_s=0.8$$

c_b is the smaller of:

$$7.5+0.9=8.4\;cm,\;\;or\;\;\frac{200-15-1.8}{14(2)}=6.54\;cm,\;i.e.,\;c_b=6.54\;cm$$

$$\frac{c_b+K_{tr}}{d_b}=\frac{6.54+0}{1.8}=3.63>2.5,\;take\;it\;equal\;to\;2.5$$

$$l_d=\frac{0.8(1.8)(4200)}{3.5(2.5)\sqrt{250}}=43.71\;cm$$

Available length $= 100.0 - 7.5 = 92.5\;cm\;>\;43.71\;cm$

b. Reinforcement in short direction ($f\,14\;mm$):

$$y_t=y_e=1=1\;and\;y_s=0.8$$

c_b is the smaller of:

$$7.5+0.7=8.2\;cm,\;\;or\;\;\frac{200-15-1.4}{14(2)}=6.56\;cm,\;i.e.,\;c_b=6.56\;cm$$

$$\frac{c_b+K_{tr}}{d_b}=\frac{6.56+0}{1.4}=4.69>2.5,\;take\;it\;equal\;to\;2.5$$

$$l_d=\frac{0.8(1.4)(4200)}{3.5(2.5)\sqrt{250}}=34.0\;cm$$

Available length $= 87.5 - 7.5 = 80.0\;cm\;>\;34.0\;cm$

9- Prepare neat design drawings, showing footing dimensions and provided reinforcement:
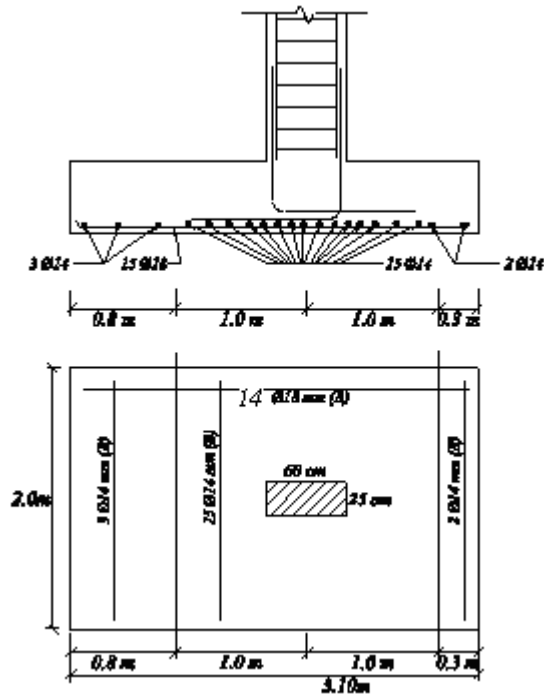
Design drawings are shown in Figure 11.10.f.

Figure 11.10.f: Design drawings

Example (11.2):

Design an isolated edge footing to support an edge column 70 *cm* × 25 *cm* in cross section and carries a dead load of 25 *tons* and a live load of 20 *tons*.

Use $f_c' = 250\,kg/cm^2$, $f_y = 4200\,kg/cm^2$, $q_{all}(gross) = 2.5\,kg/cm^2$, $g_{soil} = 1.7\,t/m^3$,   and
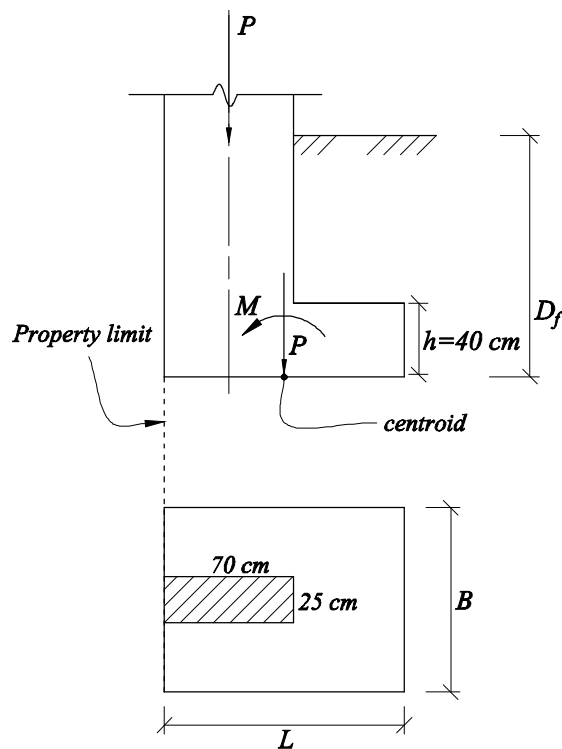
$D_f = 1.5\,m$.

Figure 11.11.a: Footing dimensions

Solution:

1- Select a trial footing depth:

Assume that the footing is 40 *cm* thick, shown in Figure 11.11.a.

2- Establish the required base area of the footing:

$q_{all}(net) = 25 - 1.1(1.7) - 0.4(2.5) = 22.13\ t/m^2$

Try 1.3 *m* × 3.0 *m* × 0.4 *m* footing

$q_{all}(net) = \dfrac{25+20}{1.3(3)} \pm \dfrac{6(25+20)(0.3)}{3(1.3)^2}$

$q_{max} = 11.54 + 15.97 = 27.51 \ t/m^2 \quad > 22.13 \ t/m^2$ (compressive)

$q_{min} = 11.54 - 15.97 = -4.43 \ t/m^2$ (tensile), as shown in Figure 11.11.b.

Try $1.0 \ m \times 4.0 \ m \times 0.4 \ m$ footing

$$q_{all} \ (net) = \frac{25 + 20}{1.0 \ (4)} \pm \frac{6 \ (25 + 20)(0.15)}{4 \ (1.0)^2}$$

$q_{max} = 11.25 + 10.125 = 21.375 \ t/m^2 \quad < 22.13 \ t/m^2$ (compressive)

$q_{min} = 11.25 - 10.125 = 1.125 \ t/m^2$ (compressive), as shown in Figure 11.11.c.

Use $1.0 \ m \times 4.0 \ m \times 0.4 \ m$ footing
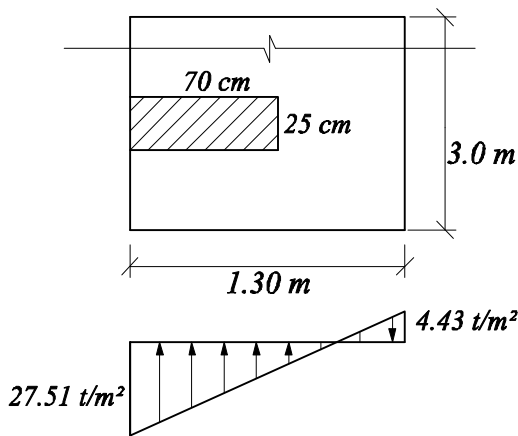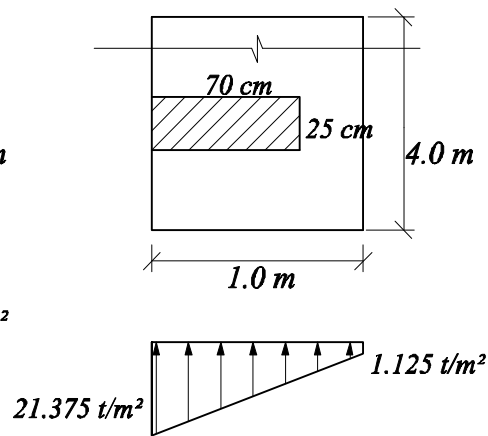

Figure 11.11.b: Net soil pressure   **Figure 11.11.c: Net soil pressure**

3- Evaluate the net factored soil pressure:

$P_u = 1.20(25) + 1.60(20) = 62 \ tons$

$$q_u \ (net) = \frac{62}{1.0(4)} \pm \frac{6 \ (62)(0.15)}{4 \ (1.0)^2}$$

$q_{u \, max} = 15.50 + 13.95 = 29.45 \ t/m^2$

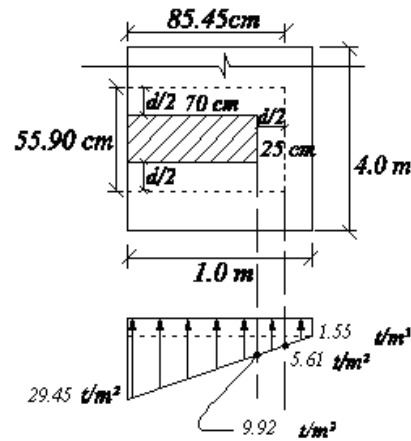$q_{u \, min} = 15.50 - 13.95 = 1.55 \ t/m^2$, shown in Figure 11.11.d.

Figure 11.11.d: Critical section for punching shear and factored soil pressure

4- Check footing thickness for punching shear:

Average effective depth $d = 40 - 7.5 - 1.6 = 30.9\ cm$

The factored shear force

$$V_u = 62 - \left(\frac{5.61 + 29.45}{2} \right)(0.8545)(0.559) = 53.72\ tons$$

$$b_0 = 2(85.45) + 25.0 + 30.9 = 226.8\ cm$$

ΦV_c is the smallest of:

$$F\ V_c = 0.53\ F\ \sqrt{f'_c}\left(1 + \frac{2}{b}\right)l\ b_0\ d$$

$$= 0.53\,(0.75)\sqrt{250}\left(1 + \frac{2}{70/25}\right)(226.8)(30.9)/1000 = 75.51\ tons$$

$$F\ V_c = 1\ F\sqrt{f'_c}\ b_0\ d$$

$$= 0.75\,\sqrt{250}\,(226.8)(30.9)/1000 = 83.11\ tons$$

$$F\ V_c = 0.27\ F\left(\frac{a_s\ d}{b_0} + 2\right)l\ \sqrt{f'_c}\ b_0\ d$$

$$= 0.27\,(0.75)\left(\frac{30\,(30.9)}{226.8} + 2\right)\sqrt{250}\,(226.8)(30.9)/1000 = 136.59\ tons$$

$$F V_c = 75.51\ tons\quad > 53.72\ tons$$

i.e. footing thickness is adequate for resisting punching shear.

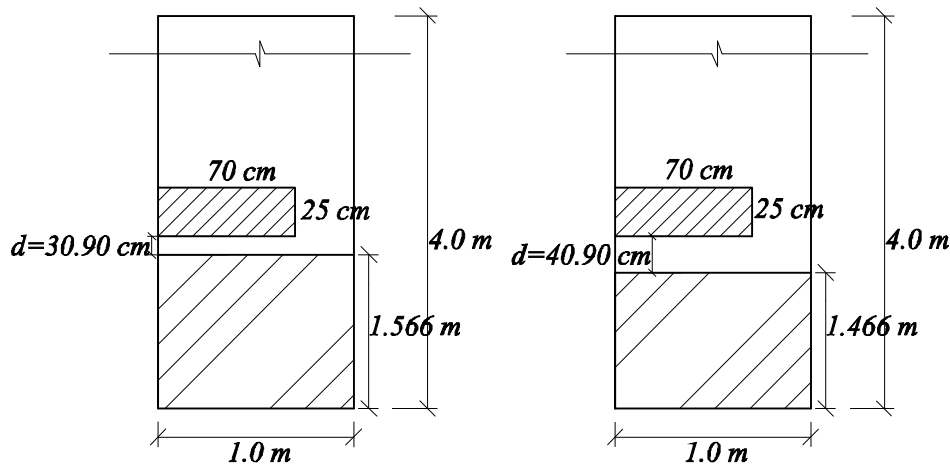## 5- Check footing thickness for beam shear in each direction:

Figure 11.11.e: Critical section for beam shear (short direction)   **Figure 11.11.f: Critical section for beam shear (short direction)**

a- In the short direction:

The critical section for beam shear is shown in Figure 11.11.e.

$$FV_c = 0.75(0.53)\sqrt{250}\,(100)(30.9)/1000 = 19.42 \; tons$$

Maximum factored shear force V_u is located at distance d from faces of column. The factored shear force

$$V_u = \left(\frac{1.55 + 29.45}{2}\right)(1.0)(1.566) = 24.27 \; tons \quad > 19.42 \; tons$$

Increase footing thickness to 50 *cm* and check for beam shear. The critical section for beam shear is shown in Figure 11.11.f.

$$FV_c = 0.75(0.53)\sqrt{250}\,(100)(40.9)/1000 = 25.71 \; tons$$

The factored shear force

$$V_u = \left(\frac{1.55 + 29.45}{2}\right)(1.0)(1.466) = 22.72 \; tons \quad < 25.71 \; tons$$

i.e. footing thickness is adequate for resisting shear.

6- Compute the area of flexural reinforcement in each direction:

a- Reinforcement in short direction:

$$M_u = 4\left[(1.55)(0.3)^2/2\right] + 4\left[\left(\frac{9.92 - 1.55}{2}\right)(0.3)(0.1)\right] = 0.78 \ t.m$$

$$A_s = 0.0018(400)(50) = 36.0 \ cm^2$$

Central band reinforcement $= \left(\dfrac{2}{1+b}\right)A_s$

$$= \left(\frac{2}{1+400/100}\right)(36) = 14.40 \ cm^2$$

Use $13 f 12 \ mm$ in the central band

For the side bands, $A_s = (36 - 14.40) = 21.60 \ cm^2$

Use $10 f 12 \ mm$ in each of the side bands

b- Reinforcement in long direction:

$$M_u = \left[\left(\frac{1.55 + 29.45}{2}\right)(1.0/2)(1.875)^2\right] = 27.25 \ t.m$$

$$r = \frac{0.85(250)}{4200}\left[1 - \sqrt{1 - \frac{2.353(10)^5(27.25)}{0.9(100)(40.9)^2(250)}}\right] = 0.0045107$$

$A_s = 0.0045107(100)(40.9) = 18.45 \ cm^2$, use $10 f 16 \ mm$ in the long direction

7- Check for bearing strength of column and footing concrete:

For column,

$$F \ P_n = 0.65(0.85)(250)(25)(70)/1000 = 241.72 \ tons \quad > 62 \ tons$$

i.e. use minimum dowel reinforcement, $A_s = 0.005(25)(70) = 8.75 \ cm^2$

8- Check for anchorage of the reinforcement:

a- Reinforcement in long direction ($f 16 \ mm$):

$y_t = y_e = 1 = 1$ and $y_s = 0.8$

c_b is the smaller of:

$$7.5 + 0.8 = 8.3 \ cm, \ \text{or} \ \frac{100 - 15 - 1.6}{10(2)} = 4.17 \ cm, \text{i.e.,} \ c_b = 4.17 \ cm$$

$$\frac{c_b + K_{tr}}{d_b} = \frac{4.17 + 0}{1.6} = 2.61 > 2.5, \; take \; it \; equal \; to \; 2.5$$

$$l_d = \frac{1.6(0.8)(4200)}{3.5(2.5)\sqrt{250}} = 38.86 \; cm$$

Available length $= 187.5 - 7.5 = 180.0 \; cm \; > \; 38.86 \; cm$

b- Reinforcement in short direction (ʄ 12 mm):

$y_t = y_e = 1 = 1$ and $y_s = 0.8$

c_b is the smaller of:

$$7.5 + 0.6 = 8.1 \, cm, \; or \; \frac{400 - 15 - 1.2}{31 \, (2)} = 6.19 \, cm \, , \; i.e., \; c_b = 6.19 \; cm$$

$$\frac{c_b + K_{tr}}{d_b} = \frac{6.19 + 0}{1.2} = 5.16 > 2.5, \; take \; it \; equal \; to \; 2.5$$

$$l_d = \frac{1.2(0.8)(4200)}{3.5(2.5)\sqrt{250}} = 29.14 \; cm$$

Available length $= 30.0 - 7.5 = 22.5 \; cm \; < \; 29.14 \; cm$

Hook all bars at their ends to provide additional anchorage length.

9- Prepare neat design drawings showing footing dimensions and provided reinforcement:

Design drawings are shown in Figure 11.11.g.

As seen in this example, the design leads to a footing that is long and narrow. Either combined or strap footing is a better solution for this eccentric case.
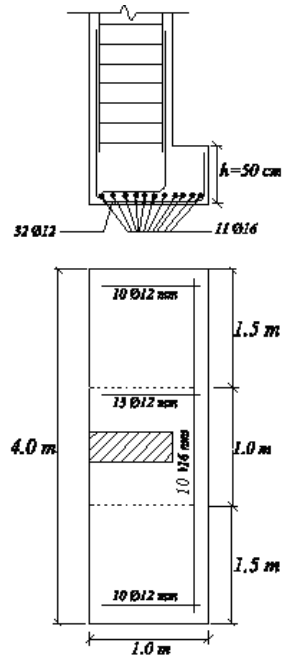
Figure 11.11.g: Design drawings

Design of Wall Footings

When a wall carries a uniformly distributed line load, wall sections along the length of the wall behave equally. Consequently, the design of the footing can be based on a strip 1-m wide along the length of the wall. Design of wall footings is summarized in the following steps.

1- Select a trial footing depth:

According to *ACI Code 15.7*, depth of footing above reinforcement is not to be less than 15 *cm* for footings on soil. **Establish the required base width of the footing:**

Width of footing is established by dividing the total service load by the allowable net soil pressure.

2- Evaluate the net factored soil pressure.

3- Check footing thickness for beam shear in the transverse direction:

The critical section for beam shear is located at distance *d* from the face of the wall.

4- Compute the area of flexural reinforcement:

If a footing carries a concrete wall, *ACI Code 15.4.2* specifies that the critical section for moment be taken at the face of the wall. Main reinforcement is provided in the short direction while shrinkage reinforcement is provided in the long direction of the footing.

5- Check for bearing strength of wall and footing concrete.

6- Check for anchorage of the reinforcement:

Both, flexural and dowel reinforcement lengths are checked for anchorage to prevent bond failure of the dowels in the footing and to prevent failure of the lap splice between the dowels and the wall reinforcing bars.

7- Prepare neat design drawings showing footing dimensions and provided reinforcement.

Example (11.3):

Design a footing to support a reinforced concrete wall 20 *cm* thick as shown in خطأ! لم يتم العثور على المرجع.a. The wall supports a service dead load of 10 *t/m* and a service live load of 7.5 *t/m* in addition to its own weight.

Use $f'_c = 300\,kg/cm^2$, $f_y = 4200\,kg/cm^2$, $q_{all}(gross) = 1.8\,kg/cm^2$, $g_{soil} = 1.7\,t/m^3$, and $D_f = 2.0\,m$.
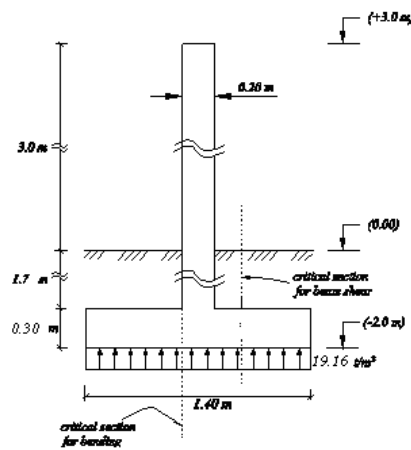

Figure 11.12.a: Footing dimensions

Solution:

1- Select a trial footing depth:

Assume that the footing is 30 *cm* thick.

2- Establish the required base width of the footing:

For a strip 1-*m* wide along the wall,

$$q_{all}(net) = 18 - 1.7(1.7) - 0.3(2.5) = 14.36 \ t/m^2$$

Total service load /m = 10 + 7.5 + 0.20 (1.7 + 3) (2.5) = 19.85 *tons*

$$A_{req} = \frac{19.85}{14.36} = 1.38\,m^2$$

Use $B = 1.4\,m$.

3- Evaluate the net factored soil pressure:

$$q_u(net) = \frac{1.2(10) + 1.6(7.5) + 1.2(0.2)(4.7)(2.5)}{1.4(1.0)} = \frac{26.82}{1.4} = 19.16 \ t/m^2$$

4- Check footing thickness for beam shear:

Effective depth $d = 30 - 7.5 - 0.70 = 21.8 \ cm$

$F V_c = 0.75(0.53)\sqrt{300}(100)(21.8)/1000 = 15.0 \ tons$

Maximum factored shear force V_u is located at distance d from the face of wall,

$V_u = (19.16)(1.0)\left[\left(\dfrac{1.4 - 0.2}{2}\right) - 0.218\right] = 7.32 \ tons < 15.0 \ tons$

i.e. provided footing thickness is adequate for resisting beam shear.

5- Compute the area of flexural reinforcement:

a- Flexural reinforcement

$M_u = 19.16 \dfrac{(0.6)^2}{2} = 3.45 \ t.m$

$r = \dfrac{0.85(300)}{4200}\left[1 - \sqrt{1 - \dfrac{2.353(10)^5(3.45)}{0.9(100)(21.8)^2(300)}}\right] = 0.00195$

$A_s = 0.00195(100)21.8 = 4.25 \ cm^2$

$A_{s,min} = 0.0018(100)30 = 5.40 \ cm^2$

use $f \ 12 \ mm \ @ \ 205 \ cm$

b- Shrinkage reinforcement:

$A_s = 0.0018(140)(25) = 6.30 \ cm^2$, use $8 f \ 10 \ mm$

6- Check for bearing strength of wall and footing concrete:

$F P_n = 0.65(0.85)(300)(20)(100)/1000 = 331.5 \ tons \ > 26.82 \ tons$

i.e, use minimum dowel reinforcement, $A_s = 0.005(20)(100) = 10.0 \ cm^2$

7- Check for anchorage of the reinforcement:

a- Flexural reinforcement ($f \ 12 \ mm$):

$y_t = y_e = 1 = 1$ and $y_s = 0.8$

C is the smaller of:

$7.5 + 0.6 = 8.1 \ cm$, or $\dfrac{15}{2} = 7.5 \ cm$, i.e., $c_b = 7.5 \ cm$

$$\frac{c_b + K_{tr}}{d_b} = \frac{7.5 + 0}{1.2} = 6.25 > 2.5 \text{, \textit{take it equal to 2.5}}$$

$$l_d = \frac{1.2(0.8)(4200)}{3.5(2.5)\sqrt{300}} = 26.60 \text{ cm}$$

Available development length = 60.0 – 7.5 = 52.5 *cm* > 26.60 cm   O.K

b- *Dowel reinforcement (f 10 mm):*

To calculate required development length for f 10 *mm* bars,

$$l_d = \frac{0.075(1.0)(4200)}{\sqrt{300}} = 18.18 \text{ }_{cm} \text{, \textit{or}}$$

$$l_d \geq 0.0044(1.0)(4200) = 18.48 \text{ cm, or}$$

$$l_d \geq 20.0 \text{ cm}$$

Available length = 30 - 7.5 - 1.2 -1 = 20.30 *cm* > 20 *cm*   O.K

c- *Reinforcement splices:*

To calculate splice length for f 10 *mm* bars,

$$l_{splice} \geq 0.0073(1.0)(4200) = 30.66 \text{ cm}$$

8- Prepare neat design drawings, showing footing dimensions and provided reinforcement:
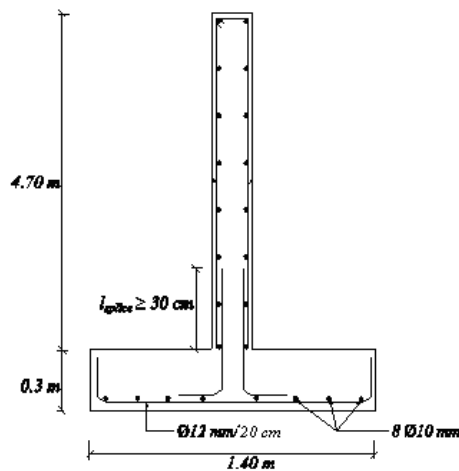
Design drawings are shown in Figure 11.12.b.

Figure 11.12.b: Design drawings