



Research Article

Modification of Schmertmann-Hartman-Brown method to estimate immediate (elastic) settlement of shallow foundations

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ABSTRACT

One of the methods intensively employed in many practical projects to estimate the immediate (elastic) settlement of shallow foundations is the Schmertmann-Hartman-Brown method (1978). In the method, two approaches are given as a function of type of the shallow foundation either a square/circular (axisymmetric condition) or a strip (plain strain condition) foundation. Thus, two sets of equations are provided to estimate the settlements for these types of shallow foundations. If a shallow foundation has a shape of rectangular, some approximations are suggested in the technical literature to estimate the elastic settlement of rectangular based shallow foundations. These approximations are tedious and time consuming. In this study, the Schmertmann – Hartman – Brown method (1978) is modified and only one set of equations used for any type (square, circular, rectangular, and strip) of shallow foundations is introduced. The modified method estimates the immediate settlement as precise as the original form of the method that is more complicated. Also, some hypothetical cases are considered to figure out the effect of width and length/width ratios of foundations on elastic settlement.

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1. Introduction

It has been a very important issue to estimate the settlement of foundations for civil engineers. Thus, many researchers have studied the problem to get a reliable solution of it. Terzaghi and Peck (1948) proposed an empirical relationship between the settlement (S_e) of a prototype foundation measuring $B \times B$ in plan and the settlement of a test plate. Bjerrum and Eggstad (1963) provided the results of 14 sets of load settlement tests. Bazaraa (1967) also provided several field tests results. Both gave correlations of settlements between width (size) of plate used in the tests and size of foundation that would be designed. Jeyapalan and Boehm (1986) and Papadopoulos (1992) summarized the case histories of 79 foundations. DeBeer and Martens (1957) and DeBeer (1965) proposed another formula to estimate the elastic settlement of a foundation. Burland and Burbidge (1985) proposed a method for calculating the elastic settlement of sandy soil using the field standard

penetration number N_{60} . The methods in estimation of elastic settlements were summarized (Das et al. 2009)

The Schmertmann-Hartman-Brown method (1978) is commonly used for the estimation of elastic (immediate) settlement of shallow foundations. In the procedure on the estimation of immediate settlement, two approaches are used. One for axisymmetric (square and circular foundations) cases, and the other is for plane strain (strip foundations) condition as seen in Fig. 1. In case of rectangular foundations, there is an approximation in the method by using both axisymmetric and plane strain conditions.

2. Schmertmann-Hartman-Brown Method (1978)

In this method, immediate (or elastic) settlement (S_e) of shallow foundations is calculated by Eq. (1) as seen below.

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

where

$$C_1 = 1 - 0.5 \left(\frac{\sigma'_{zD}}{q - \sigma'_{zD}} \right) \quad (2)$$

Correction for strain relief due to excavation,

$$C_2 = 1 + 0.2 \left(\frac{t}{0.1} \right) \quad (3)$$

Correction for creep,

$$C_3 = 1.03 - 0.03 \left(\frac{L}{B} \right) \geq 0.73 \quad (4)$$

where q is the gross contact pressure of footing; σ'_{zD} is the effective stress at the base level of footing before the construction; Δz_i is the thickness of soil layer i ; I_{zi} is the strain influence factor of layer i ; E_{si} is the modulus of elasticity of layer i ; B is the width of foundation; L is the length of foundation.

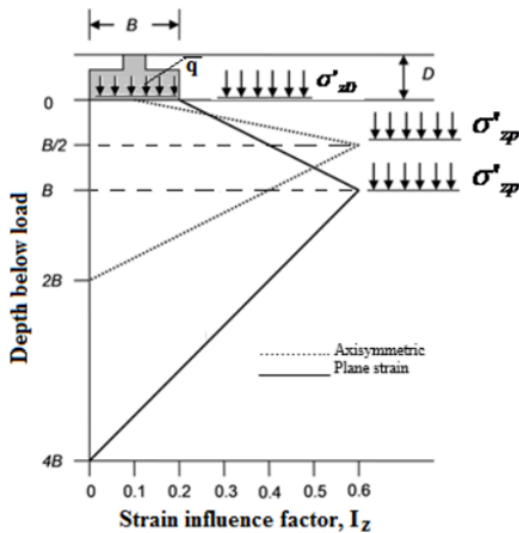


Fig. 1. Variation of stress influence factors for square/circular based (axisymmetric) and strip (plane strain) foundations (Schmertmann et al. 1978).

According to Fig. 1, the exact value of I_{zi} at any depth can be determined as follows; for square and circular footings ($L/B=1$):

$$I_z = 0.1 + \frac{z}{B} (2I_{zp} - 0.2) \quad \left(0 \leq z \leq \frac{B}{z} \right) \quad (5)$$

$$I_z = 0.667I_{zp} + \left(2 - \frac{z}{B} \right) \quad \left(\frac{B}{z} \leq z \leq 2B \right) \quad (6)$$

For strip (continuous) footings $L/B \geq 10$:

$$I_z = 0.2 + \frac{z}{B} (I_{zp} - 0.2) \quad (0 \leq z \leq B) \quad (7)$$

$$I_z = 0.333I_{zp} \left(4 - \frac{z}{B} \right) \quad (B \leq z \leq 4B) \quad (8)$$

For rectangular footings in which the length is greater than ten times of the width, the plane strain approach is used. In other words, the foundation is considered as a strip foundation. For rectangular foundations in which the length is less than or equal to ten times the width, a linear interpolation between the axisymmetric and plane strain cases is performed, dependent on the length to width ratio. For the rectangular foundations ($1 < L/B \leq 10$):

$$I_z = I_{zp} + 0.111(I_{zc} - I_{zs}) \left(\frac{L}{B} - 1 \right) \quad (9)$$

where I_{zp} is the strain influence factor at the depth of z_p (peak value); I_{zc} is the strain influence factor for strip footing that has a width of B ; I_{zs} is the strain influence factor for square footing that has a width of B , this value must be at least zero or larger.

As it is seen above, the calculations of strain influence factors are complicated and time consuming. To avoid these problems, the method is modified and a new procedure much simpler than the original Schmertmann et al. (1978) method is introduced in this paper.

3. Modification of the Schmertmann-Hartman-Brown (1978) Method

In this paper, the Schmertmann-Hartman-Brown (1978) method is modified by considering boundary conditions of the square/circular ($L/B = 1$) and strip ($L/B > 10$) foundations. Equations on the calculation of strain influence factors for any type of shallow foundation such as rectangular, square, circular, strip in Eq. (1) have been re-driven. Thus, the following procedure has been prepared to estimate immediate settlements of any type of shallow foundations. In the modified method, the assumed variation of the strain influence factor is seen in Fig. 2. The user should not be worried about the problem whether it is an axisymmetric or plane strain problem. The data that are needed to be used in the modified method are the size, depth of foundation, load (or bearing pressure), unit weight of soil, number and thickness of soil layers and their modulus of elasticity values under the foundation within the depth of $2B$ or maximum $4B$. The author suggests to users that consider the layers only within the depth of z_{max} that can be calculated by Eq. (18) from the base of foundation as seen in Fig.2.

3.1. Calculation steps of the modified method for any type of shallow foundations:

1. Calculate the followings:

a) Total bearing pressure (contact pressure):

$$q = \frac{P + W_f}{A} \quad (10)$$

where P is the column load; W_f is the weight of footing; A is the base area of footing ($B \cdot L$).

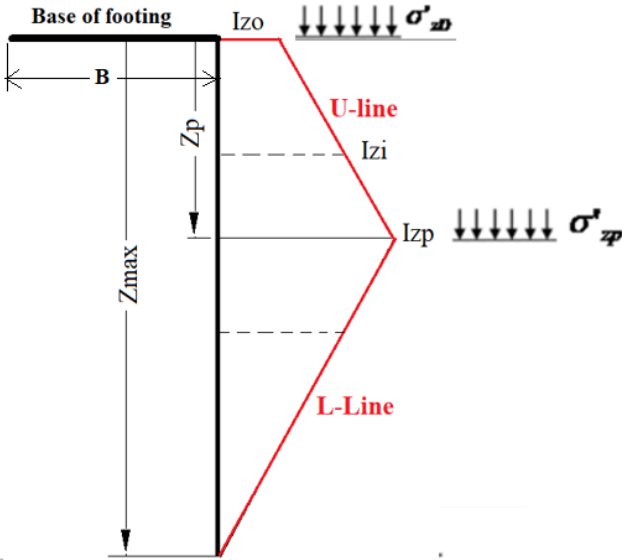


Fig. 2. Variation of the strain influence factor for any type (square, circular, rectangular or strip) of shallow foundations in the modified method.

b) Effective overburden pressure at the base level of foundation before the construction of foundation:

$$\sigma'_{zD} = \gamma D_f - u_D \quad (11)$$

c) Net bearing pressure

$$q_{net} = q - \sigma'_{zD} \quad (12)$$

where u_D is the pore water pressure at the base level of footing; γ is the unit weight of soil above the base-level of foundation; D_f is the depth of foundation from the ground surface.

Up to this point, all the procedure and calculations are same as the original method. After this point, the modifications would take place.

d) Depth of z_p at which the peak of the strain influence factor (I_{zp}) occurs (see Fig. 2). Its value must be $B/2$ and B for square/circular based footings and strip footings, respectively. The following equation can be used for any type of shallow foundations to get the depth at which peak strain influence factor occurs.

$$z_p = \left(\frac{L}{B} - 1\right) \frac{B}{18} + \frac{B}{2} \quad \frac{B}{2} \leq z_p \leq B \quad (13)$$

As an alternative, Fig. 3 can be used to get z_p value as follows.

$$z_p = B \cdot C_p \quad (14)$$

where C_p is a coefficient that can be taken from Fig. 3.

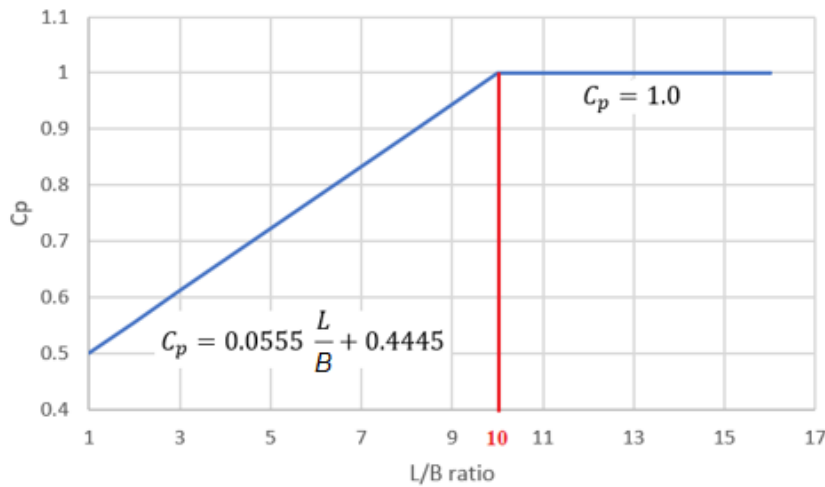


Fig. 3. C_p -coefficient as a function of L/B ratio.

Effective overburden pressure at the depth of z_p at which peak of strain influence factor takes place:

$$\sigma'_{zp} = \sigma'_{zD} + z_p \gamma' \quad (15)$$

where γ' is the submerged unit weight of soil if there is ground water otherwise, bulk unit weight of soil.

e) The strain influence factor, I_{zo} (seen in Fig. 2 at the base of any shape of a shallow foundation) can be calculated by Eq. (16). Its value must be between 0.1 and 0.2 (Fig. 4).

$$I_{zo} = \frac{8}{90} + \frac{1}{90} \left(\frac{L}{B}\right) \quad \left(\frac{L}{B} \leq 10\right) \quad (16)$$

(if $\frac{L}{B} > 10$, take $\frac{L}{B} = 10$)

As an alternative, I_{zo} can be taken from Fig. 4 as a function of L/B ratio.

f) The peak value of strain influence factor same as Schmertmann et al. (1978) method:

$$I_{zp} = 0.5 + 0.1 \sqrt{\frac{q_{net}}{\sigma'_{zp}}} \quad (17)$$

g) Depth z_{max} at which the strain influence factor would be reduced to zero.

$$z_{max} = \frac{2}{9}L + \frac{16}{9}B \quad (2B \leq z_{max} \leq 4B)$$

(if $z_{max} > 4B$, take $z_{max} = 4B$)

(18)

As an alternative, Fig. 5 can be used to get z_{max} value by Eq. (19).

$$z_{max} = B \cdot C_m \quad (19)$$

where C_m is a coefficient that can be taken from Fig. 5.

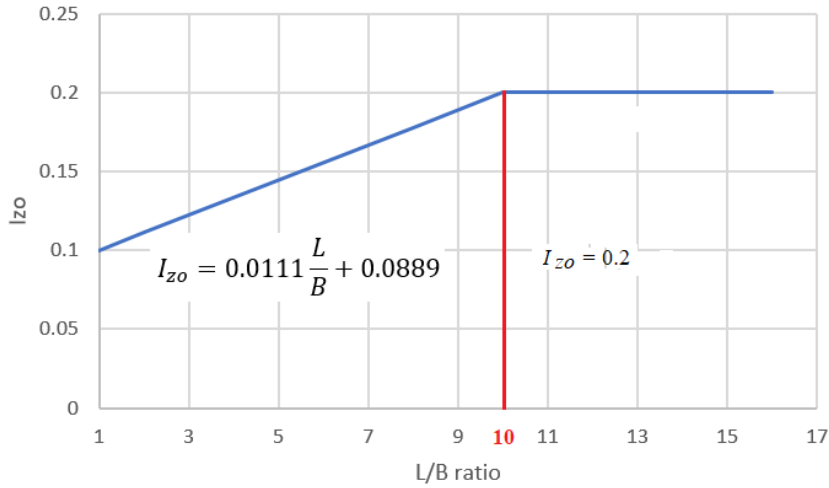


Fig. 4. Variation of I_{zo} as a function of L/B ratio.

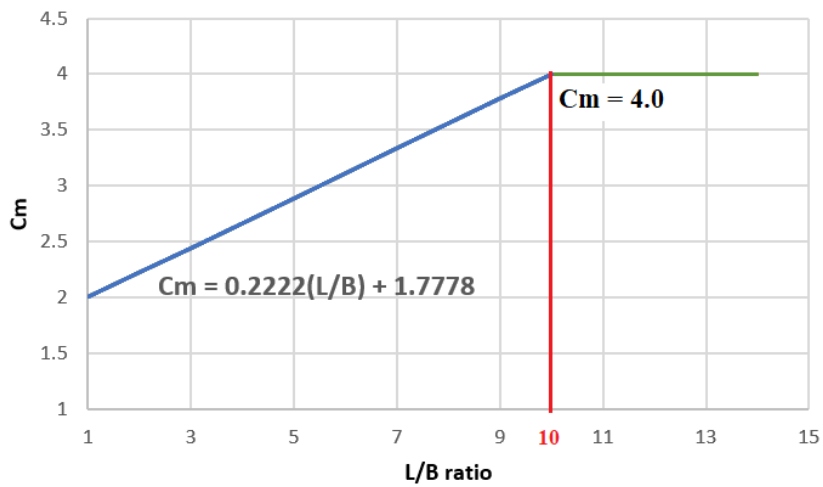


Fig. 5. Coefficient of C_m as a function of L/B ratio.

h) Calculation of I_{zi} values on U-line in Fig. 2 by Eq. (20).

$$I_{zi} = I_{zo} + \left(\frac{I_{zp} - I_{zo}}{z_p}\right)z_i \quad (0 \leq z_i \leq z_p) \quad (20)$$

i) Calculation of I_{zi} values on L-line in Fig. 2 by Eq. (21).

$$I_{zi} = I_{zp} - \left(\frac{I_{zp}}{z_{max} - z_p}\right)(z_i - z_p) \quad (z_p \leq z_i \leq z_{max}) \quad (21)$$

2. Modulus of elasticity is estimated by tip resistance, q_c , of Cone Penetration Test, CPT, if E_s values are not known Eq. (22).

$$E_s = q_c \left(2.389 + 0.111 \frac{L}{B}\right) \quad \left(\frac{L}{B} \leq 10\right) \quad (22)$$

Terzaghi et al. (1996) suggests using the following equation.

$$\frac{E_s(L/B)}{E_s(L/B=1)} = 1 + 0.4 \log \left[\frac{L}{B}\right] \leq 1.4 \quad (23)$$

where $E_{s(L/B=1)} = 3.5q_c$ and q_c is the cone resistance in CPT (Cone Penetration Test).

Note: If the modulus of elasticity of soil layers are known, no need the estimation by Eqs. (22) or (23).

3. Elastic (immediate) settlement is calculated by Eq. (1), the Schmertmann et al. (1978) method.

4. Hypothetical Cases

Once modification of Schmertmann-Hartman-Brown method was completed, the calculations of the elastic (immediate) settlements became very simple with a simple computer code prepared. Then, the effect of L/B (length/width ratio) and B (width) on elastic settlement is investigated. For the hypothetical cases, the foundation and soil profile seen in Fig. 6 are employed.

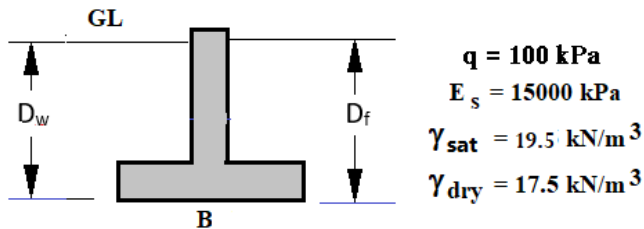


Fig. 6. Soil profile and foundation in hypothetical cases.

The variation of settlements with L/B starting from 1 to 12 (1, 2, 3, 6, 8, 10, 12) for $B=1, 3, 5$ meters have been estimated by the code and plots are given in Fig. 7. As it is seen in Fig. 7, when L/B is increased, settlement increases too until $L/B=10$. Then, there is no change on the settlement. Similarly, when B is increased, settlement increases too.

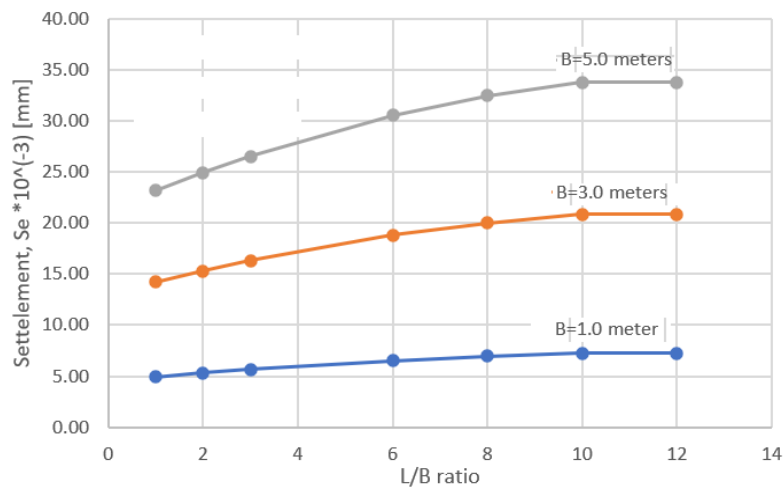


Fig. 7. Settlement/Width ratio versus L/B ratios.

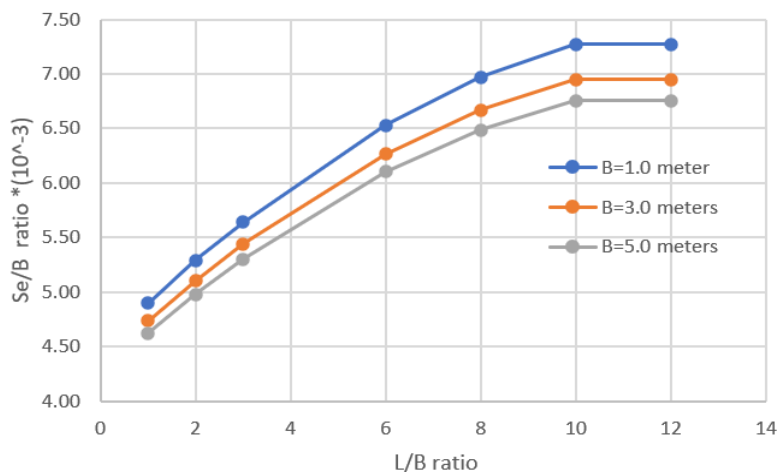


Fig. 8. Settlement/Width ratio versus L/B ratios.

However, once the settlements are normalized as (S_e/B) , it has been seen that when L/B increased (S_e/B) increases, and when B is increased, (S_e/B) ratios are decreased as seen in Figs. 8 and 9.

5. Conclusions

From the investigation, following points have been drawn.

- The Schmertmann-Hartman-Brown (1978) method is modified, and a more convenient approach is proposed, so that there would be no worries about the foundation whether it is an axisymmetric problem or a plain strain problem. Also, only two equations would be employed to calculate the strain influence values in place of five equations in the original method.
- The settlements increase from $L/B = 1$ to 10, after that ($L/B > 10$) no more settlement would occur.
- It has been seen that the settlement/width ratio decreases while the width of footing is increased. In other words, settlement increment is not linear. This result shows that angular distortion of footings with larger width (B) would be less than the angular distortion of footings with smaller B .

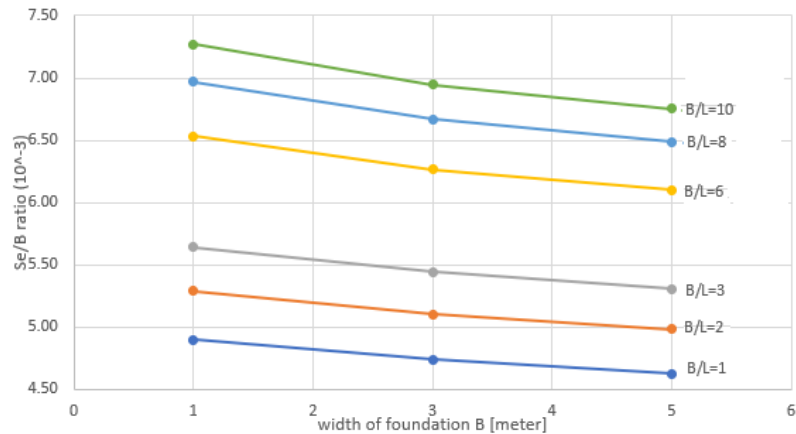


Fig. 9. Settlement/Width ratio versus width (B) of foundation.

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Conflict of Interest

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