Foundation or Footing Theories and Design: Part 2

Isolated Foundation or Footing transmit column load to the underlying soil.

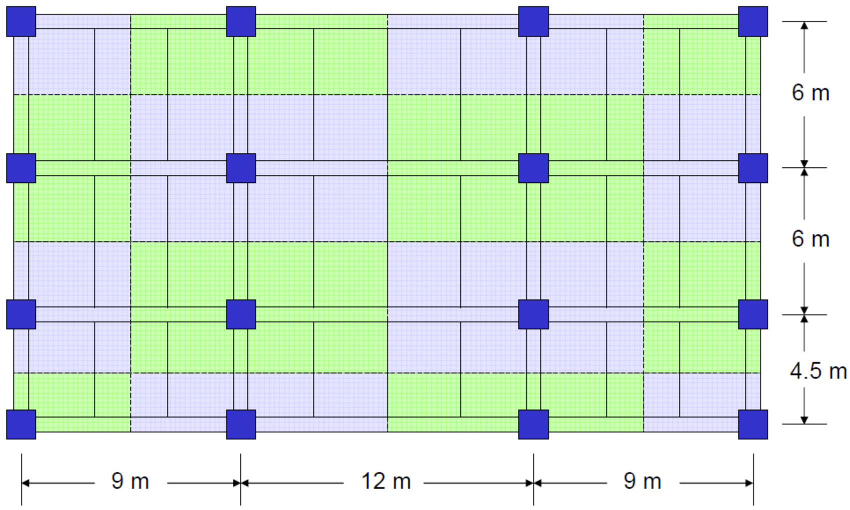


Figure: Tributary area for columns shown in shades/colors

Design of Square Isolated Footings

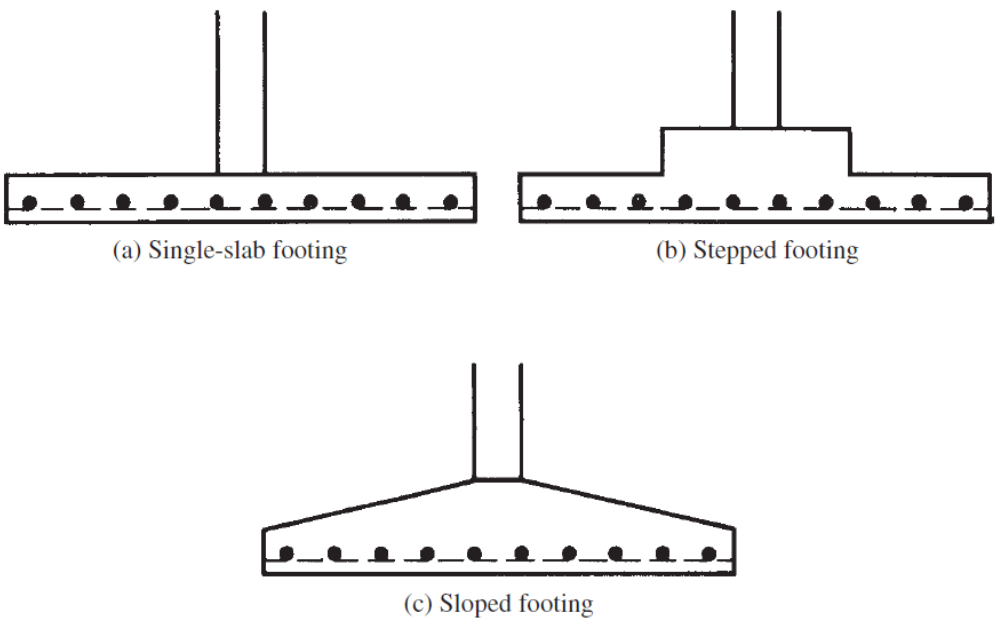
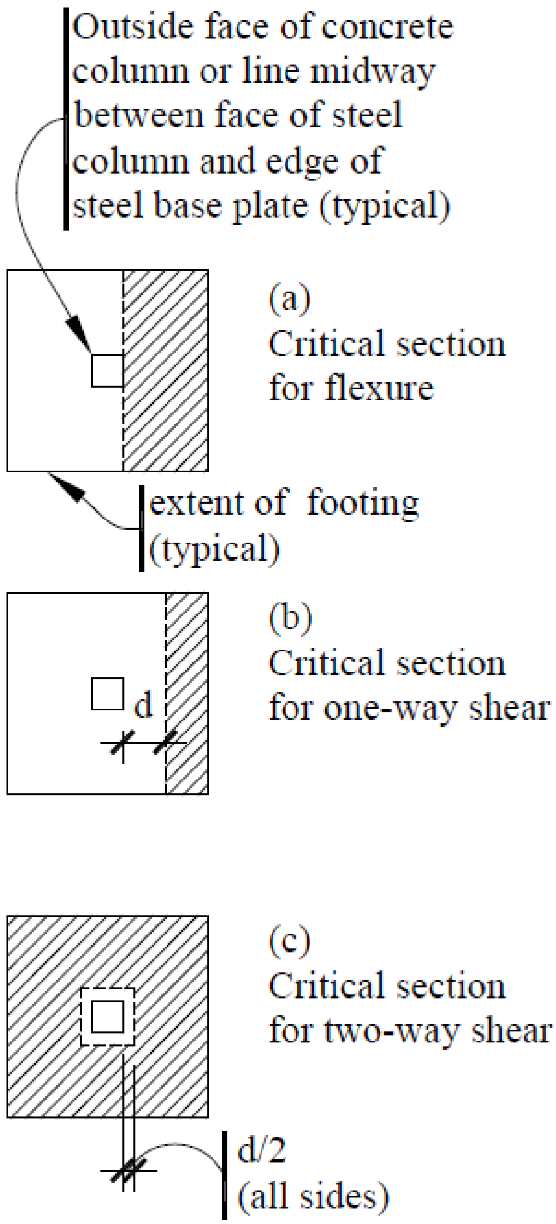
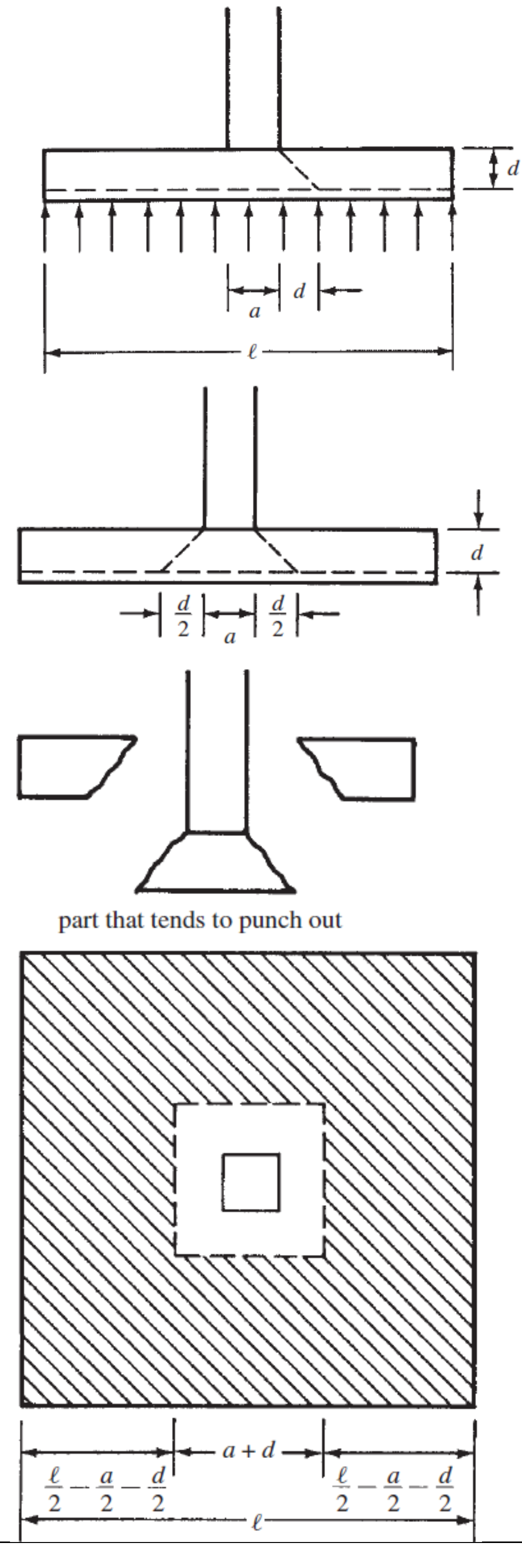


Figure: Shapes of isolated footings.

Shear


Outside face of concrete column or line midway between face of steel column and edge of steel base plate (typical)
(a)
Critical section for flexure
extent of footing (typical)
(b)
Critical section for one-way shear
d
(c)
Critical section for two-way shear
d/2 (all sides)


d
a
d
ℓ
d
d/2
a
d/2
part that tends to punch out
a + d
ℓ/2 − a/2 − d/2
ℓ/2 − a/2 − d/2
ℓ

Moments

The bending moment in a square reinforced concrete footing with a square column is the same about both axes because of symmetry. If the column is not square, the moment will be larger in the direction of the shorter column dimension. It should be noted, however, that the effective depth of the footing cannot be the same in the two directions because the bars in one direction rest on top of the bars in the other direction. The effective depth used for calculations might be the average for the two directions or, more conservatively, the value for the bars on top.
The critical section for bending is taken at the face of a reinforced concrete column or halfway between the middle and edge of a masonry wall or at a distance halfway from the edge of the base plate and the face of the column if structural steel columns are used.

Two way or Punching Shear

As discussed in Section 13.10, the ACI Code equations (13.11*a,b,c*) give the nominal punching-shear strength on this perimeter:

$$V_c = 4\lambda\sqrt{f'_c}\, b_o d \qquad (16.7a)$$

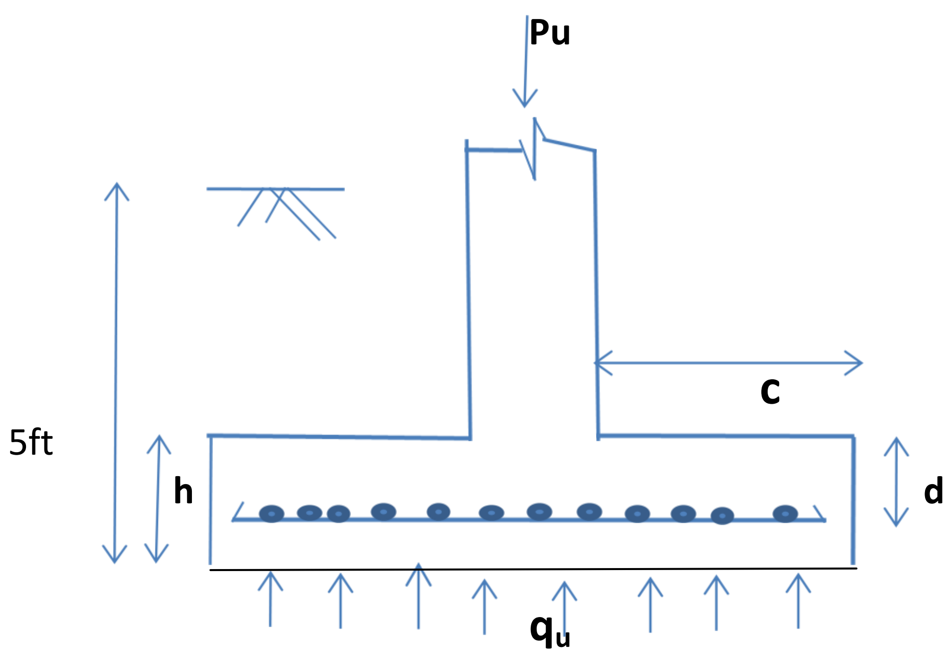
One way or Beam Shear

$$V_c = 2\lambda\sqrt{f'_c}\, bd$$

The required depth of footing *d* is then calculated from the usual equation

$$V_u \le \phi V_c$$

Example.1: Design footings for the interior column of a building. Assume, base of footing location 5' below ground level . Permissible soil pressure , $q_a = 6$ ksf .Gravity loads: P_{DL} = 351 kips , P_{LL} = 56.4 kips, Service Moment, $M_{service}$ = 75.4 k-ft, column size = 16" x 16"



1.Design Data :

Assume, Weight of soil plus concrete above footing base =135 pcf
(When, soil is wet packet use, weight of soil = 130 pcf; otherwise 100 pcf)
Interior column = 16” x 16”
f’c = 4000 psi (for both footing and column), fy = 60ksi

2.Load Combination :

a) Gravity loads: from column, P_{DL} = 351 kips, P_{LL} = 56.4 kips
Service Moment for column, $M_{service}$ = 75.4 k-ft

3. Base Area of Footing Calculation:

Weight of surcharge, soil plus concrete depth for footing = (135pcf ×5ft/1000) = 0.675 ksf
Total surcharge = 0.675+0.00, extra surcharge if any = 0.675 ksf

so, Net permissible soil pressure = (6 – 0.675) = 5.325 ksf

Area of footing , $A_f = (\frac{351+56.4}{5.325})$ = 76.5 sq. ft.

Try 9ft × 9ft square footing . (A_f = 81 sq. ft.)

Now, we know, Sectional Modulus, S = I/c, where c is the distance from the neutral axis to the most extreme fibre, I= moment of inertia, or, S = I/c = (bh^3/12) / (h/2)

so**, S = bh^2/6**

$$\mathbf{S} = \left(\frac{9 \times 9^2}{6}\right) = 121.5 \text{ ft}^3$$

As, $A_f = 81$ ft^2

Now, Stress, $q = \frac{P}{Af} + \frac{M}{Sf} = \frac{407.4}{81} + \frac{75.4}{121.5}$ =5.02+0.62 =5.64 ksf > 5.325 ksf (Not OK)

Try, 9.5 ft × 9.5 ft square footing (A_f = 90.25 ft^2),S = $\left(\frac{9.5 \times 9.5^2}{6}\right)$ = 121.5 ft^3**= 142.9** ft^3

$$q = \frac{351+56.4}{90.25} + \frac{75.4}{142.9}$$
= 5.04 ksf < 5.325 ksf (Ok)

4. Footing Thickness :

Now, *ρ for bending =As/bd* [Note: Minimum steel ratio for shrinkage and temperature in slab for 60 grade steel, is $\rho = 0.0018$. Now assume, $\rho = 0.002$ in the Rn equation below, since slab thickness, h > d]

$R_n = \rho$ fy (1- $0.5\rho fy/(0.85f'c)$)
$= 0.002 \times 60,000 \left(1- \frac{0.5\times0.002\times60000}{0.85 \times 4000}\right)$
= 117.9 psi

$d^2_{\ required} = \frac{Mu}{\varphi\ Rn} = \frac{Mu\ \times1000}{0.9 \times 117.9} = 9.43\ Mu$ .... (1)

However, wL.(L/2) **Mu = $(\frac{Pu}{Af})(\frac{c^2}{2})$** .... (2) [as, (Pu / A_f) = w = q_u] [Note; wL.(L/2)]

Now, from eqn. (1) , d^2_{req} = 9.43 Mu

$= 9.43x\ (\frac{Pu}{Af})(\frac{c^2}{2})$ (from eqn. 2)

$= \sqrt{9.43 * \frac{Pu}{Af} * \frac{c^2}{2}}$

so, $\mathbf{d_{required} = 2.2\ c \sqrt{\frac{Pu}{Af}}}$

Now, **bearing pressure for strength design** = Factored load/ Area of footing = P_u/A_f

Pu = 1.2DL(351)+1.6LL(56.4) = 511.44

Bearing pressure =511.44/90.25 =5.67 ksf, or **q_u net** =5.67 ksf

Footing projection , c = $\frac{(9.5-\frac{16}{12})}{2} ft = 4.08'$

h = 2.2 c $\sqrt{\frac{Pu}{Af}}$ + 4 (considering, more than 3" required clear cover + bar dia.)

h = 2.2 *4.08* $\sqrt{\frac{511.44}{90.25}}$ + 4

= 25.4 in

Try, h = 27 in.

so, d = 27-4 = 23 in.

One way shear check:

<u>Considering beam Shear or One way shear :</u>

Beam shear , Vb = qu × Beam strip length × (c-d)

=5.67×9.5×2.167

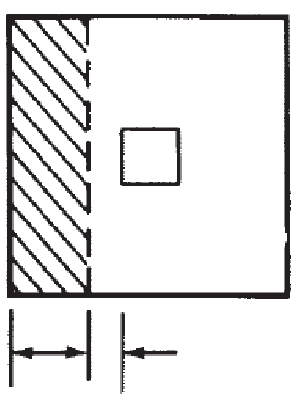
=116.72 kips

Allowable shear, Va = 2φ$\sqrt{f'c}$ b d

= (2×.75×$\sqrt{4000}$× (9.5×12) ×23)/1000

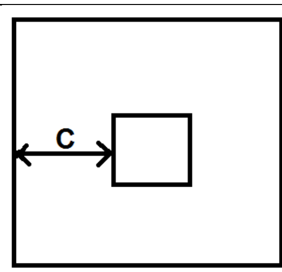
= 248.71 Kips

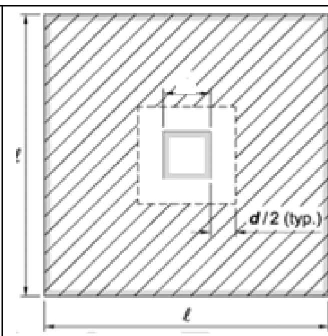
Since, Va > Vb , therefore, OK.



<C-d><d>

Beam or One way Shear





Two –way or Punching Shear

<u>Considering punching Shear or Two way shear :</u>

Punching shear , Vp = Factored load, or q_u× Footing area – Punched out area× q_u

= 9.5×9.5×5.67 – [(39×39)/144] ×5.67 = 451.55 Kips

Allowable shear, Va = 4φ$\sqrt{f'c}$ b d

= (4*.75*$\sqrt{4000}$*(39*4)*23)/1000

= 680.77 Kips

Since, Va > Vp , therefore OK.

<u>The Bending Moment:</u>

Mu =(5.67*9.5*(4.08))^2)/2 = 448.3 k-ft

[Note: Mu = ($q_u \times b \times c^2$)/2; considering moment for the whole width of footing]

Reinforcements : $A_s = \frac{Mu}{\emptyset fy\,(d-\frac{a}{2})}$

=448.3*12/[0.9*60*(23-8/2)]; [assumed, a = 8 inches]

= 5.24 in^2 ;

a= $\frac{As\,fy}{.85f'cb}$

= (5.43*60)/*(.85*4*12) = =7.98 inches; very close to 8 inches assumed, therefore, OK;

A_s required= 5.24 in^2.

Now, Minimum reinforcement for flexure,

A_s (minimum) = 200*b*d/fy

=(200*9.5*12*23)/60000 =8.74 in^2

A_s (minimum) =8.74 in^2; within 9.5 ft footing width, controls.

Since, it is square footing, use 9 #9 bar (Area provided 9 in^2) in each direction.

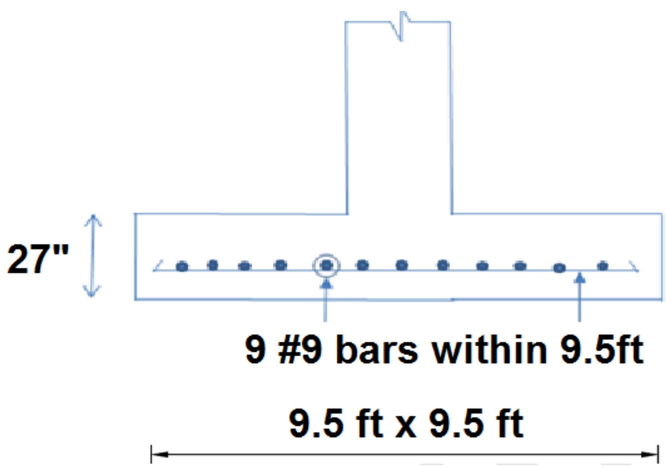


Figure: Detail of reinforcement

The reinforcement ratio is calculated based on rectangular section design, where the minimum reinforcement ratio ρ_{min} is not to be less than *0.0018*.