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Impact of adjacent footings on immediate settlement of shallow footings

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ABSTRACT

When the settlement of a footing under a structure is estimated by considering the bearing pressure of that footing only, the estimated value of the settlement may not be good enough since the other neighboring footings are going to effect the settlement of the footing under consideration also. Thus, in the settlement estimation of a footing, the effect of neighboring footings must be considered. In this study, impact of adjacent footings is considered on the estimation of elastic settlement of shallow foundations. In the estimation of elastic (immediate) settlement, the Schmertmann's method that is a very popular method in the elastic settlement estimation of shallow foundations is employed. In order to consider effect of neighboring footings on elastic settlement of main footing in different configurations, a MATLAB script has been generated. Elastic settlements of the various configurations are estimated by the script and several conclusions have been reached.

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1. Introduction

Several methods are in use for estimation of elastic (immediate) settlement of shallow footings in foundation engineering applications. Almost all of these methods consider only one isolated spread footing in the estimation of immediate settlement (Das, 2007; Coduto, 2001). In the real life of practice, it is very seldom to see a single footing is constructed. Mostly, a spread footing would have other footings around it. To estimate the elastic settlement of shallow footings that rest on granular soil like sand and/or gravel, several methods are available in the literature (Das, 2010; Cernica, 1995). Most of these methods are based on elastic approach. Modulus of elasticity, E_s, is employed in the elastic settlement calculations.

In these methods, the elastic settlement of footings estimated by considering the net pressure increment under the footing only but not considered the stress increment due to the neighboring footings at the same depth. Actually, the net stress increments under the spread footings would be larger when neighboring footings effect is considered. Thus, the estimated value of elastic settlement will be less than what is going to occur in the field since only the stress increment due to the one single footing has been considered. There are several methods to estimate the elastic settlement of shallow foundations. Schmertmann's method is one of several methods that was developed primarily as a means of estimating the spread footing settlement on sandy soils (Meyerhof, 1965; Schmertmann et al., 1978; Berardi et al., 1991). The method is employed with cone penetration test (CPT) and/or standard penetration test (SPT).

Unlike many of the other methods that are purely empirical to estimate elastic settlement, the Schmertmann's method is based on physical model in which strain influence factors are employed. Estimation of modulus of elasticity is a very important issue in the method. Thus, data from filed tests such as tip resistance of CPT or SPT-N value is used. Lee J at al., (2010) claimed that the depth of influenced zone under the isolated footing is deeper than the depth assumed by the Schmertmann's method. However, the Schmertmann's method gives reasonable estimations of shallow foundations.

2. Schmertmann's Method

The Schmertmann's method (1970) considered the variation of soil strain under a footing with an assumption of peak strain would occur at a depth of half width

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of footing ($B/2$) as seen in Fig.1. Then, the strain would be equal to zero at a depth of twice of the width of the footing. However, when he had more investigation Schmertmann (1978) proposed a modified variation of strain within the depth as seen in Fig.2.

In the modified model there are two types of stain variations. One of them is for axisymmetric problems that are for spread footings. The other one is for plane strain problems that are for strip footings.

The method uses a simple triangular strain distribution that was corrected in 1978 as seen in Fig. 1, and estimates the strain influence factor at the midpoint of each layer. Then using the proper strain influence factors estimates the elastic settlement of a footing. Later on, a time factor also be included to account for time dependent (creep) effects. However, the author does not believe it is essential on the calculation of immediate settlement that is assumed to be independent of time. In the method, an *influence factor*, I_z is defined depends on the type of the problem. The problem can be either an axisymmetric or plain strain state. In the axisymmetric state, I_z has a value of 0.1 at the base level of the footing and then varies linearly to a peak value of I_{zp} at a depth of $B/2$. After the peak value of strain influence, it diminishes to zero at a depth of $2B$. In the plane strain state I_z has a value of 0.2 at the base level of the foundation and then varies linearly to a peak value of I_{zp} at a depth of B. After the peak value of strain influence, it diminishes to zero at a depth of $4B$ as seen in Fig. 2.

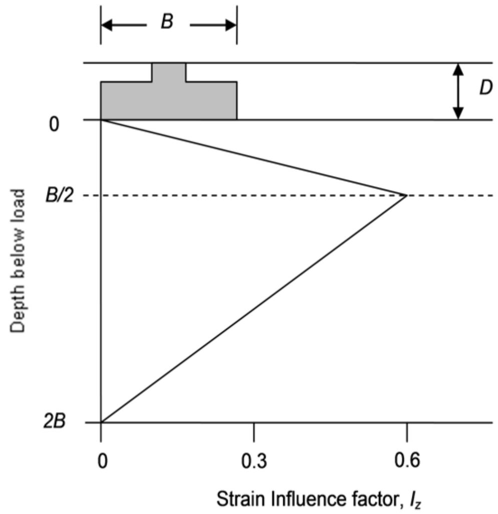

Fig. 1. Variation of strain under a footing (Schmertmann, 1970).

The peak value for influence factor, is calculated by Eq. (1)

$$I_{zp} = 0.5 + 0.1\sqrt{\frac{q-\sigma'_{zD}}{\sigma'_{zp}}}\,, \quad (1)$$

where

σ'_{zD} = effective overburden pressure at bottom of the footing

q = the applied footing pressure (contact pressure)

σ'_{zp}= effective stress at the depth of $B/2$ for axisymmetric strain (square and circular footing), and effective stress at the depth of B for plane strain (strip footing)

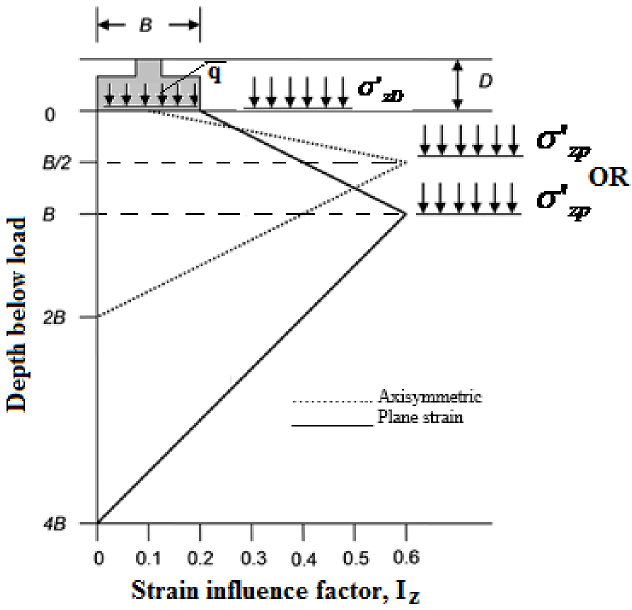

Fig. 2. Strain influence factors (Schmertmann et al. 1978).

According to Fig.1, the exact value of I_{zi} at any depth can be determined as follows;

For square and circular footings (L/B=1)

$$I_z = 0.1 + \frac{z}{B}\left(2I_{zp} - 0.2\right) \quad if \quad \left(0 \le z \le \frac{B}{2}\right), \quad (2)$$

$$I_z = 0.667 I_{zp}\left(2 - \frac{z}{B}\right) \quad if \quad \left(\frac{B}{2} \le z \le 2B\right), \quad (3)$$

For strip (continuous) footings $\frac{L}{B} \ge 10$

$$I_z = 0.2 + \left(\frac{z}{B}\right)\left(I_{zp} - 0.2\right) \quad if \quad (0 \le z \le B), \quad (4)$$

$$I_z = 0.333 I_{zp}\left(4 - \frac{z}{B}\right) \quad if \quad (B \le z \le 4B), \quad (5)$$

For rectangular footings in which the length is greater than ten times the width, the plane strain approach is used. For rectangular loads in which the length is less than ten times the width, a linear interpolation between the axisymmetric and plane strain case is performed, dependent on the length to width ratio.

For rectangular footings $1 < \left(\frac{L}{B}\right) < 10$

$$I_z = I_{zp} + 0.111(I_{zc} - I_{zs}) * \left(\frac{L}{B} - 1\right), \quad (6)$$

where

I_{zc} = strain influence factor for strip footing that has a width of B,

I_{zs} = strain influence factor for square footing that has a width of B, this value must be at least zero or larger.

The equation for settlement is:

$$S_i = C_1 C_2 C_3 (q - \sigma'_{zD}) \sum_{i=1}^{n} \frac{\Delta z_i I_{zi}}{E_{si}}, \quad (7)$$

where

$$C_1 = 1 - 0.5\left(\frac{\sigma'_{zD}}{q-\sigma'_{zD}}\right), \quad (8)$$

the correction to account for strain relief from excavated soil

$$C_2 = 1 + 0.2\,log\left(\frac{t}{0.1}\right), \quad (9)$$

correction for time-dependent creep

$$C_3 = 1.03 - 0.03\left(\frac{L}{B}\right) \geq 0.73 \;, \quad (10)$$

the correction for shape of the footing base

t = time (years)

E_{si} = one-dimensional elastic modulus of soil layer i

Δ_{zi} = thickness of soil layer

I_{zi} = the influence factor at the centre of soil layer i as described below.

The elastic modulus E_s can be estimated from the results of a Cone Penetration test:

$E_s = 2.5q_c$ (1978 formulation, axisymmetric footing)

$E_s = 3.5q_c$ (1978 formulation, plane strain footing)

where q_c is the cone tip bearing resistance. If the Schmertmann's 1978 formulation is being used, the value for E_s is calculated to be between the axisymmetric case and plane strain case if the length of the footing is less than ten times the width.

The accuracy of the Schmertmann's method improves when the strain profile is sampled more densely. If the soil profile is fairly homogeneous, it is tedious to specify many layers with the same properties in order to improve the accuracy.

3. Effect of Adjacent Footings on Settlement

In the elastic settlement estimation of footings, interactions between adjacent footings are not taken into account in the conventional approach. However, it is noted that shallow foundations for typical buildings consist of multiple footings that are generally in close proximity.

In this paper, four configurations that could be possible in practice seen in Fig.2 have been considered: a) only main footing, b) one adjacent footing c) two adjacent footings d) three adjacent footings d) four adjacent footings. A MATLAB code has been generated to calculate the settlement under the footing by the Schmertmann's Method for the four cases mentioned. In order to simplify the problem it is assumed that all of the footings have identical contact pressure and their bases are square with a width of B. However, different widths and contact pressures can also be considered for the practical applications. In the estimation of stress increment under the footing at a depth of $B/2$, the stress increments due to the neighboring footings are considered by Boussinesq's theory (Fig.3). Then, as it is seen in Fig. 4, an increment on bearing pressure of footing under which the settlement would be estimated is back calculated and added to the contact pressure at the base of the footing. This process is repeated up to the number of adjacent footings that may have impact on the settlement. Then, settlement of the footing is calculated for the four different configurations seen in Fig. 3 by the Schemertmann's method that has been programmed in the MATLAB script.

In the modeling of the problem L1= L2=L is assumed. Also, four cases have been investigated namely "Case I, L/B=0.5", "Case II, L/B=0.75", "Case III, L/B=1", and "Case IV, L/B=3". In each case, the number of the neighboring footings has been varied from 1 to 4 with respect to the configurations seen in Fig. 3. Then, four different settlements were calculated by the MATLAB script.

The calculated increments of settlements due to the adjacent footings have been normalized by dividing the settlement of main footing with no adjacent footing. Finally, normalized settlement increments versus number of adjacent footings have been plotted as seen in Fig.4. As it is seen in Fig.4, stress increments due to adjacent footings at the depth of $B/2$ under the foundation for which the settlement will be calculated. Depend on the number of adjacent footings, all the stress increments are superimposed under the main foundation at the depth of $B/2$ at which the strain increment is the maximum.

The percentages of settlement increments can be estimated by the following equations found for the cases investigated in this study.

Case$I$ $\quad S_p = 1.6981n - 0.0046 \;, \quad (11)$

CaseII $\quad S_p = 0.731n - 0.0008 \;, \quad (12)$

CaseIII $\quad S_p = 0.3843n - 0.0002 \;, \quad (13)$

CaseIV $\quad S_p = 0.0348n \;, \quad (14)$

where

S_p= percentage of settlement increment,

n= number of adjacent footings

As it can be seen in Fig. 6, the effect of adjacent footings on settlement is decreased rapidly with increased distance to the main footing, and there is no effect with a distance larger than 3B on the settlement.

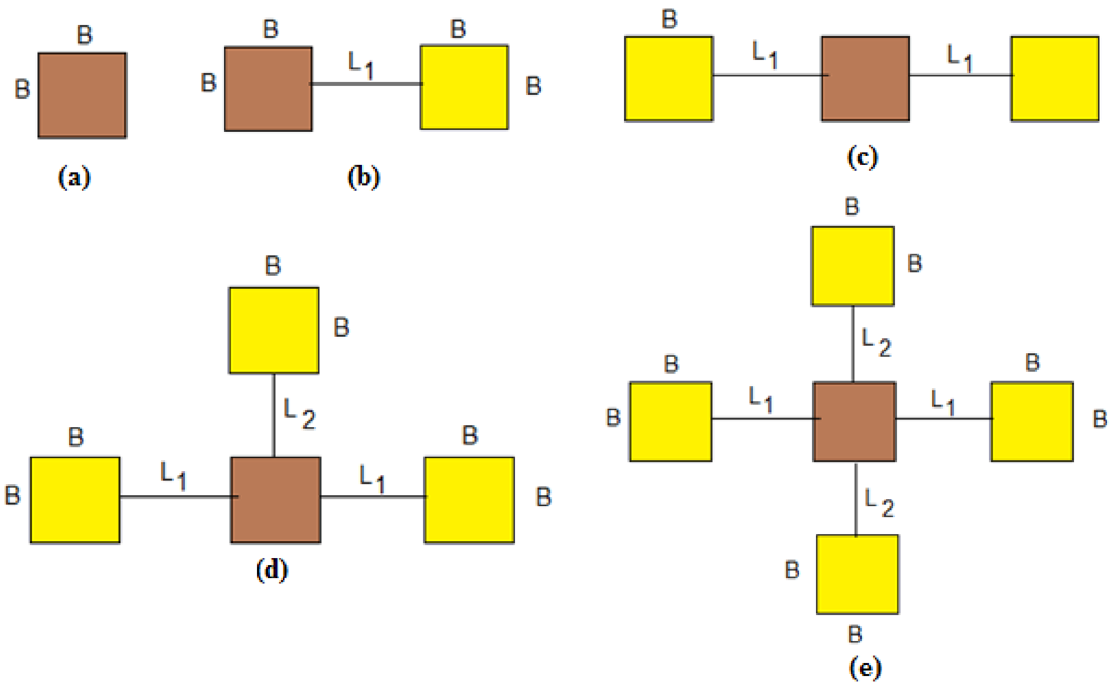

Fig. 3. Configuration of multiple footing arrangements.

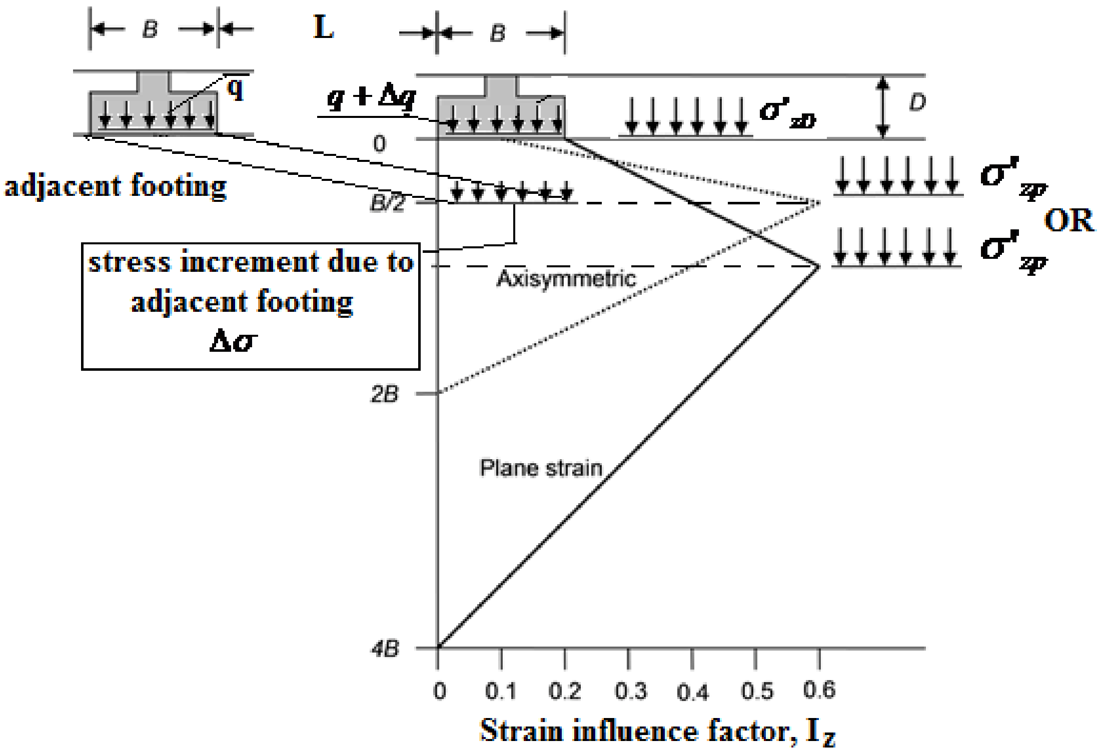

Fig. 4. Stress increment due to adjacent footing under the main footing.

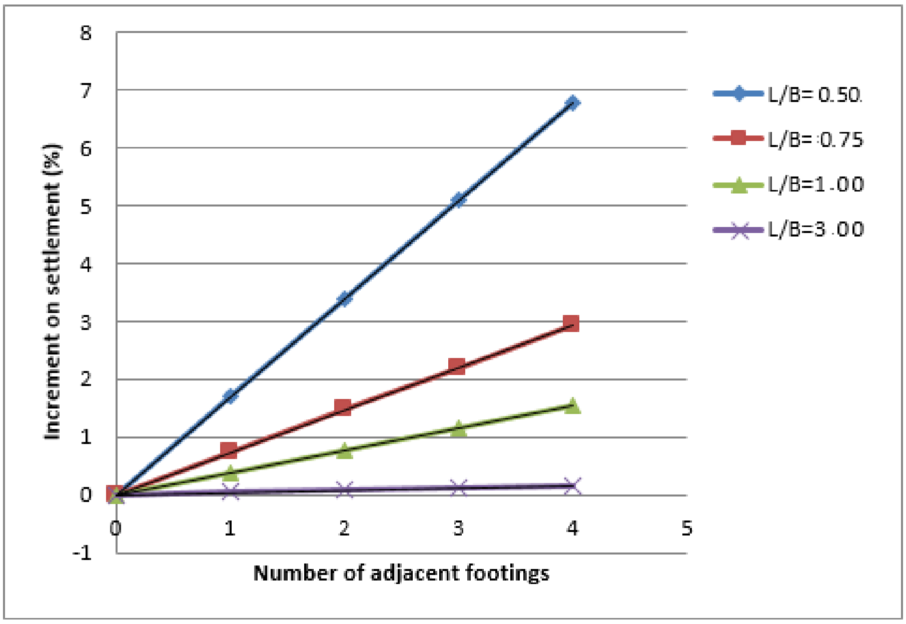

Fig. 5. Increment ratio versus number of adjacent footings.

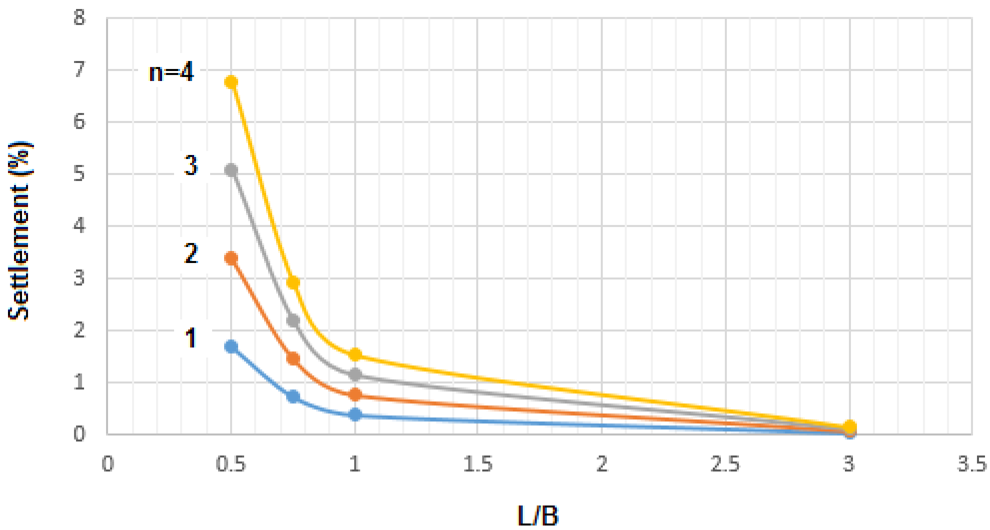

Fig. 6. Variation of settlement (%) versus ratio of distance between footings and their widths.

4. Conclusions

In this paper, a method of settlement estimation that takes account of the proximity of adjacent footings is presented based on Schmertmann's method. The following conclusions may be drawn based on the results of this study:

- The settlement of an isolated footing with adjacent footings is always larger than one with no adjacent footing. The effect of adjacent footings on settlement of main footing is increased linearly with the number of adjacent footing.
- The effect of adjacent footings on settlement is decreased more with smaller increment on distance to the main footing, and there is no effect with a distance larger than 3*B* on settlement.
- The derived equations [11 to 14] can be employed to estimate settlement increment of a main footing under the conditions explained in four cases. Also, similar equations can be driven for various conditions.

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