SETTLEMENT AND TILT of TWO INTERFERING FOOTINGS ON CLAY

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ABSTRACT

In this investigation a novel approach has been developed to study the settlement and tilt of two interfering footings using non-liner constitutive laws of soils. Non-dimensional correlations to compute maximum settlement and minimum settlement of the interfering footings have been developed for its use in the design of interfering footings. Further it has been concluded that tilt is sensitive to these factors and should be considered in the design. It is expected that the findings of this study will lead to more economical and safe design of geotechnical structures in built up areas.

INTRODUCTION

The phenomenon of interference of adjacent footings is of greater practical significance as footings in field are rarely isolated and they interfere with each other to some extent. Due to interference, unequal stress concentration occur below a footing which causes tilting and it changes the behaviour of the footings.

A study of interference effect on the bearing capacity, settlement and tilt characteristics of the footings is, therefore, very important.

The study of interference between adjacent footings was initiated by STUART (1962). He developed an analytical analysis to examine the interference effect of two parallel strip footings placed on cohesionless soil. DASH (1981) analysed this problem for surface strip footing on $c - \phi$ soil. The details of these studies are given elsewhere (Amer,1992).

It was observed that the above investigators, in general, investigated the interference effect on sand in terms of bearing capacity and settelment and not studied the important aspect i.e the tilt of the footings. Secondly very meagre data is available on interfering footings on clay.

In the present analysis settlement and tilt of two adjacent surface strip footings of same width resting on Dhanori clay loaded simultaneously have been studied using constitutive laws of soils. Methodology has been developed to prodict the pressure-settlement and pressure-tilt characteristics of such footings resting on clay.

CONSTITUTIVE LAWS

Constitutive laws define the stress-strain behaviour of soil. Since the behaviour of soil over a wide range of stresses is non-linear KONDNER (1963) hyperbolic function as given in equation (1) and (2) has been taken in the analysis.

$$\frac{\epsilon}{\sigma_1 - \sigma_3} = a + b\epsilon \qquad \text{..........(1)}$$

or

$$\epsilon = \frac{a(\sigma_1 - \sigma_3)}{1 - b(\sigma_1 - \sigma_3)} \qquad \text{.........(2)}$$

where,

	ϵ	=	Axial strain
	a,b	=	Constants of hyperbola
	σ_1, σ_3	=	Major and minor principal stresses respectively.

For demonstrating the methodology developed in subsequent sections DHANORI clay have been considered. Some of the important properties of Dhanori clay reported by Mukhopadhyay (1978) are given below in Table 1.

TABLE 1 : Properties of Dhanori Clay

Liquid Limit	55.5 %
Plastic Limit	25 %
Moisture Content	42 %
Specific Gravity	2.71 g/cc
Undrained Shear Strength	0.55 kg/cm^2

The undrained triaxial test results show negligible influence of confining pressure on tangent modulus E_i (= 1/a) and shear strength σ_u (= 1/b). The average values of E_i and σ_u was found to be 181.18 1 kg/cm^2 and 1.6 kg/cm^2 respectively (Fig.1).

THEORETICAL ANALYSIS

ASSUMPTIONS

Following assumptions have been made in the analysis:

1. The soil mass is semi-infinite and isotropic medium.
2. The footings base is rough.
3. The roughness of footings is assumed to generate uniform tangential stress at the contact surface, which follows the relationship, $t_a = c(q/q_u)$ for cohesive soils. The value of pressure at failure (q_u) may be taken as cN_c, with,

   N_c = Terzaghi's bearing capacity factor.
   c = Unit cohesion.
   q = Applied pressure intensity.
4. Interference is considered between two fully flexible strip footings. Both the footings are loaded with equal load intensities.
5. The contact pressure distribution is uniform.
6. The whole soil mass supporting the footings has been divided into a large number of thin horizontal strips up to a depth beyond which the stresses are less than 0.08 q, q being the applied stress on the footing.
7. The stresses in each layer are computed using Boussinesq's thoery since the stress equations for various types of loads are available. The strains are computed from the known stress conditions using constitutive laws.
8. There is no slippage at the interface of layers of the soil mass.

Vertical Settlement and Tilt :

The procedure adopted for the evaluation of pressure-settlement and pressure-tilt characteristics under a set of two interfering footings is described in the following steps :

Step 1 : For a given intensity of pressure (q) and spacing of footings (s), the contact pressure distribution and tangential stresses at the interface of footing bases and supporting soil media have been taken as shown in Fig.2 which induces stresses in the soil.

Step 2 : Evaluation of stresses in each layer of the soil mass Fig .2 at vertical sections due to q and ta have been obtained separately and then added. Superimposing of stresses due to the two footings have been done to get the total stresses. Principal stresses and their directions with respect to the vertical z-axis are determined.

Step 3 : Strip footings representing the plane strain condition, after simplifying the expressions for principal strains, we get

$$\frac{\epsilon_3}{\epsilon_1} = \frac{\sigma_3-\mu_1\sigma_1}{\sigma_1-\mu_1\sigma_3} = -\mu_2 \quad (say) \qquad (3)$$

where , ϵ_1, ϵ_3 = Major and minor principal strains respectively.

$$\mu_1 = \frac{\mu}{1-\mu} \qquad \ldots\ldots\ldots(4)$$

μ = poissons ratio

Step 4 : The strain in the direction of major principal stress is computed from constitutive relations as given below:

$$\epsilon_1 = \frac{a'(\sigma_1-\sigma_3)}{1-b'(\sigma_1-\sigma_3)} \qquad \ldots\ldots\ldots\ldots(5)$$

Where, $a' = a(1-\mu^2)$ and $b' = 1.1 \times b$

The strain in the minor principal stress direction is given by,

$$\epsilon_3 = -\mu_2\epsilon \qquad \ldots\ldots\ldots\ldots(6)$$

Step 5 : The strain in the vertical direction (ϵ_z) for each layer is computed using the following expression:

$$\epsilon_z = \epsilon_1 \cos^2\theta_1 + \epsilon_3 \cos^2\theta_3 \quad ....(7)$$

where θ_1 and θ_3 are the directions of the principal strains with respect to the vertical axis.

Step 6 : The vertical settlement (S_e) of any layer is computed by multiplying the strain ϵ_z with the thickness of each layer δ_z

$$S_e = \epsilon_z . \delta_z \quad ....(8)$$

The total settlement (S_t) along any vertical section is computed by numerically integrating the expression:

$$S_t = \int_O^n \epsilon_z . d_z \quad ....(9)$$

The total settlement is computed along all vertical sections for each pressure intensity.
An exaggerated case of settlement under a set of two interfering footings are shown in Fig.3

Step 7 : Tilt of footing is calculated from the following equation.

$$Tilt = \frac{(S_{max})_{in} - (S_{min})_{in}}{B} \quad ....(10)$$

where:

$(S_{max})_{in}$ = Maximum settlement of one of the interfering footings.
$(S_{min})_{in}$ = Minimum settlement of one of the interfering footings.
B = Width of the footing.

Step 8 : Settlement and tilt for various pressure intensities on footing is computed by repeating steps 1 to 7. The pressure versus settlement and pressure versus tilt were obtained.

Step 9 : The clear spacing of the footings is changed and steps 1 to 8 were repeated.

INTERPRETATION AND RESULTS :

Taking both the footings of width 30 cm, average settlements and tilt were computed, using the above described analysis for different S/B ratio varies from 0.5 to 3. Isolated footing were analysed for comparison purposes. Pressure-settlement and pressure-tilt curves for rough strip footings resting on Dhanori clay were obtained as shown in Fig 4 and 5.

It is evident from the figures that, for a particular pressure intensity, settlement and tilt generally increases with the decrease in S/B ratio. The tilt of the interfering footings takes place toward the center of the system (i.e they tilt towards each other). The value of tilt depends on the magnitude of pressures and relative spacing.

Non-dimensional relationships at factors of safty 2 and 3 have been obtained to predict maximum and minimum settlements of interfering footings by investigating footings of width (B = 10 cm, 20 cm, 30 cm, 40 cm and 60 cm) Fig. 6 and 7.

CONCLUSIONS

1. Analytical procedures have been given in this paper using none-linear stress-strain behaviour of soil, to predict the behaviour of two interfering footings resting on clay.
2. Ultimate bearing capacity of interfering footings is almost same as of isolated footings in case of clay. therefore, from shear failure consideration the interfering footings may be designed as isolated footing.
3. Magnitude of settlement and tilt of the interfering footings is affected by S/B ratios. Therefore, proportioning of interfering footings should be carried out by actual estimation of settlement and tilt.
4. Tilt of interfering footings takes place toward the center of the system (i.e they tilt towards each other).

REFERENCES

1. AMER, A.A., (1992)."Interference effect on the behaviour of footings," thesis presented to the University of Roorkee, India, at Roorkee, in fulfillment of the requirements for the degree of Doctor of philosophy.
2. DASH,P.K. (1981), "interference between surface footings on purely cohesive soil." Indian Geotech., J., 11 (4),PP. 397-402.
3. KONDNER, R. L. (1963). "Hyperbolic stress-strain response of cohesive soils." J. soil Mechanics and Foundation Engrg., ASCE, 89 (1), PP. 115-143.
4. STUART, J.G. (1962). "Interference between foundations with special reference to surface footings in sand." Geotechnique,12 (1),PP. 15-23.

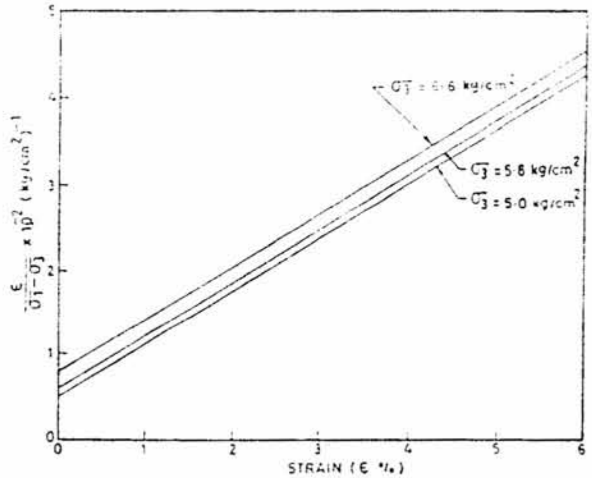


FIG.1 — TRANSFORMED STRESS STRAIN CURVE FOR DHANORI CLAY (AFTER MUKHOPADHYAY, 1978)

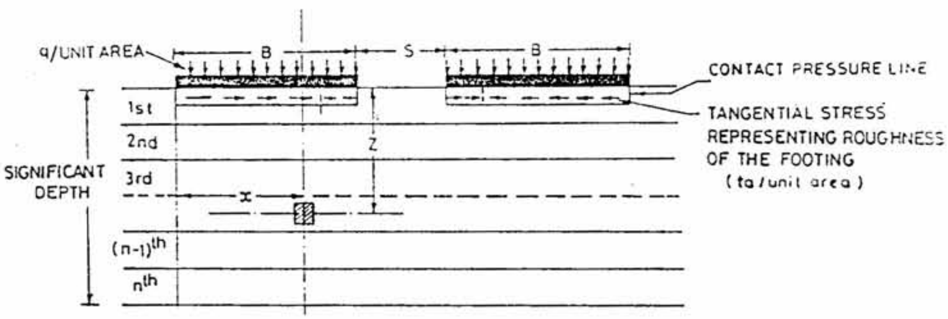


FIG.2 -TWO INTERFERING ROUGH STRIP FOOTINGS & SOIL MEDIA DIVIDED INTO n LAYERS

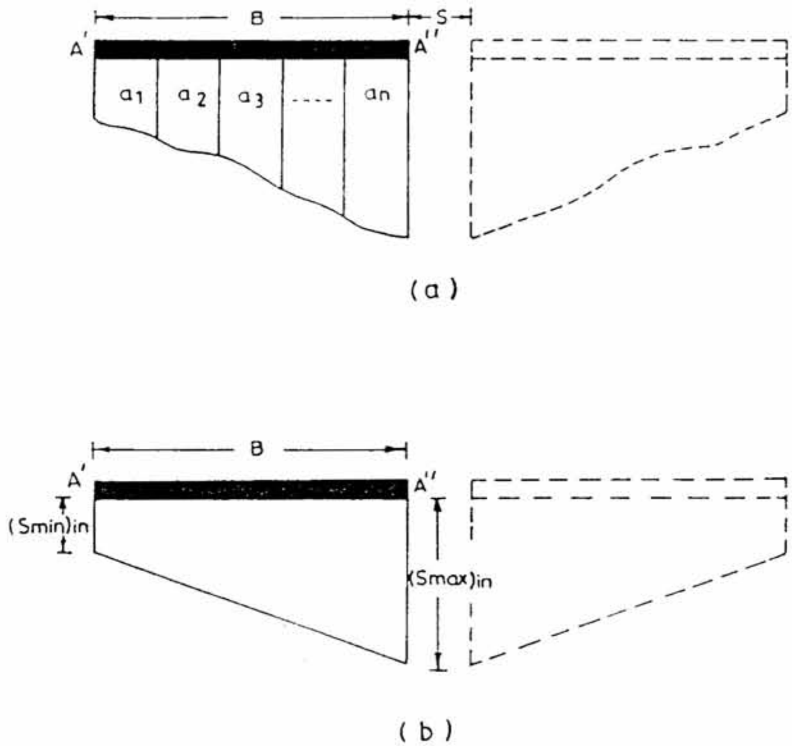


FIG. 3 —SETTLEMENTS DIAGRAM UNDER A SET OF TWO INTERFERING STRIP FOOTINGS

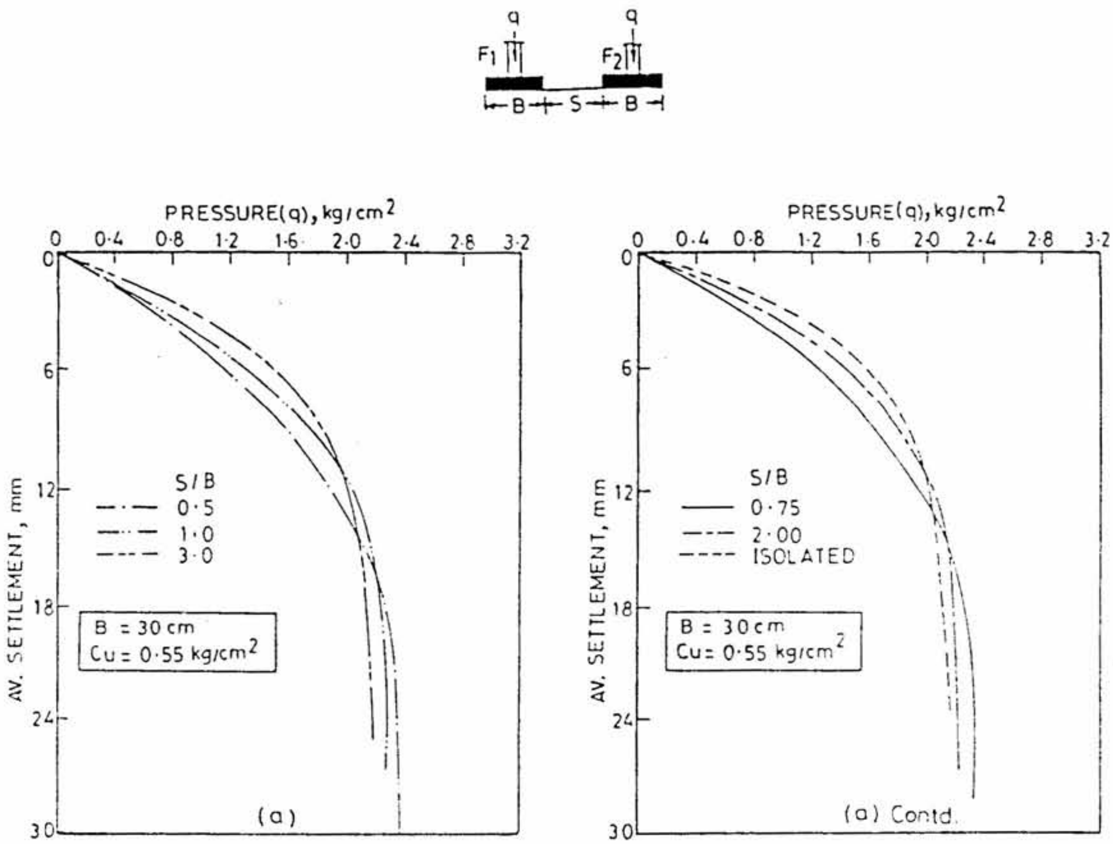


FIG. 4 — PRESSURE VERSUS SETTLEMENT CURVES

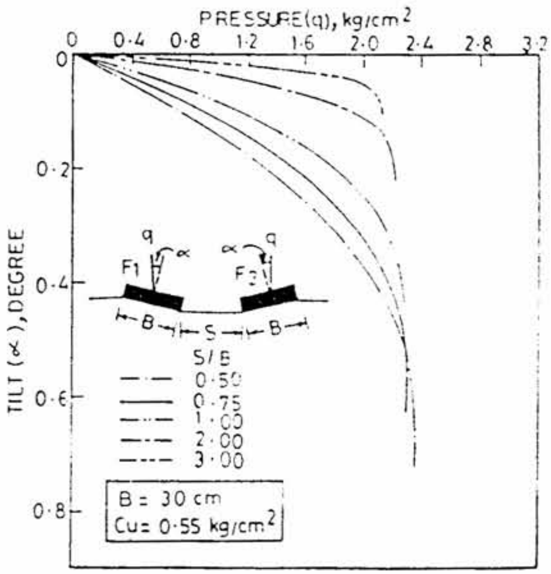
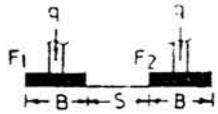


FIG. 5 — PRESSURE VERSUS TILT CURVES



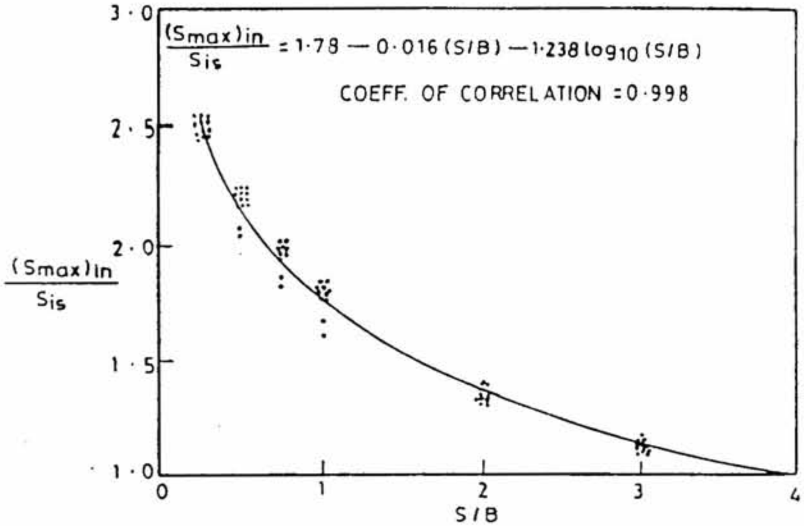


FIG.6 — $\frac{(S_{max})_{in}}{S_{is}}$ VERSUS S/B

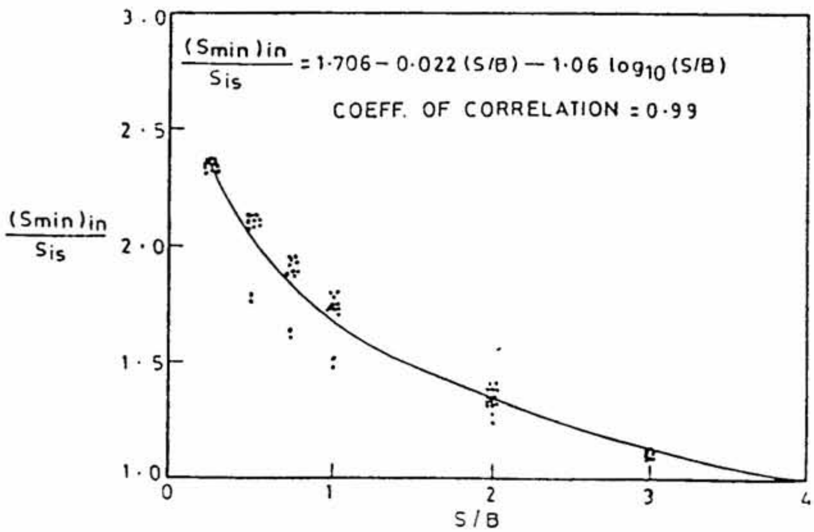


FIG.7 — $\frac{(S_{min})_{in}}{S_{is}}$ VERSUS S/B