Module 5

(Lectures 17 to 19)

MAT FOUNDATIONS

Topics

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(Lectures 17)

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Topics

INTRODUCTION

Mat foundations are primarily shallow foundations. They are one of four major types of combined footing (see **figure 5.1a**). A brief overview of combined footings and the methods used to calculate their dimensions follows:

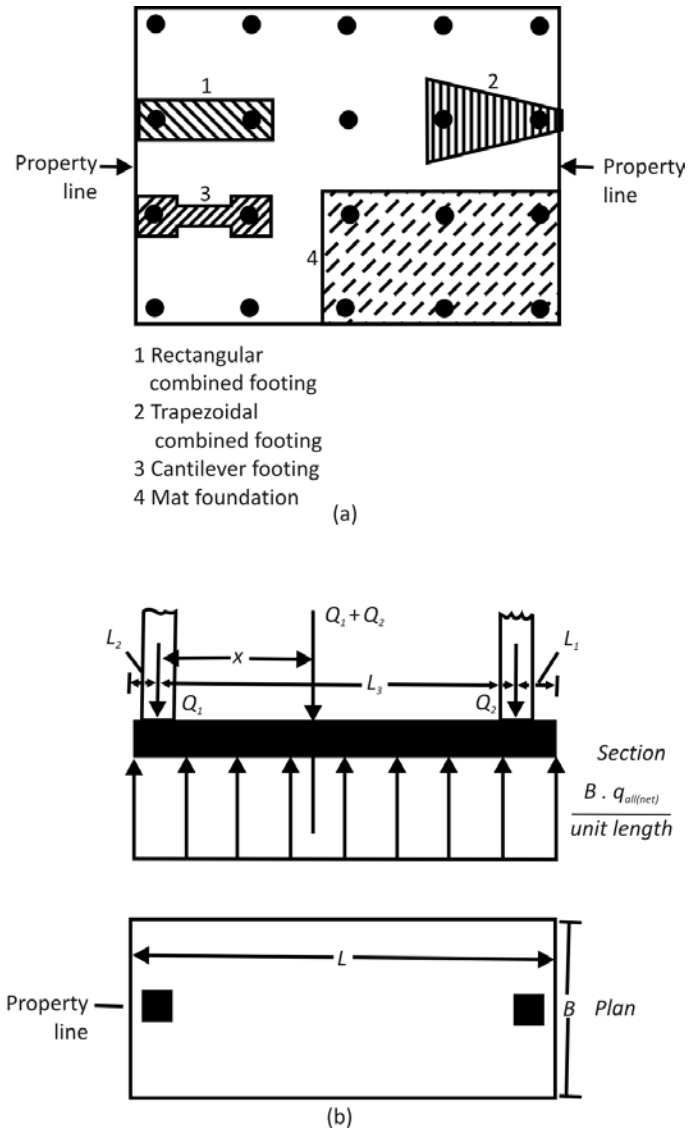

Figure 5.1 (a) Combined footing; (b) rectangular combined footing

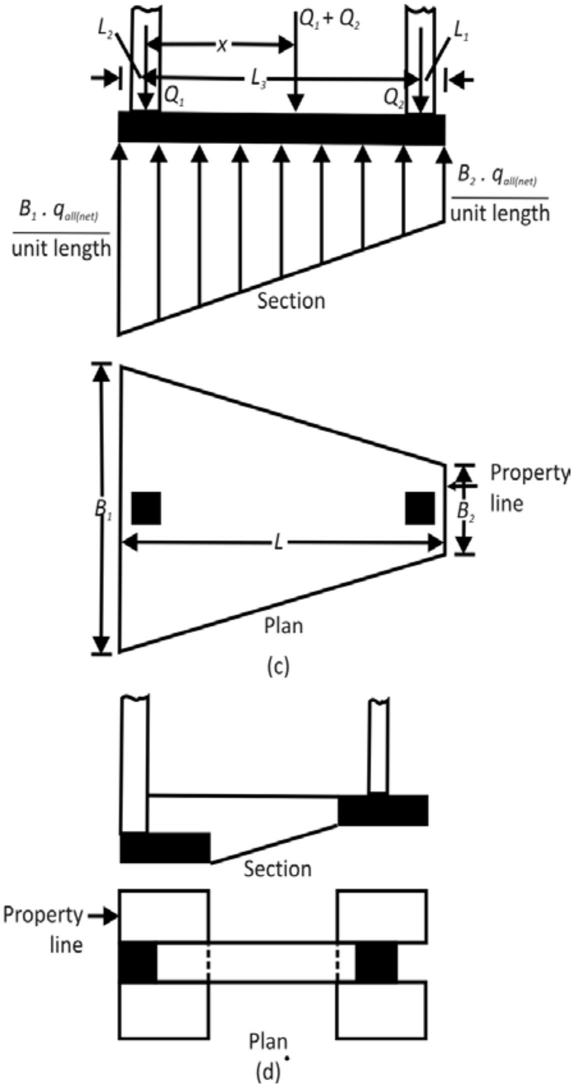

Figure 5.1 (Continued) (c) Trapezoidal combined footing; (d) cantilever footing

1. **Rectangular Combined Footing**: In several instances, the load to be carried by a column and the soil bearing capacity are such that the standard spread footing design will require extension of the column foundation beyond the property line. In such a case, two or more columns can be supported on a single rectangular foundation, as shown in figure 5.1b. If the net allowable soil pressure is known, the size of the foundation ($B \times L$) can be determined in the following manner.

a. Determine the area of the foundation, A:

$$A = \frac{Q_1 + Q_2}{q_{\text{all (net)}}} \qquad [5.1]$$

Where

$Q_1 + Q_2 =$ column loads
$q_{\text{all (net)}} =$ net allowable soil bearing capacity

b. Determine the location of the resultant of the column loads. From figure 5.1b.

$$X = \frac{Q_2 L_3}{Q_1 + Q_2} \qquad [5.2]$$

c. For uniform distribution of soil pressure under the foundation, the resultant of the column load should pass through the centroid of the foundation. Thus

$$L = 2(L_2 + X) \qquad [5.3]$$

Where

$L =$ length of the foundation

d. Once the length L is determined, the value of L_1 can be obtained:

$$L_1 = L - L_2 - L_3 \qquad [5.4]$$

Note that the magnitude of L_2 will be known and depends on the location of the property line.

e. The width of the foundation then is

$$B = \frac{A}{L} \qquad [5.5]$$

2. **Trapezoidal Combined Footings:** This type of combined footing (figure 5.1c) is sometimes used as an isolated spread foundation of a column carrying a large load where space is tight. The size of the foundation that will uniformly distribute pressure on the soil can be obtained in the following manner.

   a. If the net allowable soil pressure is known, determine the area of the foundation:

$$A = \frac{Q_1 + Q_2}{q_{\text{all (net)}}}$$

From figure 5.1c,

$$A = \frac{B_1 + B_2}{2} L \qquad [5.6]$$

b. Determine the location of the resultant for the column loads:

$$X = \frac{Q_2 L_3}{Q_1 + Q_2}$$

c. From the property of Trapezoid,

$$X + L_2 = \left(\frac{B_1 + 2B_2}{B_1 + B_2}\right)\frac{L}{3} \qquad [5.7]$$

With known values of $A, L, X,$ and L_2, solve equations (6 and 7) to obtain B_1 and B_2. Note that for a trapezoid

$$\frac{L}{3} < X + L_2 < \frac{L}{2}$$

3. **Cantilever Footing:** This type of combined footing construction uses a *strap beam* to connect an eccentrically loaded column foundation to the foundation of an interior column (figure 5.1d). Cantilever footings may be used in place of trapezoidal or rectangular combined footings when the allowable soil bearing capacity is high and the distances between the columns are large.
4. **Mat foundation:** This type of foundation, which is sometimes referred to as a *raft foundation,* is a combined footing that may cover the entire area under a structure supporting several columns and walls (figure 5.1a). Mat foundations are sometimes preferred for soils that have low load-bearing capacities but that will have to support high column and/or wall loads. Under some conditions, spread footings would have to cover more than half the building area, and mat foundations might be more economical.

COMMON TYPES OF MAT FOUNDATIONS

Several types of mat foundations are used currently. Some of the common types are shown schematically in **figure 5.2** and include:

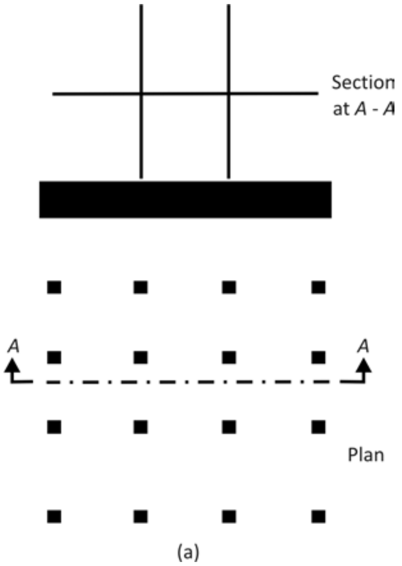

Figure 5.2 Types of mat foundation: (a) flat plate

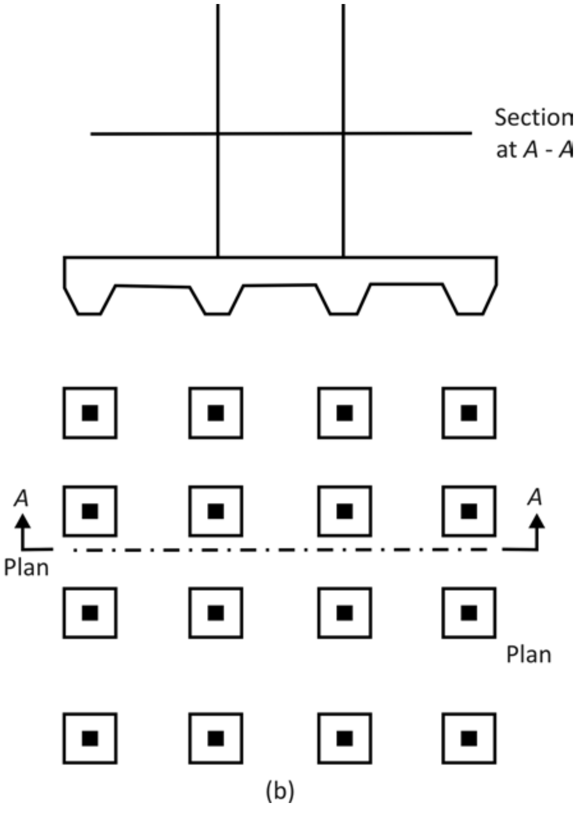

Figure 5.2 (Continued) (b) Flat plate thickened under column

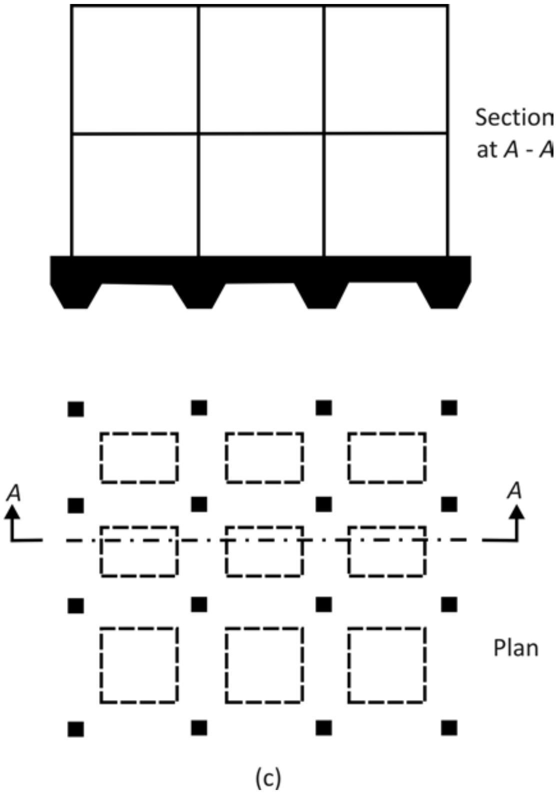

Figure 5.2 (Continued) (c) Beams and slab

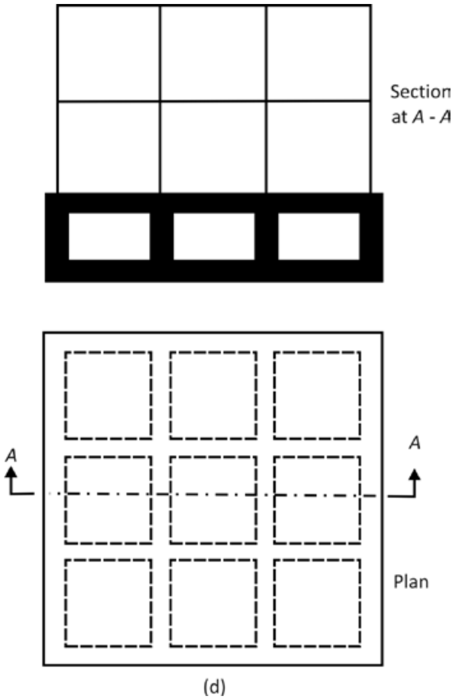

Figure 5.2 (Continued) (d) Slab with basement wall

1. Flat plate (figure 5.2a). The mat is of uniform thickness.
2. Flat plate thickened under columns (figure 5.2b)
3. Beams and slap (figure 5.2c). The beams run both ways and the columns and, located at the intersection of the beams.
4. Slab with basement walls as a part of the mat (figure 5.2d). The walls act as stiffeners for the mat.

Mats may be supported by piles. The piles help in reducing the settlement of a structure built over highly compressible soil. Where the water table is high, mats are often placed over piles to control buoyancy.

BEARING CAPACITY OF MAT FOUNDATIONS

The gross ultimate bearing capacity of a mat foundation can be determined by the same equation used for shallow foundations, or

$$q_u = cN_c F_{cs} F_{cd} F_{ci} + qN_q F_{qs} F_{qd} F_{qi} + \tfrac{1}{2}\gamma B N_\gamma F_{\gamma s} F_{\gamma d} F_{\gamma i}$$

(Chapter 3 gives the proper values of the bearing capacity factors, and shape, depth, and load inclination factors). The term B in equation (25 from chapter 3) is the smallest dimension of the mat. The *net ultimate capacity* is

$$q_{\text{net (u)}} = q_u - q$$

A suitable factor of safety should be used to calculate the net *allowable* bearing capacity. For rafts on clay, the factor of safety should not be less that 3 under dead load and maximum live load. However, under the most extreme conditions, the factor of safety should be at least 1.75 to 2. For rafts constructed over sand, a factor of safety of 3 should normally be used. Under most working conditions, the factor of safety against bearing capacity failure of rafts on sand is very large.

For saturated clays with $\phi = 0$ and vertical loading condition, equation (25 chapters 3) gives

$$q_u = c_u N_c F_{cs} F_{cd} + q \qquad [5.8]$$

Where

$c_u =$ undrained cohesion

(Note: $N_c = 5.14, N_q = 1,$ and $N_\gamma = 0$)

From table 5 (chapter 3) for $\phi = 0$,

$$F_{cs} = 1 + \frac{B}{L}\left(\frac{N_q}{N_c}\right) = 1 + \left(\frac{B}{L}\right)\left(\frac{1}{5.14}\right) = 1 + \frac{0.195B}{L}$$

And

$$F_{cd} = 1 + 0.4\left(\frac{D_f}{B}\right)$$

Substitution of the preceding shape and depth factors into equation (8) yields

$$q_u = 5.14c_u\left(1 + \frac{0.195B}{L}\right)\left(1 + 0.4\frac{D_f}{B}\right) + q \qquad [5.9]$$

Hence the net ultimate bearing capacity is

$$q_{\text{net}\,(u)} = q_u - u = 5.14c_u\left(1 + \frac{0.195B}{L}\right)\left(1 + 0.4\frac{D_f}{B}\right) \qquad [5.10]$$

For $FS = 3$, the net allowable soil bearing capacity becomes

$$q_{\text{all}\,(\text{net})} = \frac{q_{u\,(\text{net})}}{FS} = 1.713c_u\left(1 + \frac{0.195B}{L}\right)\left(1 + 0.4\frac{D_f}{B}\right) \qquad [5.11]$$

Figure 5.3 shows a plot of $q_{\text{all}\,(\text{net})}/c_u$ for various values of L/B and D_f/B, based on equation (11).

The net allowable bearing capacity for mats constructed over granular soil deposits can be adequately determined from the standard penetration resistance numbers. From equation (53 chapter 4), for shallow foundations,

$$q_{\text{all}\,(\text{net})}(\text{kN/m}^2) = 11.98N_{cor}\left(\frac{3.28B+1}{3.28B}\right)^2 F_d\left(\frac{S_e}{25.4}\right)$$

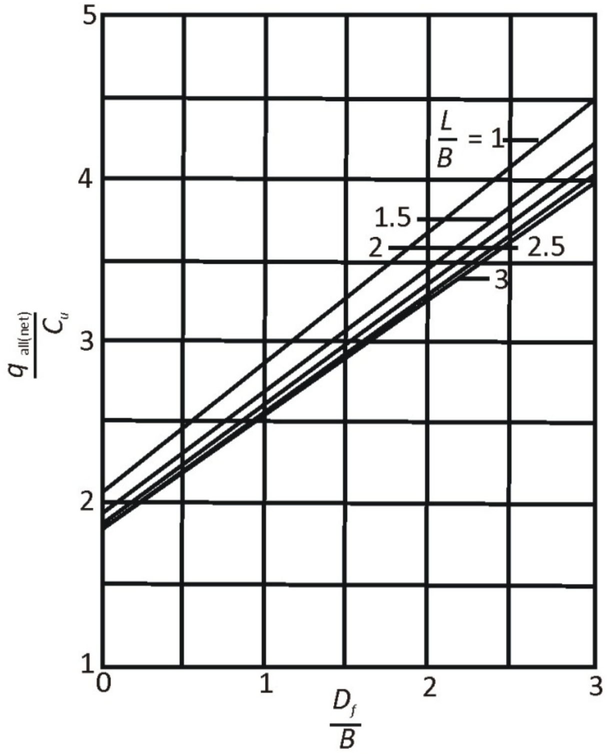

Figure 5.3 Plot of $q_{\text{all (net)}}/c_u$ against D_f/B

Where

N_{cor} = corrected standard penetration resistance

B = width (m)

$F_d = 1 + 0.33(D_f/B) \leq 1.33$

S_e = settlement, in mm

When the width, B is large, the preceding equation can be approximated (assuming $3.28B + 1 \approx 3.28B$) as

$$q_{\text{all (net)}}(\text{kN/m}^2) \approx 11.98N_{cor}\,\text{F}_\text{d}\left(\frac{S_e}{25.4}\right)$$

$$= 11.98N_{cor}\left[1 + 0.33\left(\frac{D_f}{B}\right)\right]\left[\frac{S_e(\text{mm})}{25.4}\right] \qquad [5.12]$$

$$\leq 15.93N_{cor}\left[\frac{S_e(\text{mm})}{25.4}\right]$$

In English units, equation (12) may be expressed as

$$q_{\text{all (net)}}(\text{kip/ft}^2) = 0.25N_{cor}\ \left[1 + 0.33\left(\frac{D_f}{B}\right)\right][\text{S}_\text{e}(\text{in.})] \qquad [5.13]$$

$$\leq 0.33N_{cor}\,[\text{S}_\text{e}(\text{in.})]$$

Note that equation (13) could have been derived from equations (54 and 56 from chapter 4)

Note that the original equations (53 and 56 from chapter 4) were for a settlement of I in. (25.4 mm) with a differential settlement of about 0.75 in. (19mm). However, the widths of the raft foundations are larger than the isolated spread footings. As table 3 chapter 4 shows, the depth of significant stress increase in the soil below a foundation depends on the foundation width. Hence, for a raft foundation, the depth of the zone of influence is likely to be much larger than that of a spread footing. Thus the loose sol pockets under a raft may be more evenly distributed, resulting in a smaller differential settlement. Hence the customary assumption is that, for a maximum raft settlement of 2 in. (50.8 mm), the differential settlement would be 0.75 in. (19 mm). Using this logic and conservatively assuming that F_d equals 1, we can approximate equations (12 and 13) as

$$q_{\text{all (net)}}(\text{kN/m}^2) \approx 23.96N_{cor} \qquad [5.14]$$

And

$$q_{\text{all (net)}}(\text{kip/ft}^2) = 0.5N_{cor} \qquad [5.15]$$

The net pressure applied on a foundation (**figure 5.4**) may be expressed as

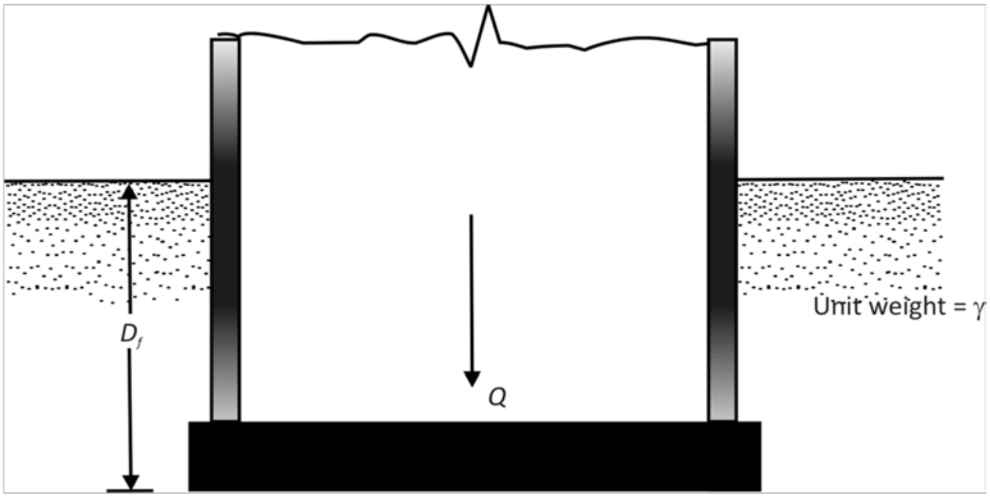

Figure 5.4 Definition of net pressure on soil caused by a mat foundation

$$q = \frac{Q}{A} - \gamma D_f \qquad [5.16]$$

Where

$Q =$ dead weight of the structure and the live load

$A =$ area of the raft

In all cases, q should be less than or equal to $q_{\text{all (net)}}$.

Example 1

Determine the net ultimate bearing capacity of a mat foundation measuring $45 \text{ ft } \times 30$ ft on saturated clay with $c_u = 1950 \text{ lb/ft}^2$, $\phi = 0,$ and $D_f = 6.5$ ft.

Solution

From equation (10)

$$q_{\text{net (u)}} = 5.14 c_u \left[1 + \left(\frac{0.195B}{L}\right)\right]\left[1 + 0.4\frac{D_f}{B}\right]$$

$$= (5.14)(1950)\left[1 + \left(\frac{0.195 \times 30}{45}\right)\right]\left[1 + \left(\frac{0.4 \times 6.5}{30}\right)\right]$$

$$= 12{,}307 \text{ lb/ft}^2$$

Example 2

What will the net allowable bearing capacity of a mat foundation with dimensions be of $45 \text{ ft } \times 30$ ft constructed over a sand deposit? Here, $D_f = 6$ ft, allowable settlement = 1 in., and corrected average penetration number $N_{cor} = 10$.

Solution

From equation (13)

$$q_{\text{all (net)}} = 0.25 N_{cor}\left(1 + \frac{0.33 D_f}{B}\right) S_e \leq 0.33 N_{cor} S_e$$

$$q_{\text{all (net)}} = 0.25(10)\left[1 + \frac{0.33(6)}{30}\right](1) \approx 2.67 \text{kip/ft}^2$$

DIFFERENTIAL SETTLEMENT OF MATS

The American Concrete Institute Committee 336 (1988) suggested the following method for calculating the differential settlement of mat foundations. According to this method, the rigidity factor (K_r) is calculated as

$$K_r = \frac{E' I_b}{E_s B^3} \qquad [5.17]$$

Where

$E^{'}$ = modulus of elasticity of the material used in the structure

E_s = modulus of elasticity of the soil

B = width of foundation

I_b = moment of inertia of the structure per unit length at right angles to B

The term $E' I_b$ can be expressed as

$$E' I_b = \left(I_F + \sum \; I_b + \sum \frac{ah^3}{12} \right) \qquad [5.18]$$

Where

$E^{' I_b}$ =
flexural rigidity of the superstructure and foundation per unit length at right angles to B

$\sum \mathrm{E}' \; I_b^{'}$ = flexural rigidity of the framed members at right angles to B

$\sum (E^{' ah^3}/12)$ = flexural rigidity of the shear walls

a = shear wall thickness

h = shear wall height

$E^{'} I_F$ = flexibility of the foundation

Based on the value of $K_{r'}$ the ratio (δ) of the differential settlement to the total settlement can be estimated in the following manner:

1. If $K_r > 0.5$, it can be treated as a rigid mat, and $\delta = 0$.
2. If $K_r = 0.5$, then $\delta \approx 0.1$.
3. If $K_r = 0$, then $\delta = 0.35$ for square mats ($B/L = 1$) and $\delta = 0.5$, for long foundations ($B/L = 0$).