Combined Footings

- When a foundation is built close to an existing building or the property line, there may not be sufficient space for equal projections on the sides of the exterior column. This results in an eccentric loading on the footing. It may lead to the tilting of the foundation. To counteract this tilting tendency, a combined footing is provided which joins the exterior column with an interior column. A combined footing is also required when the two individual footings overlap.

- The footing is proportioned such that the centre of gravity of the footing lies on the line of action of the resultant of the column loads. The pressure distribution thus becomes uniform.
- A combined footing is generally rectangular in plan if sufficient space is available beyond each column.
- If one of the columns is near the property line, the rectangular footing can still be provided if the interior column is relatively heavier.
- However, if the interior column is lighter, a trapezoidal footing is required to keep the resultant of the column loads through the centroid of the footing. Thus the resultant of the soil reaction is made to coincide with the resultant of the column loads.

COMBINED FOOTINGS

Definition:

A footing supporting two or more columns in a single row is called as a combined footing. This is used:

1. For a boundary column to reduce differential settlement
2. For weak soils having high compressibility and
3. Small spacing of columns carrying heavy loads

Design Philosophy:

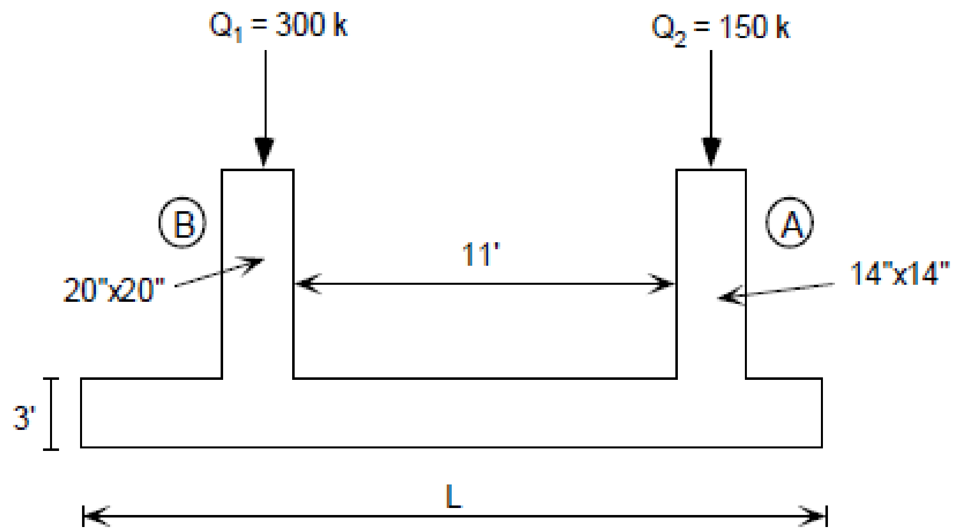
Design the footing so that the centre of gravity (c.g) of the footing coincides with the line of action of the resultant force. This will help in generating a uniform pressure underneath the common pad, reduce the tendency of overturning and differential settlement.

1. For a case where exterior column loading is greater than interior; a trapezoidal shape will be needed.

2. When the interior column is heavily loaded, then a rectangular footing is required.

Example:

Design a combined footing of width $B = 5$ ft



Q_1 and Q_2 are net loads, $q_a = 4$ ksf $\gamma_c = 150$ pcf

Solution:

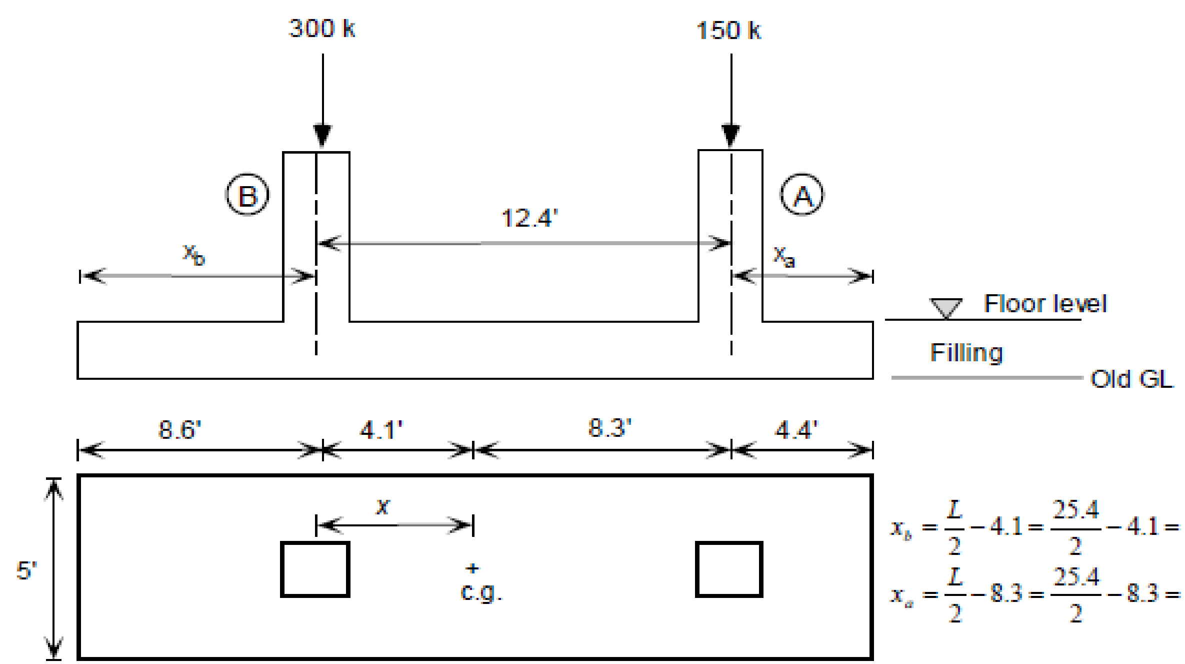
Safe net bearing capacity, $q_{sn} = 4000 - 3\times150 = 3550$ psf = 3.550 ksf

Area of footing, $A = \dfrac{Q_n}{q_{sn}} = \dfrac{450}{3.550} = 126.76\ \text{ft}^2$

For $B = 5$ ft $\qquad L = 126.76/5 = 25.352$ ft $\qquad$ use $L = 25.4$ ft.

Locate the position of the resultant force R by taking moment about column B. Let x be the distance between column B and the resultant force.

$450 \times x = 150\ (11 + 10/12 + 7/12) \qquad \Rightarrow x = 4.14$ ft $\qquad$ use 4.10 ft



$x_b = \dfrac{L}{2} - 4.1 = \dfrac{25.4}{2} - 4.1 = 8.6'$

$x_a = \dfrac{L}{2} - 8.3 = \dfrac{25.4}{2} - 8.3 = 4.4'$

Example:

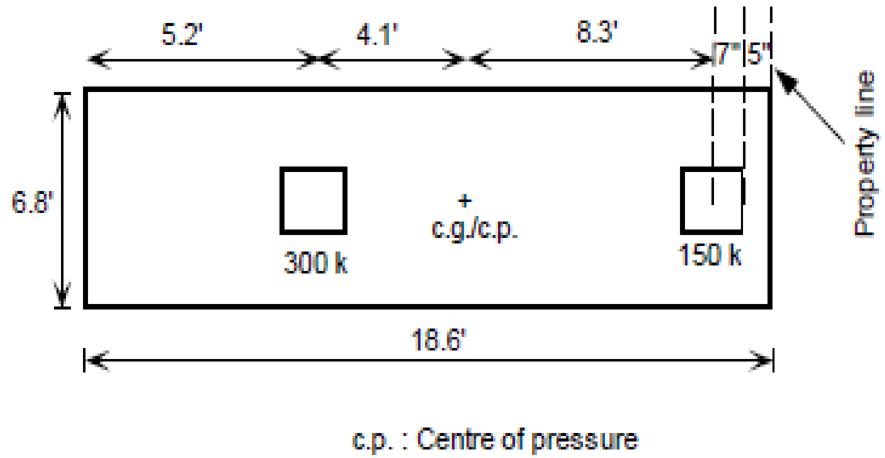
Redo the previous example if outer edge of column *A* is 5 inch from the property line.

Solution:

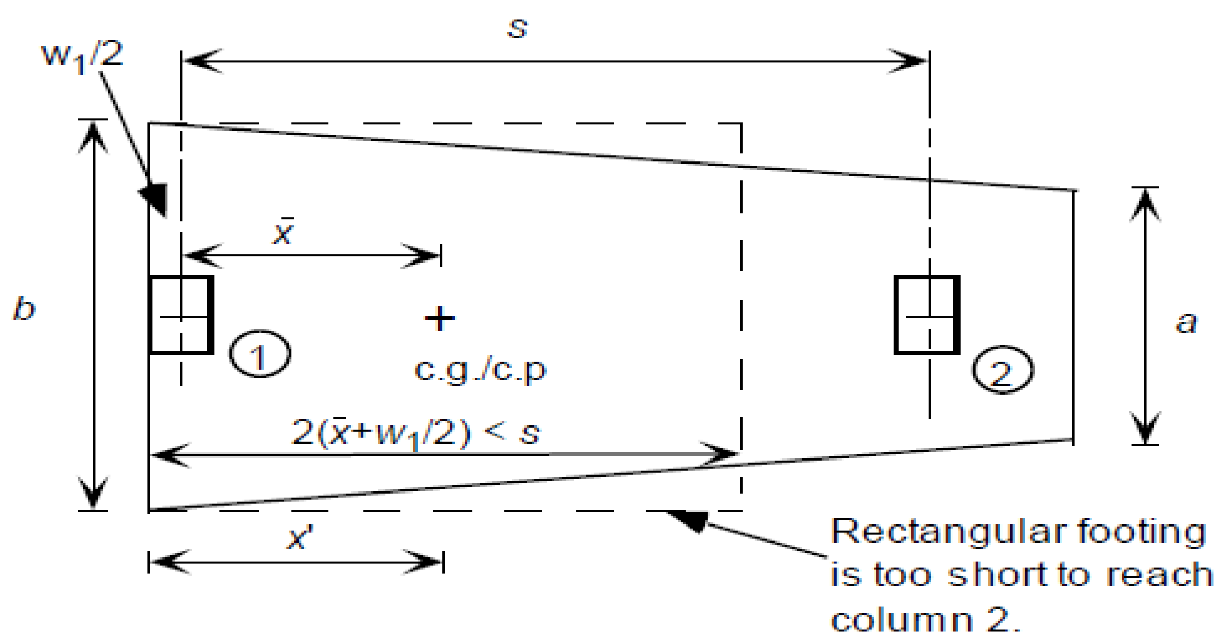
$$\frac{L}{2}=\left(8.3+\frac{7''+5''}{12}\right)=9.3'$$

$\therefore \quad L = 18.6$ ft

and $\quad B=\dfrac{126.76}{18.6}=6.8$ ft



Design of Trapezoid-shaped Footings



A combined footing will be trapezoid-shaped if the column which has too limited space for a spread footing carries the larger load. In this case the resultant of the column loads (including moments) will be closer to the larger column load and doubling the centroid distance as done for the rectangular footing will not provide sufficient length to reach the interior column. The footing geometry necessary for a trapezoid-shape footing is illustrated in the Figure above from which we obtain:

$$A = \frac{a+b}{2} L \qquad 1$$

$$x' = \frac{L}{3} \frac{2a+b}{a+b} \qquad 2$$

From Eq. 2 and the Figure, it can be seen that the solution for $a = 0$ is a triangle and if $a = b$, we have a rectangle. Therefore, it follows that a trapezoid solution exists only for $L/3 < x' < L/2$ with minimum value of L as out-to-out of the column faces. The value of L must be known and the area A will be based on the soil pressure and column loads ($A = \frac{\sum P}{q_a}$ or $\frac{\sum P_u}{q_{ult}}$). The forming and reinforcing steel for a trapezoid shape footing is somewhat awkward to place. For these reasons, it may be preferable to use a strap footing where possible, since essentially the same goal of producing a computed uniform soil pressure is obtained.

Example: Proportion a trapezoidal footing using factored loads (i.e. USD).

Solution:

$Q_{u1} = 1.4 \times 1200 + 1.7 \times 816 = 3067.2$ kN

$Q_{u2} = 1.4 \times 900 + 1.7 \times 660 = 2382.0$ kN

$\therefore\ Q_u = 3067.2 + 2382.0 = 5449.2$ kN

and $Q = 2016 + 1560 = 3576$ kN

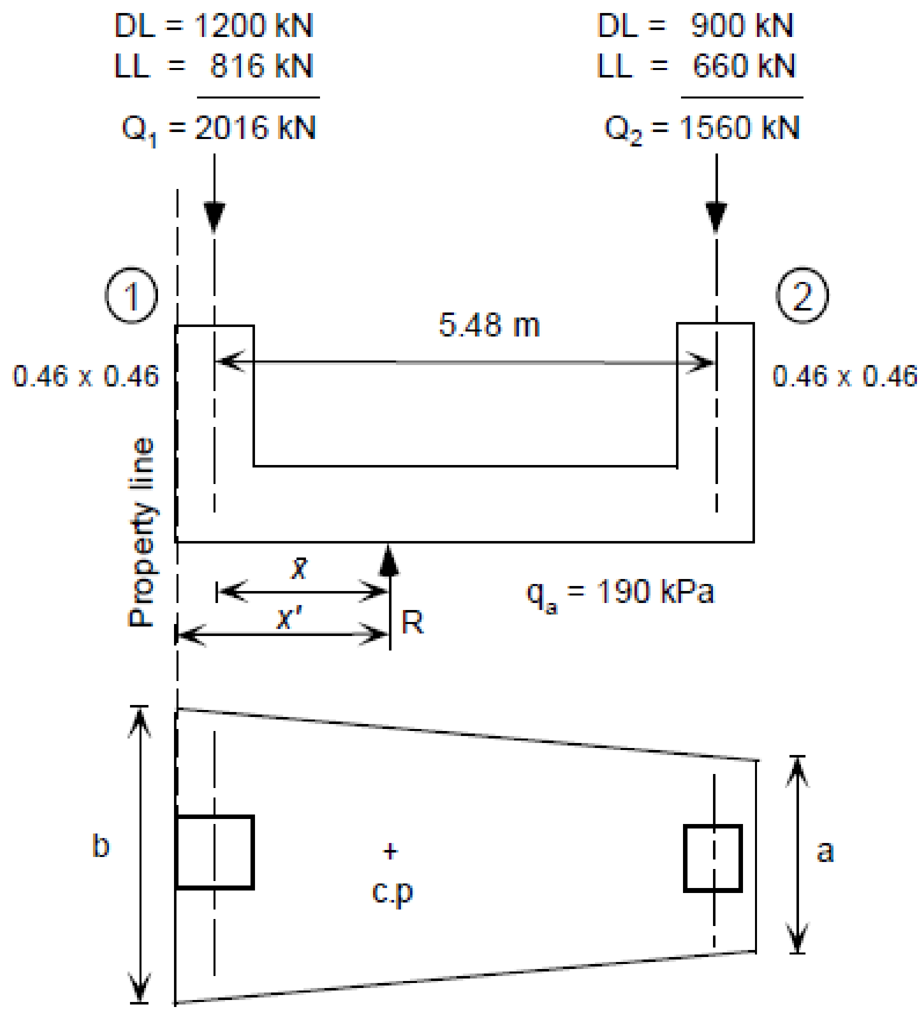
Pseudo bearing capacity (ultimate),

$$q_u = \frac{Q_u}{Q} q_a = \frac{5449.2}{3576} \times 190 = 289.53 \text{ kPa}$$

Taking moment about column 1:

$5449.2 \times \bar{x} = 5.48 \times 2382 \quad \Rightarrow$

$\bar{x} = 2.395$ m



$$\therefore\ x' = \bar{x} + \frac{0.46}{2} = 2.395 + 0.23 = 2.625\ \text{m} \qquad \text{(i)}$$

$L_{\text{min.}} = 5.48 + 0.46 = 5.94$ m

Since $\frac{L}{2} > x' > \frac{L}{3}$ we have a trapezoid for which

$$x' = \frac{L}{3} \times \frac{2a+b}{a+b} \qquad \text{or}$$

$$x' = \frac{5.94}{3} \times \frac{2a+b}{a+b} = 2.625 \qquad \text{or} \qquad \frac{2a+b}{a+b} = 1.326 \qquad \text{(ii)}$$

For a trapezoid, $A = \left(\frac{a+b}{2}\right) \times L$ Also $A = \frac{Q_u}{q_u} = \left(\frac{a+b}{2}\right) \times 5.94$

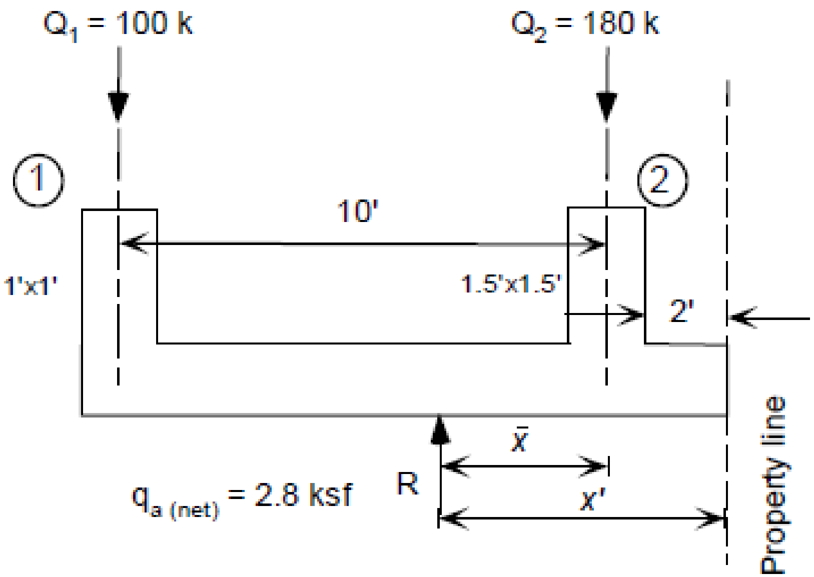
or $\frac{5449.2}{289.53} = (a+b) \times 2.97 \Rightarrow (a+b) = 6.337$ (iii)

From (ii) $2a + b = 1.326 \times 6.337 = 8.403$ (iv)

Using equations (iii) and (iv), $a = 2.065$ m $b = 4.273$ m

Example: Proportion the combined footing where Q_1 and Q_2 are the net loads.

Solution:



Taking moment about column 2

$$280 \times \bar{x} = 100 \times 10 \qquad \therefore \bar{x} = 3.57'$$

and

$$x' = \bar{x} + 0.75 + 2.0 = 3.57 + 2.75 = 6.32'$$

Length from Figure,

$$L = 10 + 0.5 + 0.75 + 2 = 13.25 \text{ ft}$$

Since $\frac{L}{2} > x' > \frac{L}{3}$ we have a trapezoid for which

$$x' = \frac{L}{3} \times \frac{2a+b}{a+b} = \left(\frac{13.25}{3}\right)\left(\frac{2a+b}{a+b}\right) \qquad \text{(i)}$$

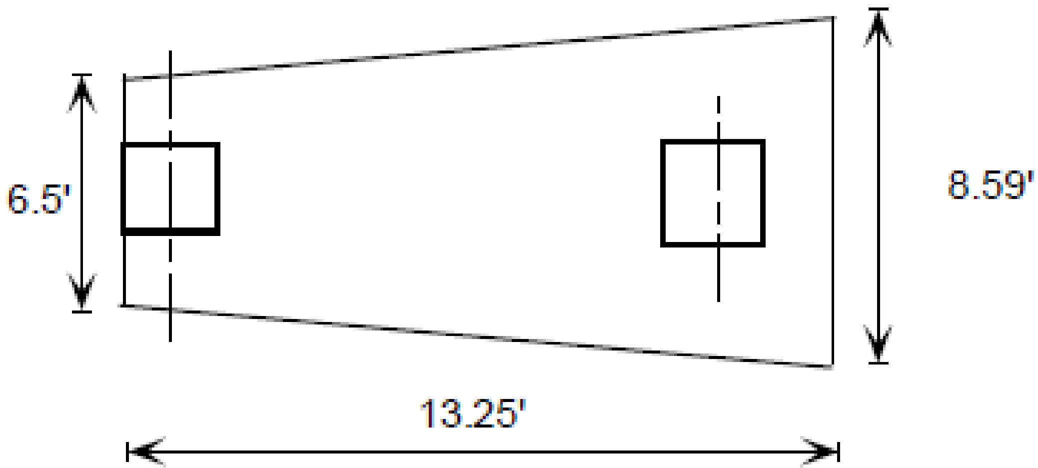
Also $A = \left(\frac{a+b}{2}\right)L = \frac{Q_n}{q_{a(net)}} = \frac{280}{2.8} = 100 \text{ ft}^2$

$$(a+b) \times \frac{13.25}{2} = 100 \qquad \text{or} \qquad (a+b) = 15.09 \qquad \text{(ii)}$$

From (i) $2a + b = 21.59$ (iii)

From (ii) and (iii)

$a = 6.5$ ft and $b = 8.59$ ft



STRAP FOOTINGS

A strap footing is used to connect an eccentrically loaded column footing to an interior column. The strap is used to transmit the moment caused from eccentricity to the interior column footing so that a uniform soil pressure is computed beneath both footings. The strap serves the same purpose as the interior portion of a combined footing but is much narrower to save materials.

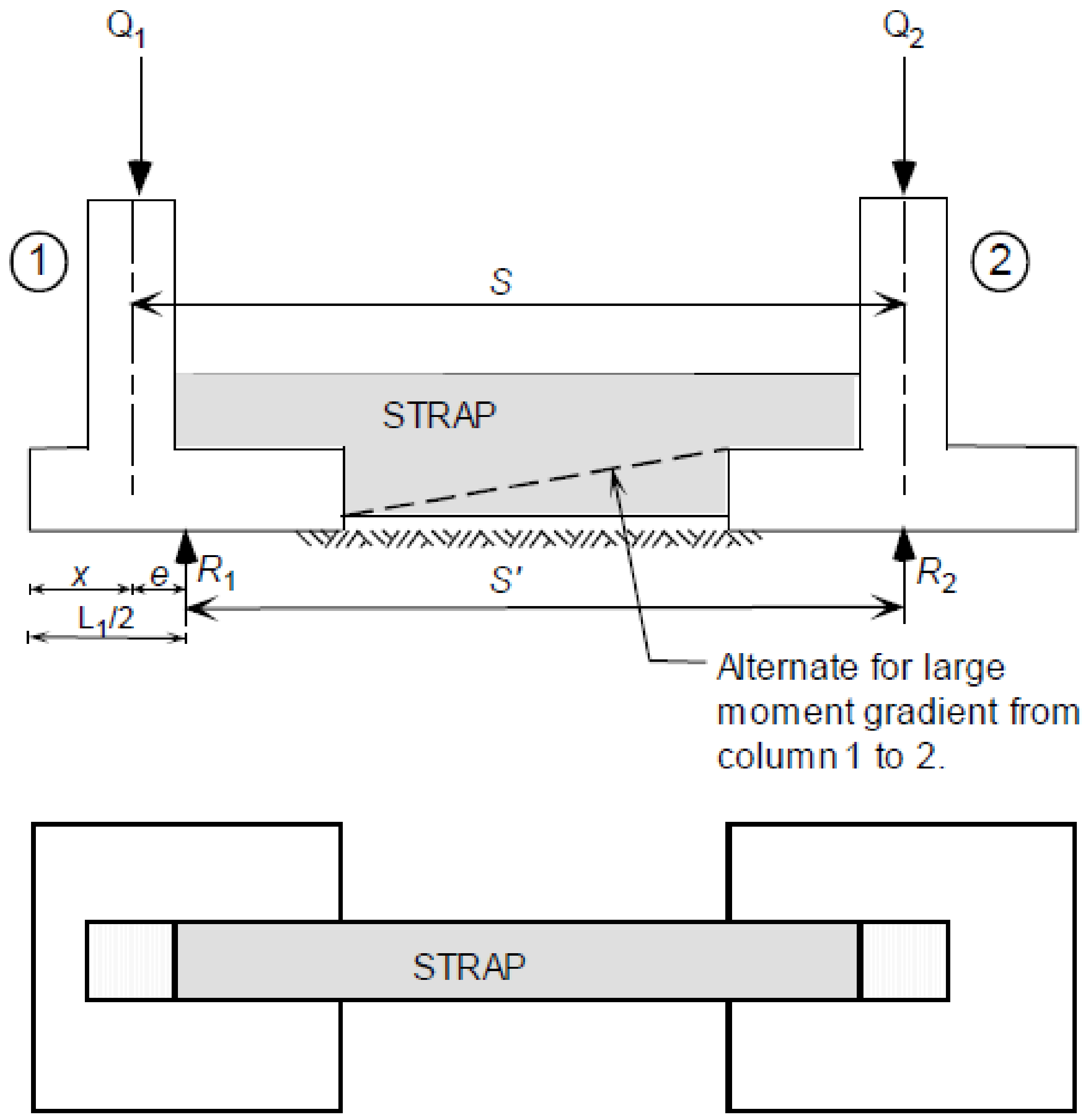
A strap footing is used in lieu of a combined footing or trapezoid footing if

1. the distance between columns is large
2. allowable soil pressure is relatively large.

There are three basic design considerations for strap footings:

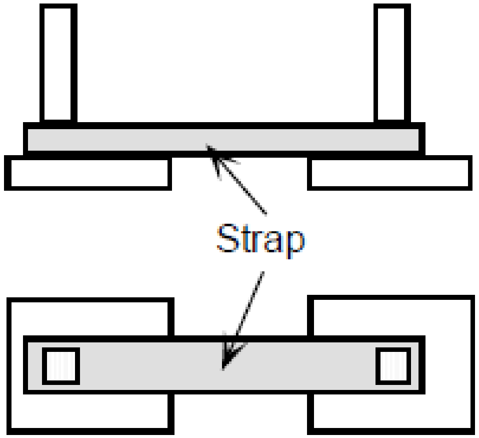
1. Strap must be rigid, i.e. $I_{strap}/I_{footing} \geq 2$. This rigidity is necessary to control rotation of the exterior column
2. Footings should be proportioned for approximately equal soil pressure and approximately equal widths to reduce differential settlement.
3. Strap is a pure flexural member to withstand bending moments and shear stresses. For this purpose strap should be out of contact with underneath soil so that no soil reactions are developed. This purpose can also achieved by loosening several inches of the underlying soil prior to the placement of the concrete.

A strap footing should be considered as one of the 'last resort' due to extra labour and forming costs. The strap may have a number of configurations; however, that shown in figure 'a' should produce the greatest rigidity with the width at least equal to the smallest column width. If the depth is restricted, it may be necessary to increase the strap width to obtain the necessary rigidity. The strap should be securely attached to the column and footing by dowels so that the system acts as a unit.

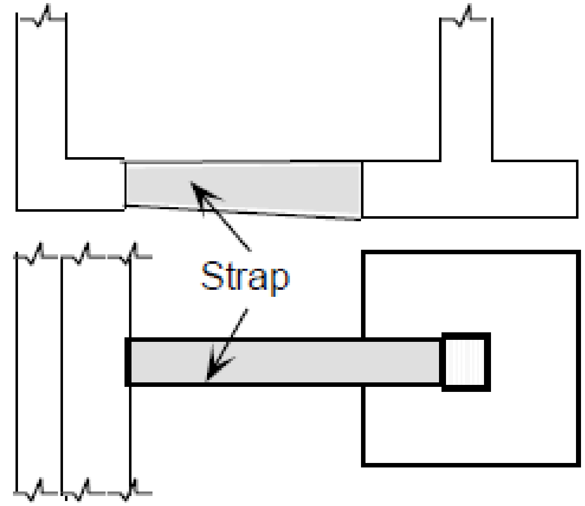


Q1
Q2
1
2
S
STRAP
R1
R2
x
e
L1/2
S′
Alternate for large moment gradient from column 1 to 2.
STRAP

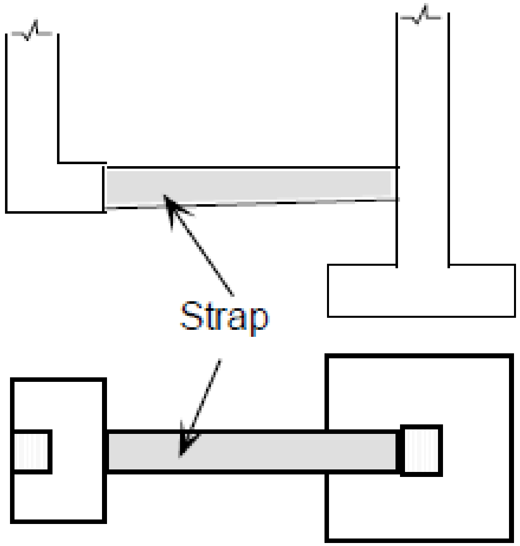
(a)



(b)



(c)



(d)

Common arrangements of strap footings