UNIT 16 DESIGN OF STRIP AND SPREAD FOOTINGS

Structure

16.1 INTRODUCTION

Foundation is provided to transmit the forces and moments on a structure – mainly due to self-weight, other dead weights, overlying fill, live load, wind and seismic forces on the structure – to the soil. The transmission of load is either through shear resistance of bearing strata–generally called bearing capacity of soil – *or* through frictional resistance developed between the foundation unit and soil *or* by combination of both. Depending upon the depth of bearing and type of transference of forces, all foundations can be categorized either a *Shallow Foundation* or a *Deep Foundation*

Shallow foundations are those where transmission of loads are only through shear resistance and normally laid at less than 3m depth; whereas *deep foundation* – such as piles, cassions, diaphragm walls, well foundation etc. – are those which are themselves more than 3m deep and transmit the loads to the soil strata through friction or through bearing at greater depth on stronger strata or through combination of both.

Strip and *spread* foundations are shallow foundation type. A *strip* foundation, such as foundation below a wall or a beam is a continuous longitudinal bearing; whereas a pad or *spread foundation* may be provided to transmit loads through bearing of an isolated column or of two or more columns in a line.

Objectives

After studying this unit you should be able to

- design strip footing provided under a wall, and
- design spread footing provided under a single column.

16.2 GENERAL DESIGN CONSIDERATIONS

Loads: Generally a column is designed for the following load cases

i) Dead Load + Live Load

ii) Dead Load + Live Load + Wind or Earthquake Load

Bearing Capacity of Soil : The bearing capacity shall be based (a) on shearing strength capacity of soil as well as (b) on the permissible settlement of foundation. These informations for a particular site shall be based on site investigations and experimental results. In the absence of such data the safe bearing capacity of some of the types of soil may be taken as given in Table 16.1 for *rough guidance.*

Table 16.1: Safe Bearing Capacity of Different Soils

Types of Soil	Safe Bearing Capacity (kN/m^2)
I) *Rocks*	
(i) Hard Rocks *without* defect with lamination	3240
(ii) Rocks with lamination	1620
(iii) Residual deposits of shattered and broken bed rock, hard shell, cemented material etc.	880
(iv) Soft rock	440
II) *Non Cohesive Soils*	
(i) Gravel, sand and gravel, compact and offering high resistance to penetration when excavated	440
(ii) Coarse sand, compact and dry	440
(iii) Medium sand, compact and dry	245
(iv) Fine sand, silt (dry lump easily pulverized by fingers)	150
(v) Loose gravel or sand, gravel mixture, loose coarse to medium sand, dry	245
(vi) Fine sand, loose and dry	100
III) *Cohesive Soils*	
(i) Soft shale, hard or stiff clay in deep bed, dry	400
(ii) Medium clay readily indented with thumb nail	245
(iii) Moist clay and sand clay mixture which can be indented with strong thumb pressure	150
(iv) Very soft clay indented with moderate thumb pressure	100
(v) Very soft clay which can be penetrated several centimeter with thumb	50

Depth of Foundation **:** The depth of foundation below the ground level shall be at least 0.5 m except in case of stable rock available at ground level. The variation in depth may be due to

(i) availability of adequate bearing capacity,

(ii) effect of shrinkage and swelling of clayey soils,

(iii) effect of frost and temperature changes in silty and sandy soil,

(iv) depth of scour, proximity to pond, ditches and filled up ground,

(v) mass movement of soil to sloping ground, etc.

SAQ 1

(i) Differentiate between shallow foundation and deep foundation.

(ii) Define strip footing and spread footing.

(iii) Define Bearing capacity. Enumerate the factors to be considered fordetermination of depth of footing.

16.3 DESIGN PRINCIPLES AND PROCEDURES

***Fixing Base Size*:** Superimposed loads transferred through a wall or column is added with self-weight of footing to obtain total load to be transferred to the soil. This total load is divided by the safe bearing capacity of soil to determine area of footing. In case of wall, the breadth of footing is equal to the calculated area, because the length for design purposes is taken as unity. The base size of a rectangular footing is obtained by fixing one of its dimensions (length or breadth) and the other is determined from the calculated area. For square or circular footing, the dimension of side or radius is determined from the calculated area in the usual way.

Determination of Depth

(i) **From Bending Moment Consideration**

The bending moment of any section is determined by passing through the section a vertical plane extending *completely* across the footing and computing the moment of the forces acting over the entire area of the footing on one side of the said plane.

For calculating the greatest bending moment the section is to be located at the face of concrete wall, column or pedestal. But this section may be taken to be located at halfway between the centre line and edge in case of masonry wall. The face of round or octagonal column may be taken as the side of a square inscribed within the perimeter of the round or octagonal column or pedestal.

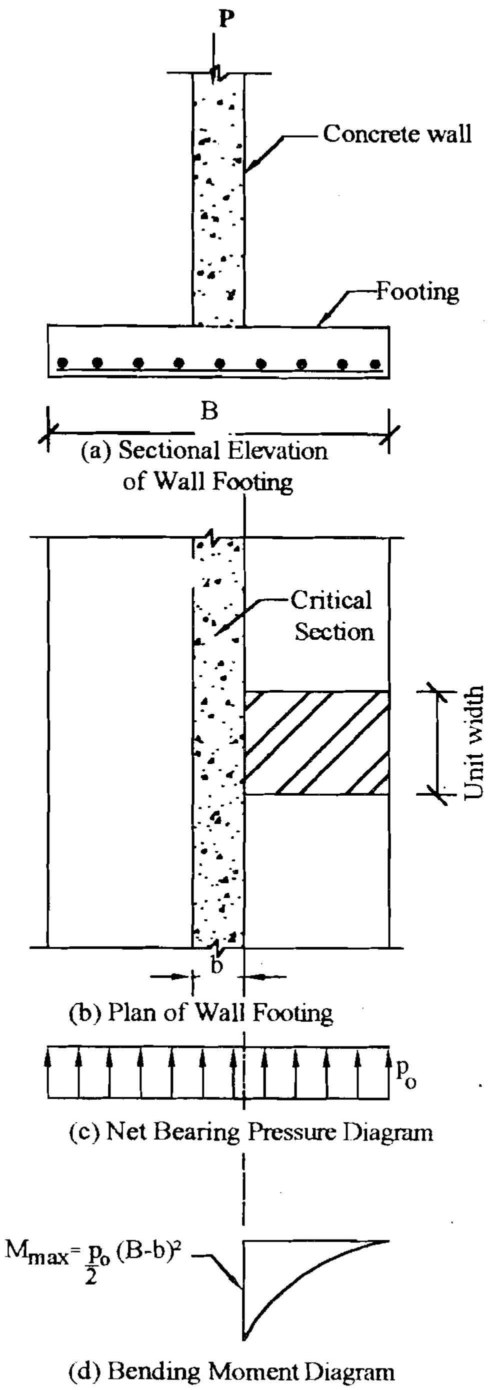


Figure 16.1: Design B. M. for a Footing of Concrete Wall

For strip footing (Figure 16.1) if

P = Load on wall / unit length, and

P' = Self weight of footing / unit length,

then required area of footing

$$A = \frac{P + P'}{p}$$

or $$B \times 1 = \frac{P + P'}{p}$$

where, p = Bearing capacity of soil, and

B = width of footing.

The *net* upward reaction on footing (i.e. net bearing capacity of soil) causing bending moment and shear force,

$$*\, p_0 = \frac{P}{A} = \frac{P}{B \times 1} = \frac{P}{B}$$

The design B.M. at the face of wall,

$$M = p_0 \frac{(B - b)}{2} \times \left(\frac{B - b}{4}\right) = \frac{p_0}{8} \times (B - b)^2 \qquad \text{...(16.1)}$$

Therefore, from bending moment consideration effective depth

$$d = \sqrt{\frac{M}{R_B \times 1}} = \sqrt{\frac{M}{R_B}}$$

For *spread or isolated* R.C. rectangular footing under a *single* column (Figure 16.2)

$$A = \frac{P + P'}{p}$$

or $$L \times B = \frac{P + P'}{p}$$

The net upward reaction on footing causing bending moment and shearing force

$$p_0 = \frac{P}{A} = \frac{P}{L \times B}$$

The design B.M. at one of the faces of column i.e., say, at y-y section

$$M_1 = p_0\, L \left(\frac{B - b}{2}\right)\left(\frac{B - b}{4}\right) = \frac{p_0}{8} L (B - b)^2 \qquad \text{...(16.2a)}$$

$$\therefore d = \sqrt{\frac{M_1}{R_B L}}$$

* The self-weight of footing is considered uniformly distributed which is deducted while taking *net* upward pressure.

Similarly design B.M. at *x*-*x* section,

$$M_2 = \frac{p_0}{8} B(p-a)^2 \qquad \text{..(16.2b)}$$

and $d = \sqrt{\frac{M_2}{R_B B}}$

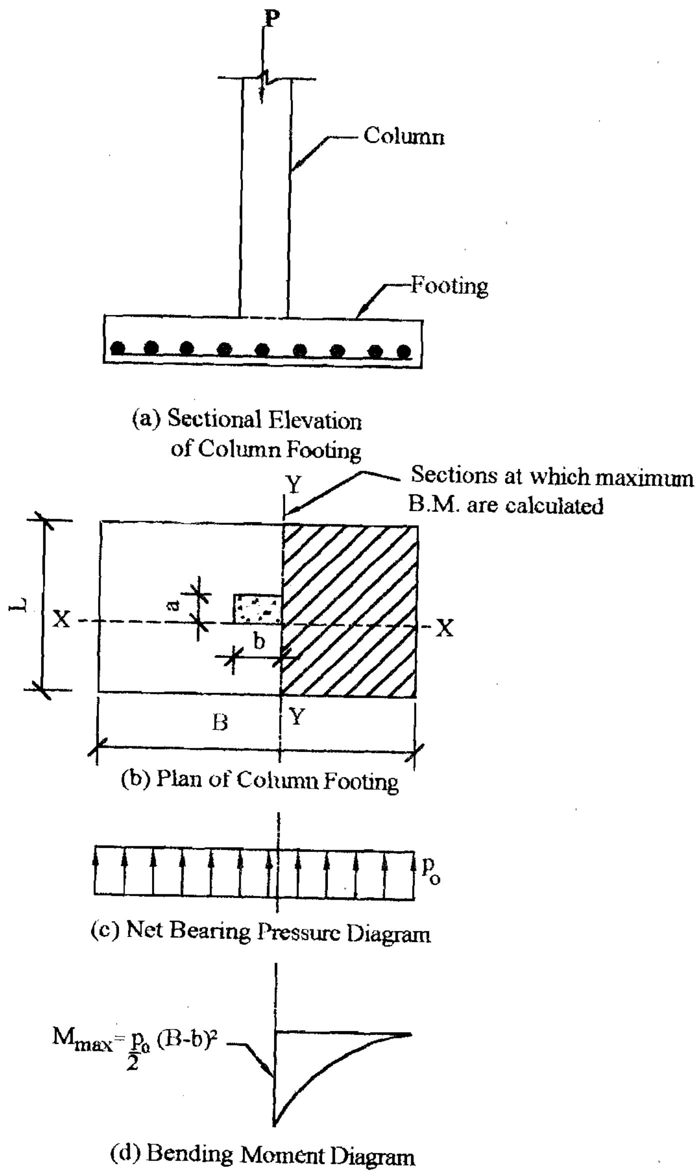


Figure 16.2: Design B. M. for a Footing of Column

(ii) **From Shear Force Consideration**

a) The critical section for determination of shear force is taken to be located at distance *d* from the face of wall, column or pedestal *across the full width of footing* (Figure 16.3). This shear force is similar to S.F. in a flexural member (a beam or slab) and is termed as '*wide beam action*' or '*one way action*'.

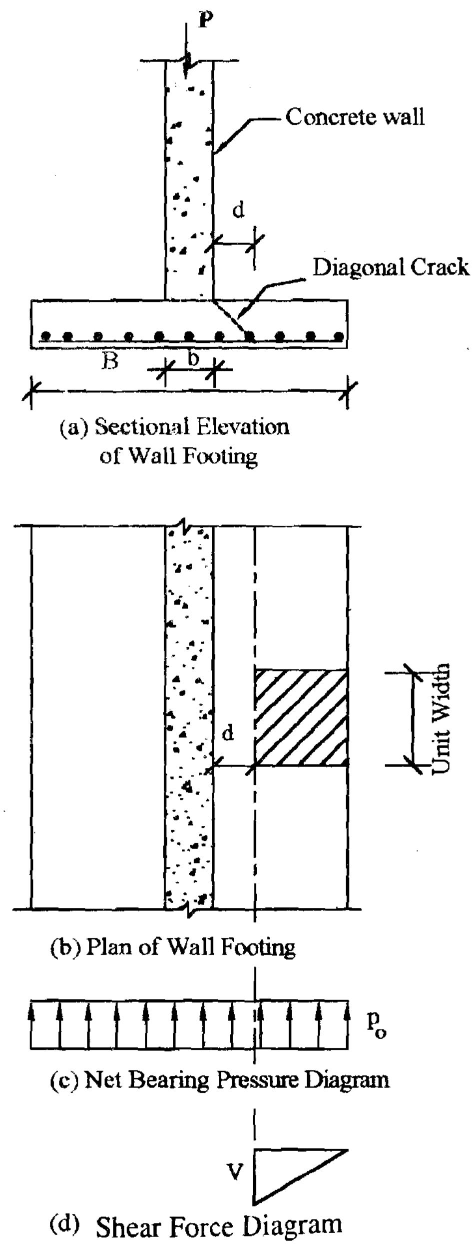


Figure 16.3: Design S. F. for Footing of Concrete Wall

For strip footing design, shear force

$$V = p_0 \left(\frac{B - b}{2} - d \right) \quad \text{....(16.3)}$$

$$\therefore \tau_v = \frac{V}{1 \times d} < k\tau_c \quad \text{...(16.4)}$$

Effective depth d is determined from Equation 16.4.

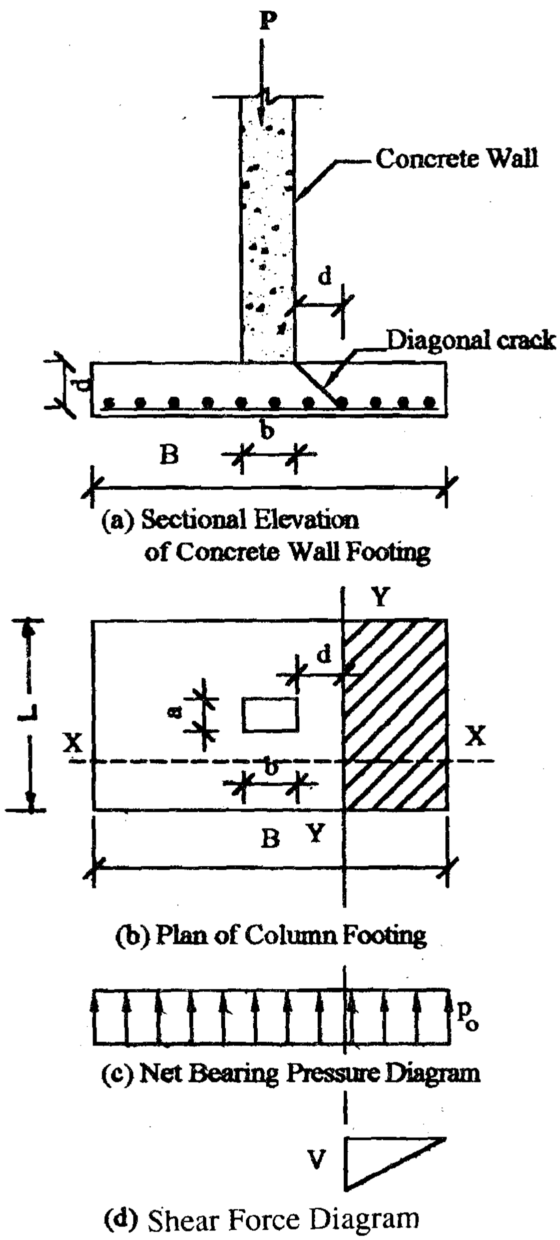


Figure 16.4: Design S. F. for Footing of Column

For spread or isolated footing (Figure 16.4) from 'wide beam action' the shear force say at section *y-y*

$$V_1 = p_0 \, L \left(\frac{B - b}{2} - d \right) \qquad \text{...(16.5)}$$

$$\therefore \tau_{v1} = \frac{V_1}{L d} \leq k \tau_c \qquad \text{...(16.6)}$$

Similarly S.F. at *x-x* section

$$V_2 = p_0 \, B \left(\frac{B - b}{2} - d \right) \qquad \text{...(16.7)}$$

$$\tau_{v2} = \frac{V_2}{B d} \leq k \tau_c \qquad \text{...(16.8)}$$

The effective depth d is determined from Equation 16.6 and 16.8 and larger of the two values is adopted.

b) A column may punch through its footing due to *shear* diagonal cracks formed along the surfaces of a truncated pyramid or cone (Figure 16.5).

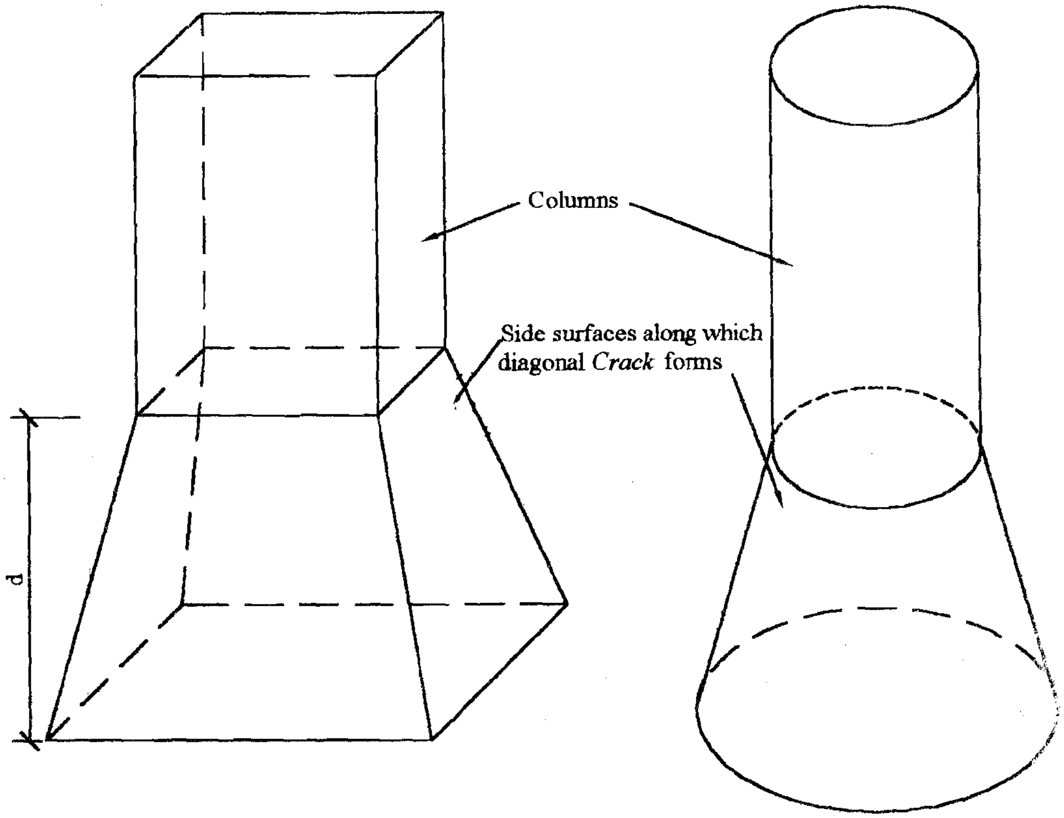


Figure 16.5: Two-way Action along the Surface of Truncated Pyramid or Cone

The critical section for such *punching shear action* shall be a distance $d/2$ from the periphery of a column shown in Figure 16.6.

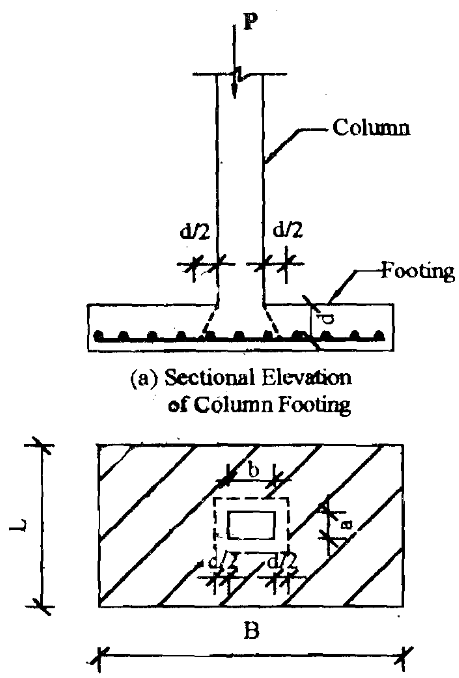


Figure16.6: Critical Section for Two-way S. F. for Column Footing

In this case, Shear Force

$V = p_u [\, L \times B - (a + d)(b + d) \,]$ ...(16.9)

$\tau_v = \dfrac{V}{b_0 \times d} \leq k_s \tau_c$ ...(16.10)

where, b_0 = Periphery of the critical section,

$k_s = (0.5 + \beta_c) < 1, \left(\beta_c = \dfrac{\text{short side}}{\text{long side}} \right)$

and $\tau_c = 0.16 \sqrt{f_{ck}}$

From Equation (16.10) d may be determined.

The determination of effective depth d from considerations of B.M. and S.F. for strip footing under masonry wall and for other types of isolated footing shall be explained through examples.

The greatest value of d so calculated is taken for evaluation of total design depth, D, of the footing.

Tensile Reinforcement: Main reinforcement is provided along the width and distribution bars of minimum specified reinforcement along the length of *strip foundation.*

In isolated footing under a single column, main reinforcements are provided in both orthogonal directions in the form of a mesh. In rectangular footing, however, reinforcement parallel to longer side are distributed uniformly; whereas out of total reinforcement, parallel to the shorter side, a portion of it is placed in central band of width equal to shorter side. The above mentioned *portion or ratio* of total reinforcement may be obtained from equation

$$\frac{\text{Reinforcement in cental band}}{\text{Total reinforcement in short direction}} = \frac{2}{\beta + 1}$$

where β = ratio of long side to short side $= \dfrac{L}{B}$

The remaining portion is distributed equally on outer parts of the footing.

Development Length : All main tensile reinforcement beyond the critical section shall extend at least equal to development length on either sides.

Control of Bearing Pressure on Base of a Column or Pedestal

The compressive bearing stress at the base of a column (i.e. at the top of supporting pedestal or footing) should not exceed the permissible bearing pressure in direct compression of $0.25 f_{ck}$ increased by a coefficient equal to $\sqrt{\dfrac{A_1}{A_2}}$ where

A_1 = (a) For supporting area of *uniform thickness* (i.e. supporting area geometrically similar to and concentric with the loaded area, A_2) is equal to area of footing.

(b) In case of *sloped or stepped footing*, it is the area of the lower base of the largest frustrum of a pyramid or cone contained wholly within the footing and having for its upper base, the area actually loaded and having side slope of one vertical to two horizontal, and

A_2 = Loaded area of footing

The maximum value of $\sqrt{\dfrac{A_1}{A_2}}$ is 2.0

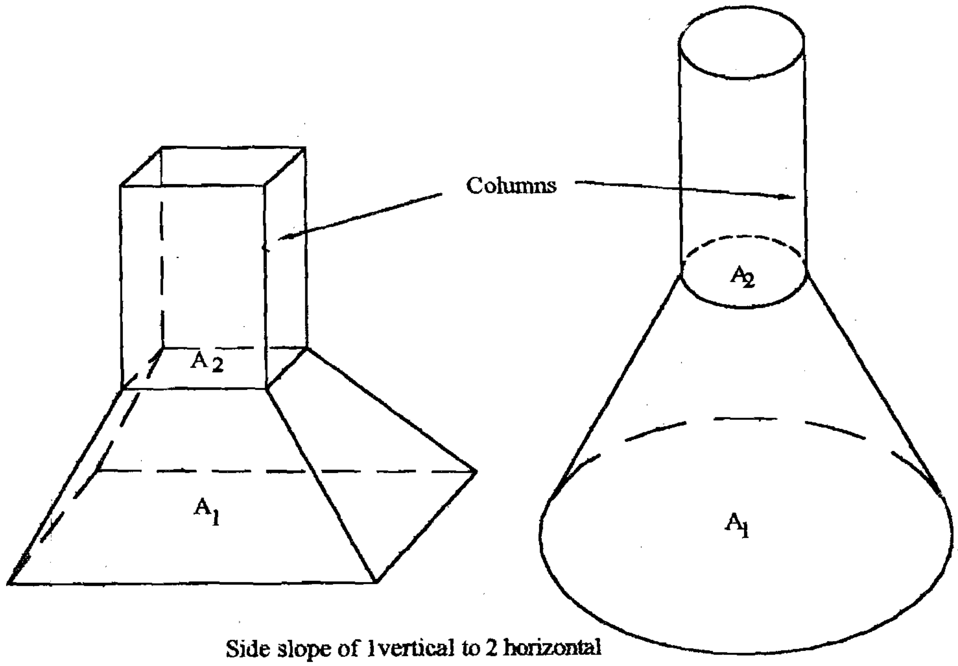


Figure 16.7: Defining A_1 & A_2 for Permissible Bearing Stress

If the permissible bearing stress is exceeded either in concrete of column or its supporting member (pedestal or footing), the excess forces may be transmitted from column to its supporting member either by extending the longitudinal bars into the supporting member or by dowels.

The code specifies the following criteria to be complied with for extended longitudinal bars or dowels:

(a) The development length of extended longitudinal bars or of dowel should be sufficient to transfer compression or tension to the supporting member.

(b) Extended longitudinal bars or dowels shall have *at least* an area of 0.5% of the cross sectional area of column or pedestal.

(c) A minimum of *four* bars shall be provided.

(d) The diameter of dowels bar shall not have a diameter greater by 3 mm than those of column, and

(e) If the diameter of column bar is more than 36 mm, the dowel bars shall have smaller diameter for necessary steel area. The development length on either side of the junction shall be in accordance with the reinforcement diameter provided.

Example 16.1

Design a R.C. footing for a *concrete* wall of 400 mm width for a super-imposed load of 800 kN/m. The safe bearing capacity, *p*, of soil is 200 kN/m^2. Use M 15 concrete and Fe 415 steel.

Solution

Design Constants

$$m = \frac{280}{3\sigma_{cbc}} = \frac{280}{3 \times 5} = 18.67 \approx 19$$

$$k_B = \frac{m\sigma_{cbc}}{m\sigma_{cbc} + \sigma_{st}} = \frac{19 \times 5}{19 \times 5 + 140} = 0.404$$

$$j_B = 1 - \frac{k_B}{3} = 1 - \frac{0.404}{3} = 0.865$$

$$R_B = \frac{1}{2}\,\sigma_{cbc}\, j_B k_B = \frac{1}{2} \times 5 \times 0.865 \times 0.404 = 0.87$$

Fixing Base Size

Considering 1m length of footing

Super-imposed load, P = 800 kN/m

Self-weight, P' (assuming it to be 10% of P = 80 kN/m

Total load $(P + P')$ = 880 kN/m

Area of footing/m length; $A = \frac{(P + P')}{p} = \frac{880}{200} = 4.4$ m² per m width of footing

Net upward pressure, $p_0 = \frac{P}{A} = \frac{800}{4.4 \times 1} = 181.81$ kN/m² = 181.81×10^{-3} N/mm²

∴ Provide 4.4 m width strip footing.

Determination of Depth

(i) **From Bending Moment Consideration**

Design B.M. (vide Eq. 16.1) and Figure 16.8.

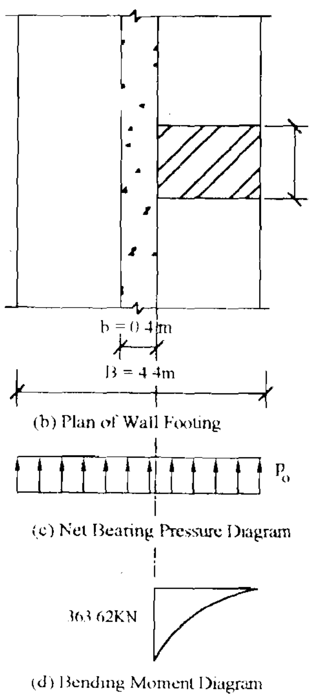


Figure 16.8: Design B. M. for Wall Footing

$$M = \frac{p_0}{8}(B - b)^2$$

$$= \frac{181.81}{8}(4.4 - 0.4)^2$$

$$= 363.62 \text{ kNm}$$

$$\therefore d = \sqrt{\frac{M}{R_B \times L}} = \sqrt{\frac{363.62 \times 10^6}{0.87 \times 1000}} = 646.49 \approx 650 \text{ mm}$$

(ii) **From Shear Force Consideration**

Distance of critical section x-x at the edge of the footing (Figure 16.9)

$$= \left(\frac{B-b}{2} - d\right)$$

$$= \left(\frac{4.4-0.4}{2}\ d\right) = (2-d)\ \text{m}$$

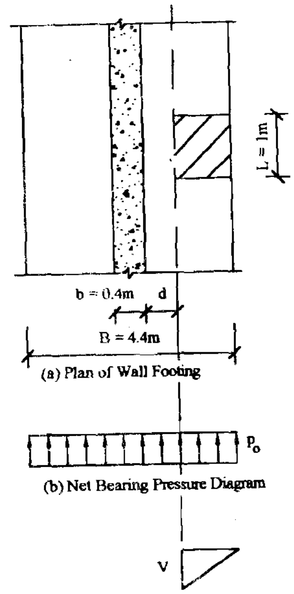


Figure 16.9: Design S. F. for Wall Footing

$$\therefore\ V = p_0\left(\frac{B-b}{2} - d\right) = 181.81 \times (2-d)\ \text{kN}$$

$$\tau_v = \frac{V}{L \times d}\ \frac{181.81 \times (2-d)}{1 \times d}$$

For M 15 concrete $p_B = 0.72\ \%$ for which $\tau_c = 0.334$ N/mm^2 and for $D \geq 300$ (assumed) $k = 1$,

permissible shear stress $k\tau_c = 1 \times 0.334$ N/mm^2

Equating τ_v and τ_c, we get

$$\frac{181.81 \times 10^{-3}(2-d)}{1000 \times d} = 0.334 \text{ (in mm units)}$$

or $d = 704.94 > 650$ mm

Using $\phi 22$ bars and a clear cover of 40

$$D = 704.94 + \frac{22}{2} + 40 = 755.94\ \text{mm}$$

Hence provided D = 760 mm total depth

$$\therefore\ d = 760 - \frac{16}{2} - 40 = 712\ \text{mm}$$

Tensile Reinforcement

Main Reinforcement

$$A_{st} = \frac{M}{\sigma_{st} j_B d} = \frac{363.62\times10^6}{140\times0.865\times712} = 4217.19 \text{ mm}^2$$

Use 22φ bars 16 @ 45 c/c

Distribution Reinforcement

$$A_s = \frac{0.15}{100} bd = \frac{0.15}{100}\times1000\times760 = 1140 \text{ mm}^2$$

$$\text{spacing for } \phi 16 \text{ bars } = \frac{\frac{\pi}{4}\times12^2\times1000}{1140} = 99.20 \text{ mm}$$

Hence provided φ 12 @ 100 c/c

Check for Development Length

$$Ld = \frac{\phi\,\sigma_s}{4\tau_{bd}} = \frac{22\times140}{4\times0.6} = 1283 \text{ mm}$$

Providing 60 mm of end cover length of bar beyond the face of wall (i.e. critical section for

bending) = $\frac{1}{2}(B-b) - 60 = \frac{1}{2}(4400-400) - 60 = 1940 > 1283$ mm **Hence O.K.**

The details of footing is shown in Figure 16.10.

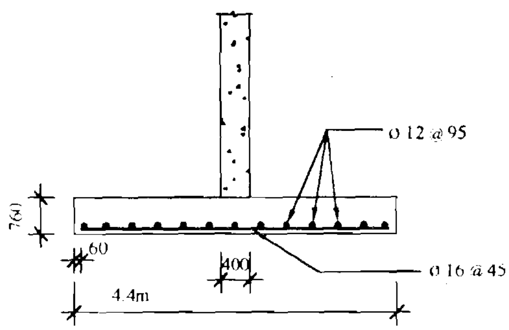


Figure 6.10: Details of Wall Footing

Example 16.2

Design a square footing for a column of cross-section 400 × 400 mm which transfers a load of 800 kN *inclusive* of self-weight of footing. The safe bearing capacity of soil is 245 kN/m². Use M 20 concrete and Fe 250 steel.

Solution

Design Constants

$$m = \frac{280}{3\sigma_{cbc}} = \frac{280}{3\times7} = 13.33 \approx 13$$

$$k_B = \frac{m\sigma_{cbc}}{m\sigma_{cbc}+\sigma_{st}} = \frac{13\times7}{13\times7+140} = 0.394$$

$$j_B = 1 - \frac{k_B}{3} = 1 - \frac{0.394}{3} = 0.869$$

$$R_B = \frac{1}{2}\sigma_{cbc} j_B k_B = \frac{1}{2} \times 7 \times 0.394 \times 0.869 = 1.198$$

Fixing Base Size

Total Load, $(P + P') = 800$ kN

Area of footing, $A = \frac{P + P'}{p} = \frac{800}{245} = 3.265\ \text{m}^2$

Side of square footing, $B = \sqrt{3.265} = 1.81$ m

Hence provided 1.85 × 1.85 m footing.

Self-weight of footing $= \frac{300}{11} = 72.7$ kN

(assuming self-weight = 10% of superimposed load)

Net upward pressure, $p_0 = \frac{P}{A} = \frac{(800 - 72.7)}{1.85 \times 1.85} = 212.51\ \text{kN/m}^2$

Determination of Depth

(i) From Bending Moment Consideration

Design B.M. (vide Eq. 16.2(a) and Figure 16.11).

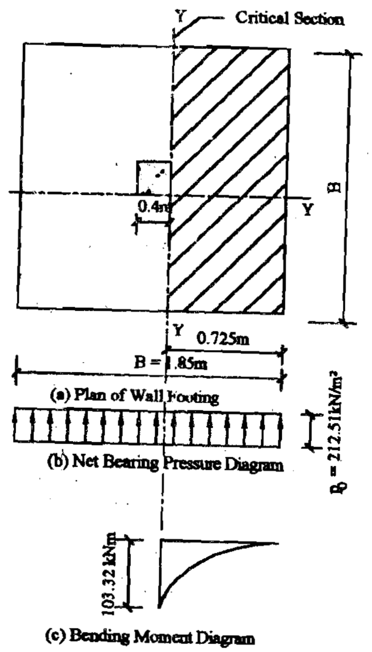


Figure 16.11: B. M. Diagram for Column Footing

$$M = \frac{p_0 B (B - b)^2}{8} = \frac{212.51 \times 1.85 \times (1.85 - 0.4)^2}{8} = 103.32\ \text{kNm}$$

$$\therefore d = \sqrt{\frac{M}{R_B \times B}} = \sqrt{\frac{103.32 \times 10^6}{1.198 \times 1850}} = 215.91\ \text{mm}$$

(ii) **From Shear Force Consideration**

(a) Distance of critical section from face of column for *one way shear* = d (Figure 16.12).

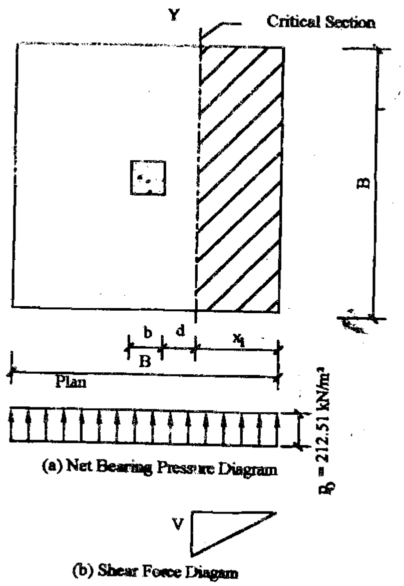


Figure 16.12 : S. F. Diagram for Column Footing

Breadth of loaded area from edge,

$$x_1 = \left(\frac{B-b}{2} - d\right) = \left(\frac{1850 - 400}{2} - d\right) = (725 - d) \text{ mm}$$

$$V = p_0\, Bx_1 = 212.51 \times 1.850 \times (0.725 - d) = 393.1435\,(0.725 - d)$$

$$\tau_v = \frac{V}{Bd} = \frac{393.1435 \times (0.725 - d)}{1.850 \times d} \text{ kN/m}^2 \qquad \text{(i)}$$

For M 15 concrete $p_B = 0.985$ %

$$\therefore \tau_c = 0.39 - \frac{(1 - 0.985)}{0.25}(0.39 - 0.35) = 0.3876 \text{ N/mm}^2 \qquad \text{(ii)}$$

Assuming $d > 300$, $k = 1$

$\therefore$ Permissible shear stress = $k\tau_c = 1 \times 0.3876$ N/mm² = 0.3876×10^3 kN/m² (ii)

Equating τ_v and τ_c

$$\frac{393.1435 \times (0.725 - d)}{1.850 \times d} = 0.3876 \times 1000, \text{ giving } d = 0.25673 \text{ m} = 256.73 \text{ mm}$$

or, $d = 256.73 > 215.91$ mm

(b) Critical section for *two way shear* is at $d/2$ from the face of the column (Figure 16.13) Perimeter of critical section

$b_0 = 4\,(0.4 + d)$

$V = p_0\,(B^2 - b_0^2)$

$= 212.51 \times 10^{-3}\,[1.850^2 - (0.4 + d)^2]$

$= [-212.51 \times d^2 - 170.008d + 693313.875]$

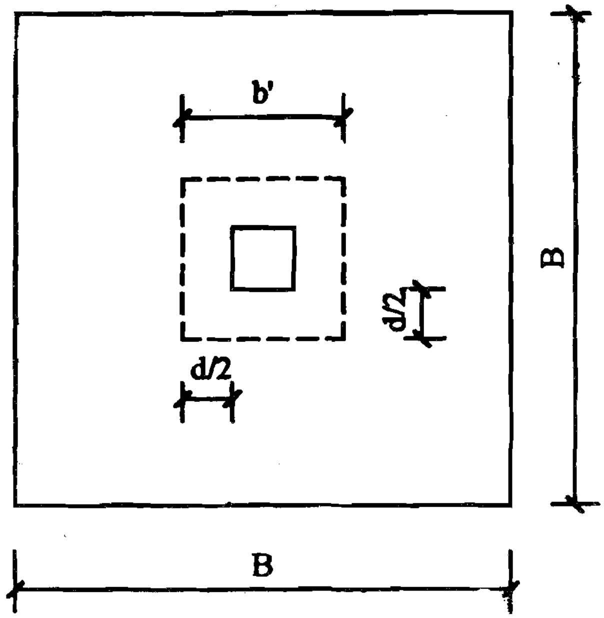


Figure 16.13: Critical Section for Two-Way Shear

$$\therefore \tau_v = \frac{V}{b_0 d} = \frac{-212.51 \times d^2 - 170.008d + 693.313}{4(0.4 + d)d} \text{ kN/m}^2$$

Permissible shear stress = $k_s \tau_c$

where, $k_s = 0.5 + \beta_c = 0.5 + \frac{400}{400} = 1.5 > 1$

Hence $k_s = 1$

$\tau_c = 0.16\sqrt{f_{ck}} = 0.16\sqrt{20} = 715.5 \text{ kN/m}^2$

Equating τ_v and $k_s \tau_c$

$$\frac{(-212.51 \times d^2 - 170.008d + 693.313)}{4(0.4 + d) \times d} = 1 \times 0.715 \times 1000$$

or $d^2 + 0.4276d - 0.2255 = 0$

or $d = 0.30698$ m = 306.98 mm

Providing ϕ16 bars and 40 mm clear cover to bottom layer of reinforcement,

$D = 306.96 + \frac{16}{2} + 16 + 40 = 370.76$ mm

Hence provided $D = 375$ mm

Effective Depth for upper layer of reinforcement

$d_u = 375 - \frac{16}{2} - 16 - 40 = 311$ mm

Effective depth for bottom layer of reinforcement

$d_b = 311 + 16 = 327$ mm

Tensile Reinforcement

Reinforcement of upper layer

$$A_{stu} = \frac{M}{\sigma_{st} j_B d_u} = \frac{103.32 \times 10^6}{140 \times 0.869 \times 311} = 2730.71 \text{ mm}^2$$

$$\text{Spacing for } \phi 16 \text{ bars} = \frac{\frac{\pi}{4} \times 16^2 \times 1850}{2730.71} = 136.22$$

Hence provided ϕ 16 @ 135 c/c

Reinforcement of Bottom layer

$$A_{stb} = \frac{M}{\sigma_{st} j_B d_b} = \frac{103.32 \times 10^6}{140 \times 0.869 \times 327} = 2597.10 \text{ mm}^2$$

$$\text{Spacing} = \frac{\frac{\pi}{4} \times 16^2 \times 1850}{2597.10} = 143.222$$

Hence provided ϕ 16 @ 140 c/c

Check for Development length

$$L_d = \frac{\phi \sigma_s}{4 \tau_{bd}} = \frac{16 \times 140}{4 \times 0.8} = 700 \text{ mm}$$

Providing 40 mm edge cover, length available beyond the critical section for bending (i.e. beyond the face of column)

$$= \frac{1}{2}(B - b) - 40 = \frac{1}{2}(1850 - 400) - 40 = 685 < 700 \text{ mm}$$

Providing 90^0 bend at ends, additional length available = $8\phi = 8 \times 16 = 128$

$\therefore$ Total available length including 90^0 bend at ends of bars = 685 + 128 = 813 > 700 mm
Hence O.K.

Check for Bearing Stress

$A_2 = 400 \times 400 = 16 \times 10^4 \text{ mm}^2$

$A_1 = (400 + 2 \times 2D)^2 = (400 + 4 \times 375)^2 = 361 \times 10^4 \text{ mm}^2$

$\therefore$ Multiplication factor to bearing stress in direct compression(σ_{cbr})

$$= \sqrt{\frac{A_1}{A_2}} = \sqrt{\frac{361 \times 10^4}{16 \times 10^4}} = 4.75 > 2 \quad \text{Hence, adopt factor} = 2$$

Hence permissible bearing stress = $\sqrt{\frac{A_1}{A_2}} . \sigma_{cbr} = 2 \times (0.25 f_{ck}) = 2 \times (0.25 \times 20) = 10 \text{N/mm}^2$

$$\text{Actual Bearing Stress} = \frac{\text{Super-imposed load}}{\text{Loaded area of column bar}}$$

$$= \frac{800 \times 10^3}{400 \times 400} = 5 \text{ N/mm}^2 < 10 \text{ N/mm}^2 \quad \textbf{Hence O.K.}$$

The detailing of the footing has been shown in Figure 16.14.

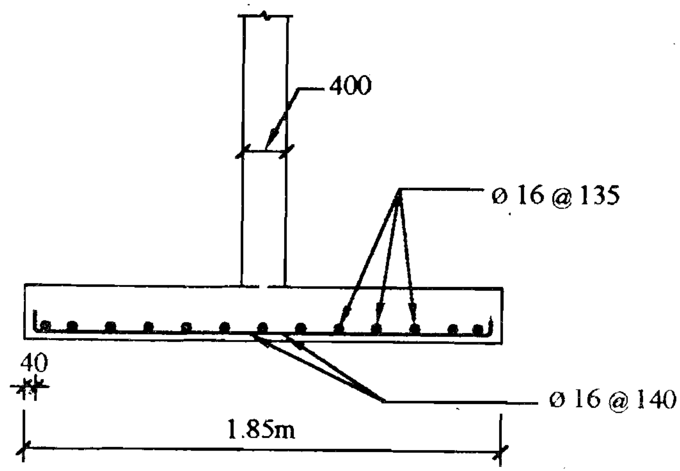


Figure 16.14: Reinforcement Detailing of the Footing

Example 16.3

Design a rectangular footing for a rectangular column of 300 × 400 mm carrying a load of 500 kN. The safe bearing capacity of soil is 150 kN/m². Use M 20 concrete and Fe 250 steel.

Solution

Design Constants

$$m = \frac{280}{3\sigma_{cbc}} = \frac{280}{3 \times 7} = 13.33 = 13$$

$$k_B = \frac{m\sigma_{cbc}}{m\sigma_{cbc} + \sigma_{st}} = \frac{13 \times 7}{13 \times 7 + 140} = 0.394$$

$$j_B = 1 - \frac{k_B}{3} = 1 - \frac{0.394}{3} = 0.869$$

$$R_B = \frac{1}{2}\sigma_{cbc} k_B j_B = \frac{1}{2} \times 7 \times 0.869 \times 0.394 = 1.198$$

Fixing Base Size

Super-imposed Load, P = 500 kN

Self-weight of footings, P'

(Assuming 10% of superimposed load = 50 kN

Total Load ($P + P'$) = 550 kN

$$\text{Area of footing} = \frac{P + P'}{p} = \frac{550}{150} = 3.67 \text{ m}^2$$

Assuming $\frac{L}{B}$ ratio of footing same as that for column

$$L = \frac{4}{3}B$$

$$A = L \times B = \frac{4}{3} B \times B = 3.67$$

or $\quad B = 1.66 \text{ m and } L = \frac{4}{3} \times 1.66 = 2.2 \text{ m}$

Hence provided $A = L \times B = 2.25$ m × 1.75 m size rectangular footing

Net upward soil pressure on footing,

$$p_0 = \frac{P}{A} = \frac{500}{2.25 \times 1.75} = 126.98 \text{ kN/m}^2$$

Determination of Depth

(i) **From Bending Moment Consideration**

Design

a) Design B.M. at *y-y* vide Equation 16.2a and Figure 16.15

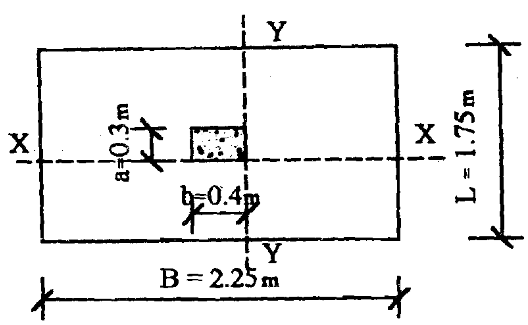


Figure 16.15: Critical Section for B. M.

$$M_1 = \frac{p_0 L}{8} (B - b)^2$$

$$= \frac{126.98 \times 1.75(2.25 - 0.4)^2}{8} = 95.066 \text{ kNm}$$

$$\therefore d_1 = \sqrt{\frac{M}{R_B L}} = \sqrt{\frac{95.066 \times 10^6}{1.198 \times 1750}} = 212.94 \text{ mm}$$

Similarly, Design B.M. at *x-x* vide Equation 16.2(b)

$$M_2 = \frac{p_0 B}{8} (L - a)^2$$

$$= \frac{126.98 \times 2.25(1.75 - 0.3)^2}{8} = 75.087 \text{ kNm}$$

$$\therefore d_2 = \sqrt{\frac{M}{R_B B}} = \sqrt{\frac{75.087 \times 10^6}{1.198 \times 2250}} = 166.90 \text{ mm}$$

(ii) *From Shear Force Consideration*

a) Distance of critical section for *one way shear* = *d* (Figure 16.16)

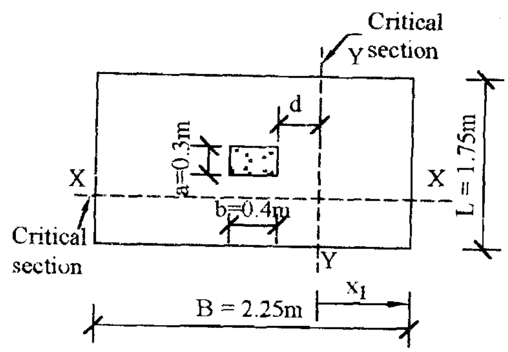


Figure 16.16: Critical Section for One-Way S.F.

Breadth of loaded area from edge parallel to B,

$$x_1 = \left(\frac{B-b}{2} - d\right)$$

$$= \left(\frac{2.25 - 0.4}{2} - d\right)$$

Then from Equation 16.5

$$V_1 = p_0\, L \left(\frac{B-b}{2} - d\right) = 126.98 \times 1.75\ (0.925 - d) = 222.215\ (0.925\ d)\ \text{kN}$$

$$\tau_{v1} = \frac{V_1}{Ld} = \frac{222215(0.925-d)}{1750 \times d} = \frac{0.12698(0.925-d)}{d}\ \text{N/mm}^2$$

For M 20 concrete and Fe 250 reinforcement p_B = 1.0% and correspondingly τ_c = 0.39 N/mm². Assuming depth of footing to be greater than 300, k = 1.

Permissible shear stress = $k\tau_c = 1 \times 0.39$ N/mm² = 0.39 N/mm²

Equating τ_{v1} and $k\tau_c$

$$\frac{0.12698(0.925-d)}{d} = 0.39$$

or $\quad d_1$ = 277.197mm

Similarly,

Breadth of loaded area parallel to L

$$y_1 = \left(\frac{L-a}{2} - d\right) = \left(\frac{1.75 - 0.3}{2} - d\right) = (0.725 - d)$$

Then from Equation 16.7

$$V_2 = p_0\, B\left(\frac{L-a}{2} - d\right) = 126.98 \times 2.25\ (0.725 - d)$$

$$= 285.705\ (0.725 - d)\ \text{kN}$$

$$\tau_{v2} = \frac{V}{Bd} = \frac{285.705(0.725-d)\times 10^3}{2250\times d\times 10^3}$$

$$= \frac{0.12698(0.725-d)}{d} \text{ N/mm}^2$$

Equating τ_{v2} and $k\tau_c$

$$= \frac{0.12698(0.725-d)}{d} = 0.39$$

or $d = 178.07$ mm

(iii) Critical section for *two way shear* is at *d/2* from the face of the column (Figure 16.17) Perimeter of critical section,

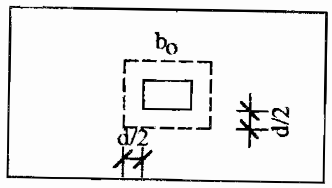


Figure 16.17: Critical Section for Two-way Shear

$$b_0 = 2[(a+d)+(b+d)]$$

$$= (1.4 + 4d)$$

$$V = p\{L\times B - (a+d)(b+d)\}$$

$$= 126.98\,[2.25\times 1.75 - (d^2 + 0.7d + 0.12)] \text{ kN}$$

$$= (-126.98\,d^2 - 88.886d + 484.746) \text{ kN}$$

$$\tau_{v2} = \frac{V}{b_0 d} = \frac{(-126.98d^2 - 88.88d + 484.746)}{(1.4+4d)d} \text{ kN/m}^2$$

Permissible shear stress $k_s\tau_c$

$$k_s = 0.5 + \frac{\text{Short side of column}}{\text{Long side of column}} = 0.5 + \frac{1.75}{2.25} = 1.278 >$$

Hence $k_s = 1$

$$\tau_c = 0.16\sqrt{f_{ck}} = 0.16\sqrt{20} = 0.7155 \text{ N/mm}^2$$

$$\therefore k_s\,\tau_c = 0.7155 \text{ N/mm}^2 = 0.7155 \times 103 \text{ kN/m}^2$$

Equating τ_v and $k_s\tau_c$

$$\frac{(-126.98d^2 - 88.886d + 484.746)}{(1.4+4d)d} = 0.7155\times 10^3$$

or $d^2 + 0.3649d - 0.1622 = 0$; giving $d = 0.25969$ m

or $d = 259.69$ mm

Hence the maximum value of $d = 259.69$ mm

Providing $\phi 12$ as main reinforcement

$D = 259.69 + 40 = 299.69$

Hence provided $D = 300$ mm

$$\therefore\ d_u \text{ for upper layer} = 300 - 40 - \frac{12}{2} - 12 = 242$$

$$\text{and } d_b \text{ for bottom layer} = 300 - 40 - \frac{12}{2} = 254$$

Tensile Reinforcement

(a) For bottom layer $A_{st} = \dfrac{M_1}{\sigma_{st}\, j_b\, d_b} = \dfrac{95.066 \times 10^6}{140 \times 0.869 \times 254} = 3076.41\ \text{mm}^2$

$$\therefore \text{Spacing of } \phi 12 \text{ bars} = \frac{\frac{\pi}{4} \times 12^2 \times 1750}{3076.41} = 64.33$$

Hence provided $\phi 12$ @60 c/c

(b) For upper layer $A_{st} = \dfrac{M_2}{\sigma_{st}\, j_b\, d_u} = \dfrac{75.086 \times 10^6}{140 \times 0.869 \times 242} = 2550.33\ \text{mm}^2$

$$\text{No. of } \phi 12 \text{ bars to be provided} = \frac{2550.33}{\frac{\pi}{4} \times 12^2} = 22.55 \approx 23$$

$$\text{No of bars in the central band} = \frac{2}{\beta + 1} \times 23$$

$$= \frac{2}{\frac{2.25}{1.75} + 1} \times 23 = 20.125 \approx 21$$

$$\text{Spacing of bars in central band} = \frac{1750}{21} = 83.33$$

Hence provided $\phi 12$ @80 c/c in the central band and one bar each on the two outer portions.

Check for Development Length

$$L_d = \frac{\phi \sigma_s}{4 \tau_{bd}} = \frac{12 \times 140}{4 \times 0.8} = 525$$

Providing 40 mm clear edge cover, length available beyond critical section for bending (i.e. beyond face of column) = $\frac{1}{2}\ (L - a) - 40$

$$\left(\frac{1750 - 300}{2}\right) - 40 = 685 > 525 \text{ mm Hence O.K}$$

Check for Bearing Stress

$A_2 = 300 \times 400 = 12 \times 10^4 \text{ mm}^4$

$A_1 = (300 + 4D) = (400 + 4D)$

$= (300 + 4 \times 300)\ (400 + 4 \times 300) = 240 \times 10^4 \text{ mm}^4$

$$\therefore \sqrt{\frac{A_1}{A_2}} = \sqrt{\frac{240 \times 10^4}{12 \times 10^4}} = 4.472 > 2$$

Hence taking = $\sqrt{\frac{A_1}{A_2}} = 2$, permissible bearing stress = $2 \times (0.25 f_{ck})$

$= 2 \times (0.25 \times 20) = 10 \text{N/mm}^2$

$$\text{Actual Bearing Stress} = \frac{\text{Super-imposed load}}{\text{Loaded area of column bar}}$$

$$= \frac{500 \times 10^3}{300 \times 400} = 4.167 \text{ N/mm}^2 < 10 \text{ N/mm}^2$$ **Hence O.K.**

The detailing of the footing has been shown in Figure 16.18.

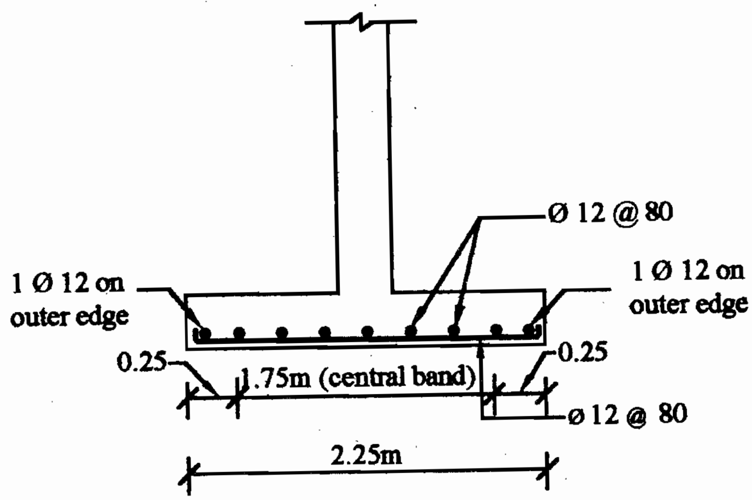


Figure 16.18: Detailing of the Footing

Example 16.4

Design a circular footing for a circular column of 400 diameter carrying 800 kN superimposed load. Use M 15 concrete and Fe 250 steel and bearing capacity of soil, $p = 100 \text{ kN/m}^2$.

Solution

Design constants

$$m = \frac{280}{3\sigma_{cbc}} = \frac{280}{3 \times 5} = 18.67 \approx 19$$

$$k_B = \frac{m\sigma_{cbc}}{m\sigma_{cbc} + \sigma_{st}} = \frac{19 \times 5}{19 \times 5 + 140} = 0.404$$

$$j_B = 1 - \frac{k_B}{3} = 1 - \frac{0.404}{3} = 0.865$$

$R_B = \frac{1}{2}\sigma_{cbc} k_B j_B = \frac{1}{2} \times 5 \times 0.404 \times 0.865 = 0.87$

Fixing Base Size

Super-imposed Load, P = 800 kN

Self-weight of footings, P'

(Assuming 10% of superimposed laod) = 80 kN

Total Load ($P + P'$) = 880 kN

Area of footing $= \frac{P+P'}{p} = \frac{880}{100} = 8.8 \text{ m}^2$

Required dia. of circular footing $= \sqrt{\frac{8.8}{\pi/4}} = 3.35$ m

Hence provided circular footing of 3.5 m diameter

Net upward soil pressure, $p_0 = \frac{P}{A} = \frac{800}{\frac{\pi}{4} \times 3.5^2} = 83.15 \text{ kN/m}^2$

Determination of Depth

(i) **From Bending Moment Consideration**

B.M. at the face A A' (Figure 16.19) of the column due to upward net pressure p_0 on area AA'B'B (i.e. area of quadrant of the circular footing minus the area OAA' beneath of the column).

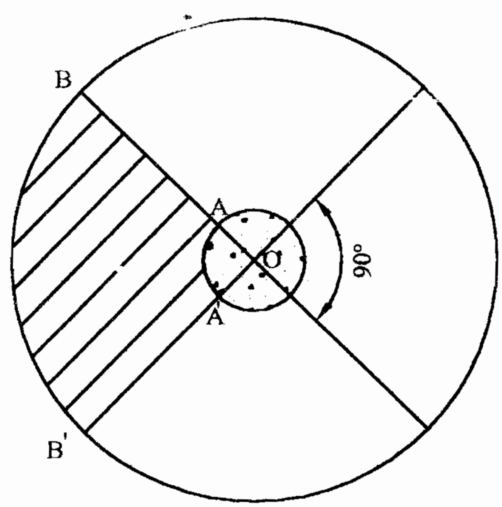


Figure 16.19: Critical Section for B. M.

$M = p_0 \frac{\pi}{20} (R - r)(3R^2 - 2Rr - 2r^2)$

where R = radius of footing, and

r = radius of column

$= 83.15 \times \frac{\pi}{20} (1.75 - 0.2)(3 \times 1.75^2 - 2 \times 1.75 \times 0.2 - 2 \times 0.2^2) = 170.208$ kNm

$$\therefore d = \sqrt{\frac{M}{R_B b}} = \sqrt{\frac{170.208 \times 10^6}{0.87 \times AA'}} = \sqrt{\frac{170.208 \times 10^6}{0.87 \times \left(\frac{\pi}{2} \times 200\right)}}$$

ii) *From Shear Force Consideration*

(a) Distance of critical section for *one way shear* = *d* (Figure 16.20).

Shear force at critical section, *aa'*

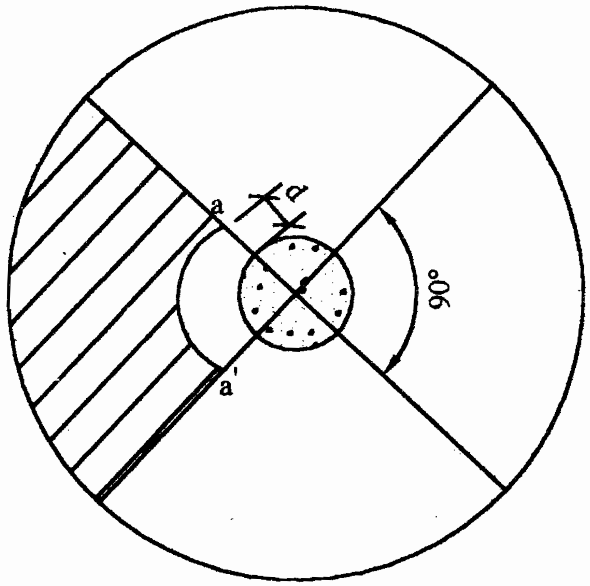


Figure 16.20: Critical Section for One-way Shear Force

$$V = p_0 \frac{\pi}{4} \left\{R^2 - (r + d)^2\right\}$$

$$= 83.15 \frac{\pi}{4} \left\{1.75^2 - (0.2 + d)^2\right\}$$

$$= 65.31 (-d^2 - 0.4d + 3.0225) \text{ kN}$$

$$\therefore \tau_v = \frac{V}{bd} = \frac{65.319(-d^2 - 0.4d + 3.0225)}{(\text{aa}')d} \text{ kN/m}^2$$

For M 15 concrete and Fe 250 steel

$p_B = 0.72\%$

$\tau_c = 0.334$ N/mm²

Assuming $D > 300$, $k = 1$,

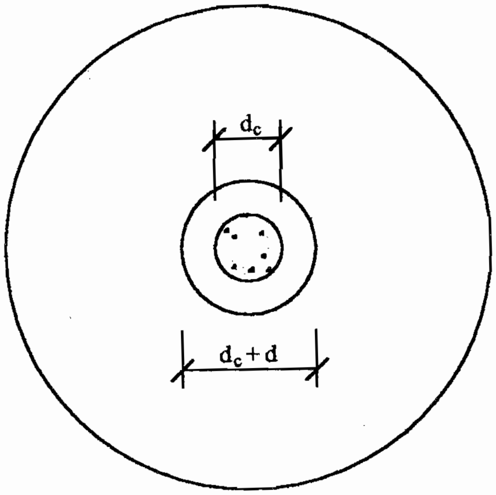
Permissible shear stress = $k\tau_c = 1 \times 0.334$ N/mm² = 0.334 N/mm² = 0.334×10^3 kN/m²

Equating τ_v and $k\tau_c$

$$\frac{65.31\,(-d^2 - 0.4\,d + 3.0225) \times 10^{-3}}{\frac{\pi}{2}(d+0.2)\,d \times 10^6} = 0.334 \times 10^3$$

or $\quad d = 0.47794 \text{ m} = 477.94\text{mm}$

(b) Critical section is at $d/2$ from the face of column for *two-way* shear (Figure 16.21).



1 1: Critical Section for Two-way Shear Force

$$V = p_0\pi\left[R^2 - \left(r + \frac{d}{2}\right)^2\right]$$

$$= 83.15\,\pi \times \left[1.75^2 - \left(0.2 + \frac{d}{2}\right)^2\right]$$

$$= 261.223\,[3.0225 - 0.2d - 0.25d^2]$$

$$\tau_v = \frac{V}{b_0 d} = \frac{261.223\,[-0.25d^2 - 0.2d + 3.0225\,] \times 10^3}{\left\{2\pi\left(0.2 + \frac{d}{2}\right)\right\} d \times 10^6}$$

Permissible shear stress = $k_s \tau_c$

where, $k_s = 0.5 + \beta_c = 0.5 + \dfrac{\text{Short side of column}}{\text{Long side of column}} = 0.5 + \dfrac{3.5}{3.5} = 1.5 > 1$

$\therefore k_s = 1$

$\tau_c = 0.16\sqrt{f_{ck}} = 0.16\sqrt{15} = 0.62 \text{ N/mm}^2$

Equating τ_v and $k_s \tau_c$

$$= \frac{261.223\ [-0.25\ d^2 - 0.2\ d + 3.0225\ ] \times 10^3}{\left\{2\pi\left(0.2 + \frac{d}{2}\right)\right\}}$$

or $d = 452.926$ mm

From above analysis the greatest value of $d = 789.143$; therefore, for $\phi 12$ tensile reinforcement

$$\therefore D = 789.143 + \frac{12}{2} + 12 + 40 = 847.143 \text{ mm}$$

Hence provided $D = 850$ mm

The effective depth for bottom tensile reinforcement $d_1 = 850 - 6 - 40 = 804$ and effective depth for top tensile reinforcement $d_2 = 804 - 12 = 792$

Tensile Reinforcement

Tensile reinforcement in the bottom layer

$$A_{st1} = \frac{M}{\sigma_{st} j_B d_1} = \frac{170.208 \times 10^6}{140 \times 0.865 \times 804} = 1748.154 \text{ mm}^2$$

$$\text{No. of } \phi 12 \text{ bar} = \frac{11748.154}{\frac{\pi}{4} \times 12^2} = 15.46 \approx 16$$

Similarly tensile reinforcement in the upper layer,

$$A_{st2} = \frac{M}{\sigma_{st} j_B d_2} = \frac{170.208 \times 10^6}{140 \times 0.865 \times 792} = 1774.641 \text{ mm}^2$$

$$\text{No. of } \phi 12 \text{ bar} = \frac{1774.641}{\frac{\pi}{4} \times 12^2} = 15.69 \approx 16$$

These $16\phi 12$ bars each shall be provided in orthogonal directions within the inscribed square shown by dotted line in Figure 16.22. Nominal reinforcements may be provided outside the inscribed square.

Check for Development Length

$$L_d = \frac{\phi \sigma_s}{4\tau_{bd}} = \frac{12 \times 140}{4 \times 0.6} = 700$$

Providing 60 mm end cover length available

$$= \frac{2475^* - 400}{2} - 60 = 977.5 > 700 \textbf{ Hence O.K.}$$

Check for Bearing Pressure

$$A_2 = \frac{\pi}{4} \times 400^2 = 125663.706 \text{ mm}^2$$

$$A_1 = \frac{\pi}{4}(400 + 4D)^2 = \frac{\pi}{4}(400 + 4 \times 850)^2 = 11341149.48 \text{ mm}^2$$

---

* = Half the side of the inscribed square.

$$\therefore \sqrt{\frac{A_1}{A_2}} = \sqrt{\frac{11341149.48}{125663.706}} = 9.5 > 2$$

Hence $\sqrt{\frac{A_1}{A_2}} = 2$

$\therefore$ Permissible bearing stress = $\sqrt{\frac{A_1}{A_2}}$ $= (0.25\, f_{ck}) = 2 \times (0.25 \times 15\ ) = 7.5\ ^{N}/_{mm^2}$

Actual bearing stress $= \frac{P}{\text{Loaded Area}} = \frac{800 \times 10^3}{\frac{\pi}{4} \times (400)^2} = 6.367\ \text{N/mm}^2 < 75\ \text{N/mm}^2$ **Hence O.K.**

The details of footing have been shown in Figure 16.22.

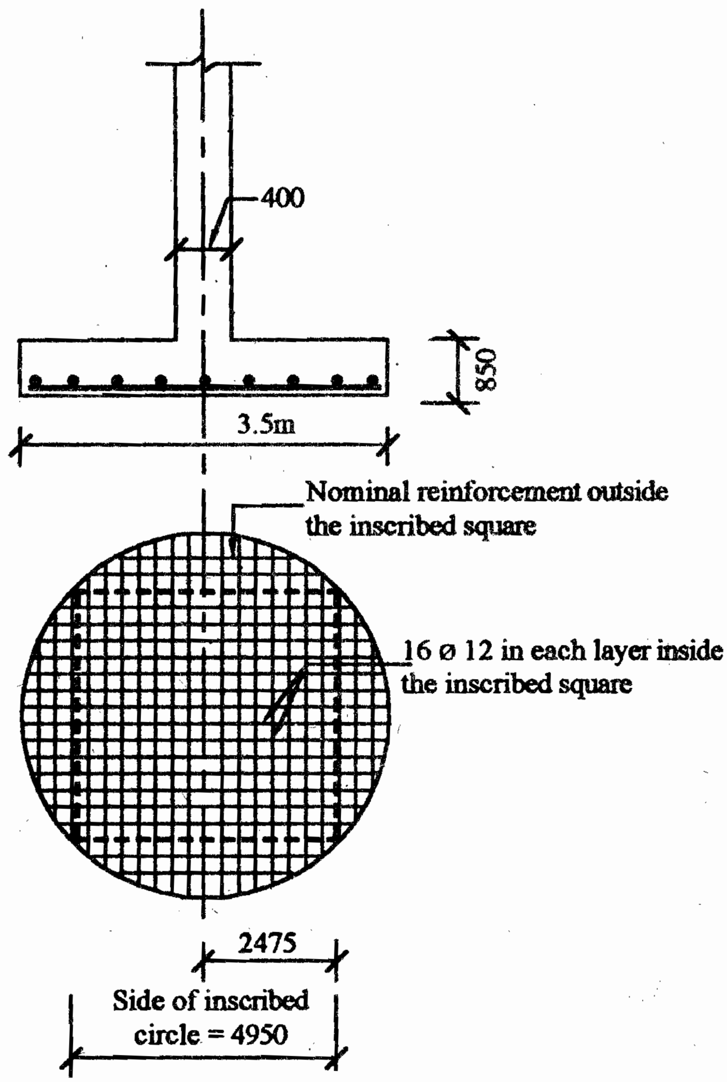


Figure 16.22: Details of the Designed Footing

SAQ 3

(i) Explain the procedure for fixing total depth D of footing.

(ii) How bearing stress at the interface of column and footing are tested ? What provisions can be made if bearing stress at the junction of column and footing is exceeded ?

(iii) Design a R.C. footing for a *masonry* wall 300 mm wide for a superimposed load of 500 kN/m, the safe bearing capacity of soil is 200 kN/m^2. Use M 20 concrete and Fe 415 steel.

(iv) Design a square footing for a circular column of 400 diameter carrying 800 kN superimposed load. Use M15 concrete and Fe 250 steel and bearing capacity of soil, p = 100 kN/m^2.

16.4 SUMMARY

A strip and spread footing are shallow foundation types transmitting superimposed loads through walls and through column respectively to the soil. Normally, loads to be transmitted are gravity and lateral loads. The transference of loads is through bearing in such types of foundation and, therefore, depth of footing below ground depends upon availability of strata of soil of adequate bearing capacity. The size of footing is a function of loads and bearing capacity of soil; whereas its depth is determined on bending moment and shear force considerations. The tensile reinforcement is provided in the usual way. The bearing of column on footing at their interface is to be within permissible limits. The determination of bearing pressure and its permissible limit is done as per IS 456-1978. The principles and procedure for design of different types of footings have been explained through examples.

16.5 ANSWERS TO SAQs

SAQ 1

i) Refer Section 16.1

ii) Refer Section 16.1

SAQ 2

i) Refer Section 16.2

SAQ 3

i) Refer Section 16.3

ii) Refer Section 16.3

iii) The design and detailing will be the same as those for footing under *concrete* wall, except that the critical section for B.M. will be taken at *half way* between centre line and edge of the wall.

iv) **Solution**

This example has the same data as those for Example 16.4. Hence only salient points of design have been given below :

Size of Footing

Side $B = \sqrt{A} = \sqrt{8.8} = 2.96$ m

Providing $B = 3$ m, $p_0 = \dfrac{800}{3^2} = 88.89$ kN/m^2

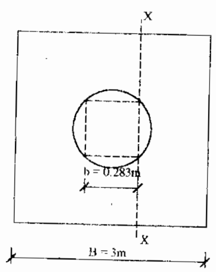


Figure 16.23: Critical Section for B. M.

Determination of Depth

i) *From B.M. consideration*

Side of inscribed square = $\frac{400}{\sqrt{2}}$ = 282.84 mm

$\therefore M = \frac{p_0}{8}(B - b) = 246.07$ kNm. (Figure 16.23)

$d = \sqrt{\frac{M}{R_B B}} = 307.05$ mm

ii) *From S.F. consideration*

a) Critical section is at d form face of side of inscribed square, and taking multiplying factor of τ_c, $k = 1$

$d = 285.55$ mm

b) Critical section is at $\frac{d}{2}$ from two-way action consideration and from which

$d = 428.12$ mm

$\therefore$ Total depth of footing $D = 500$

The remaining design is the same as that mm for a square column (inscribed square in this case) on a square footing.