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Bearing Pressure of Foundation on Strong Layer Overlying Weak Clay Accounting for Compressibility

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Abstract. The present study analyses response of a circular footing on two layered clays. Several solutions are available for the ultimate bearing capacity of foundations on two-layered soil but none consider the compressibility of the layers. Strong and stiff layer of thickness, H, overlies a soft and weak clay with $E_1 > E_2$ and $c_{u1} = 2.5c_{u2}$, where 1 and 2 correspond to top and bottom layers respectively. Finite element axisymmetric analysis is carried out to evaluate the bearing pressure, q, versus settlement responses for ranges of stiffness ratio ($R_E = E_1/E_2$), and different thicknesses of top layer. Variations of bearing pressure factors ($N_{cf} = q/c_{u1}$) for circular footings of diameter, D are obtained at different settlement ratios (SR), for a wide range of R_E. Results are validated with the Merifield and Nguyen (2006) for considered cases of layered clays with different H/D. Variation of N_{cf} with stiffness ratio, R_E for different SR and H/D ratios are presented and analyzed.

Keywords: Circular foundation, Layered clays, Stiffness, Undrained Strength, Numerical analysis.

1 Introduction

Soft soils undergo excessive settlements due to compressibility causing engineering structures to collapse or undergo serious or detrimental damage. Ground profile consists usually of several strata, which contribute to the complex behavior when subjected to various loads. Layered soft clays are commonly encountered in Geotechnical Practice. The top layer often of even normally consolidated sedimented soil is subjected to atmospheric and climatic conditions forming a crust or a desiccated layer that is stiffer and stronger than the lower one.

Button [1] proposed the bearing capacity factors for strip footing resting on two-layer cohesive soil by limit equilibrium analysis, which depends on the relationship between strength ratio and ratio of thickness of upper cohesive layer to width of footing. The effect of non-homogeneity in shear strength on the ultimate bearing capacity of a strip footing on two-layered clay was given by Siva Reddy and Srinivasan [2]. Model experiments on circular and strip footings on layered clays were carried out by Brown and Meyerhof [3] and proposed modified bearing capacity factors. Failure of the foundation happens by punching through the top layer of the rigid layer overlying the soft layer. Merifield et al. [4, 5] investigated the undrained bearing capacity of a rigid footing on two-layer clay deposit. Papadopoulou and Gazetus [6] modified the coefficients for strength ratio and normalized thickness, for the estimation of undrained bearing capacity of footings on two-layered clays.

Sunil and Sheetal [7] studied on bearing capacity of surface square footing resting on strong over weak clay using PLAXIS 2D and stated that the bearing capacity factor increases with an increase in thickness of top layer. Benmebarek [8–10] studied the effect of two-layered clays on bearing capacity of foundations using numerical FLAC software. The modified bearing capacity factor is shown to be dependent on relative thickness of top layer with respect to width of footing, the strength ratio of the soils, and the degree of non-homogeneity.

The load carrying capacity of the layered strata is also influenced by the soil's stiffness properties. McMahon et al. [11] determined the load–settlement behavior of a linear-elastic perfectly plastic soil based on the ellipsoidal cavity expansion model. Shiva et al. [12] determined the effect of compressibility on undrained bearing pressure of homogeneous soft ground.

It has been observed that none of the above works considers the effect of compressibility of soils on undrained bearing pressure – settlement response of footings on two-layered soil system. The present study considers a strong and stiff layer overlying weak and soft clay accounting for compressibility of the two layers.

2 Problem Definition

A circular foundation of diameter, D = 2 m resting on two layered clay was considered (Fig. 1). Strong and stiff top clay layer of thickness, H, possessing deformation modulus, E_1 and undrained shear strength c_{u1} overlies a weaker and softer clay with an undrained shear strength, c_{u2} of 10 kPa and deformation modulus, E_2, of 3 MPa. Undrained behavior of clays was simulated by considering Poisson's ratio of 0.495. Table 1 lists the values of soil parameters considered for the study.

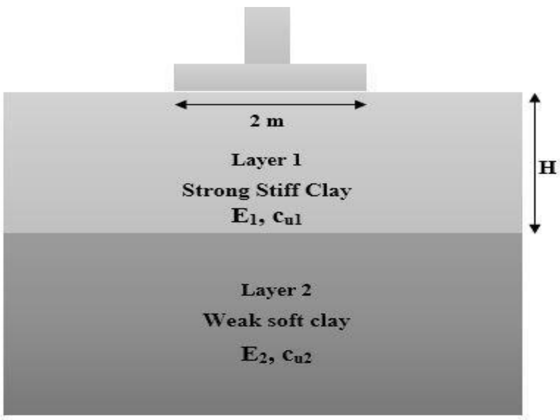


Fig. 1. Sketch describing the problem definition

Table 1. Properties of soil.

Soil Property	Values	
Soil type	Stiff Layer 1	Weak Layer 2
Undrained Strength, c_u (kN/m^2)	25	10
Poisson's ratio, ν	0.495	0.495
Unit weight of soil, γ (kN/m^3)	18	15
Deformation modulus, E (MPa)	6, 15, 30	3

3 Methodology

Numerical study was performed using finite element program PLAXIS 2D. Axisymmetric modeling was chosen for circular footing. The soil mesh was generated using 15-noded triangular elements. An undrained drainage type was chosen in Mohr-Coulomb soil model. The lateral boundaries in the radial direction were positioned at a distance of 6 times the diameter of the footing and the bottom one was fixed in both vertical and radial directions.

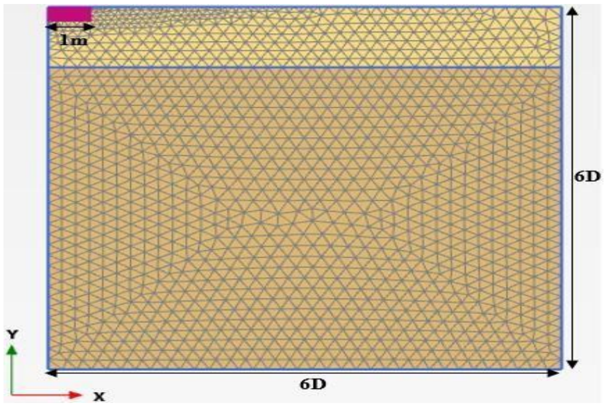


Fig. 2. Meshing of Finite element model with uniform displacement

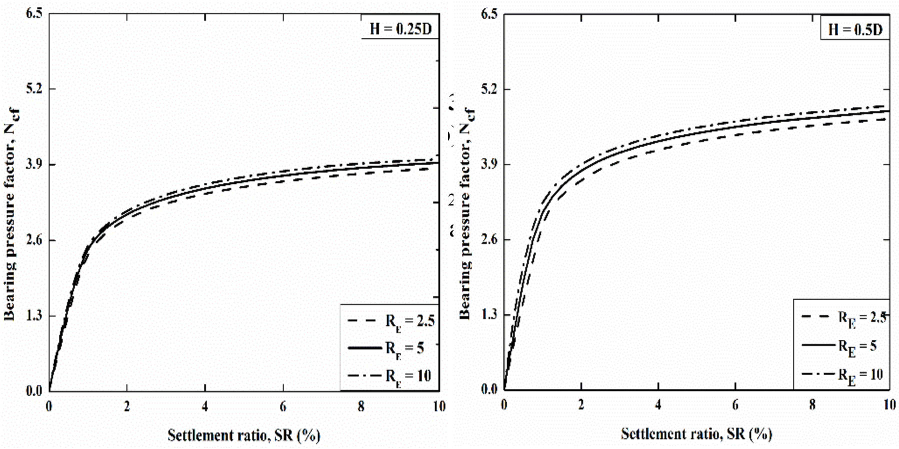
The study is confined to a strength ratio, c_{u1}/c_{u2}, of 2.5 and analyses the effect of compressibility and relative thickness of the top layer on bearing pressure–settlement response of two-layered clay. The study is limited to a vertical displacement of 20 cm, i.e., 10% of diameter of the footing.

4 Results

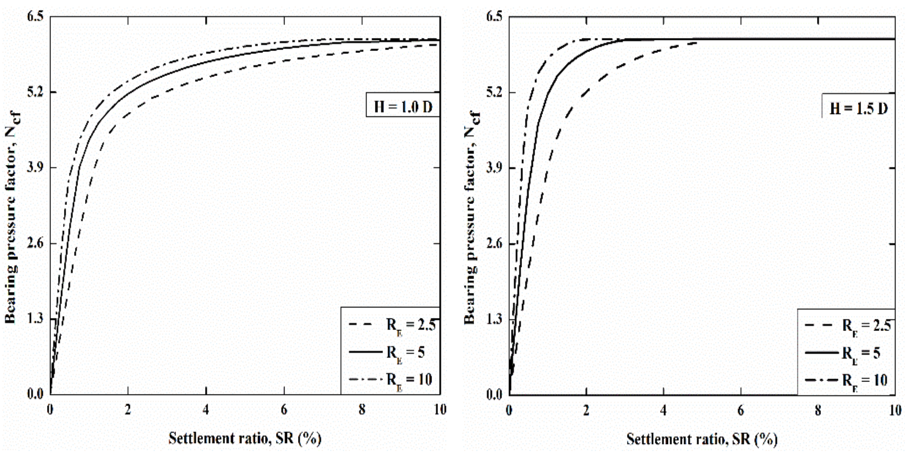
Undrained bearing pressure, q, – settlement, s, responses for the considered cases are obtained. Settlement is normalized by diameter of the footing and is defined as Settlement Ratio, $SR = 100s/D$. The bearing pressure is normalized with undrained strength of the top layer and defined as bearing pressure factor, N_{cf} $(= q/c_{u1})$. For studying the effect of compressibility on N_{cf} of this two-layered soil, for considered cases, *SR* is used as reference. Ultimate bearing capacity factors given by Merifield and Nguyen [5], for different thicknesses of top layer are compared with N_{cf} values obtained at a settlement of 10% of footing diameter (Table 2). The predicted values agree closely with those of Merifield and Nguyen (2006) with maximum deviation of about 1%.

Table 2. Comparison of Bearing capacity factors with Merifield and Nguyen 2006 [5]

H/D	Merifield and Nguyen [5]	Present analysis N_{cf} at SR 10%
0.25	4.02	4.02
0.5	5.23	5.23
1.0	6.06	6.11
1.5	6.04	6.12



settlement
c) and (d)



curves obtained for layered soil with thickness, H, of top strong and stiff clay of 0.5 m, 1.0 m, 2.0 m and 3.0 m corresponding to H/D ratios of 0.25, 0.5, 1.0 and 1.5 respectively. Bearing pressure factor (N_{cf}) increases significantly with increase in settlement but marginally with stiffness ratio of R_E for all the relative thickness ratios (H/D) implying increase in carrying capacity with increase in relative stiffness and relative thickness of the upper clay at all settlements.

For a thin top layer with H = 0.25D, N_{cf} at SR = 1% increases by 3.9 and 6.7% for the deformation modulus of top layer increasing from 2.5 to 5 and 10 times the value of the bottom layer. For an intermediate relative thickness ratio of 1, N_{cf} value at SR = 1% increases by 24% and 34% for R_E increasing by 4 folds. For a relatively thick top layer with H = 1.5D, bearing pressure factors increase by 33% and 49% signifying that the effect is more on bearing pressure at larger thicknesses of the top layer. The effect of R_E on bearing pressure factor is much less at larger settlement say at SR = 5%, with increments of 4.3 and 6.7% for H/B = 1.0 and negligible for H/B = 1.5.

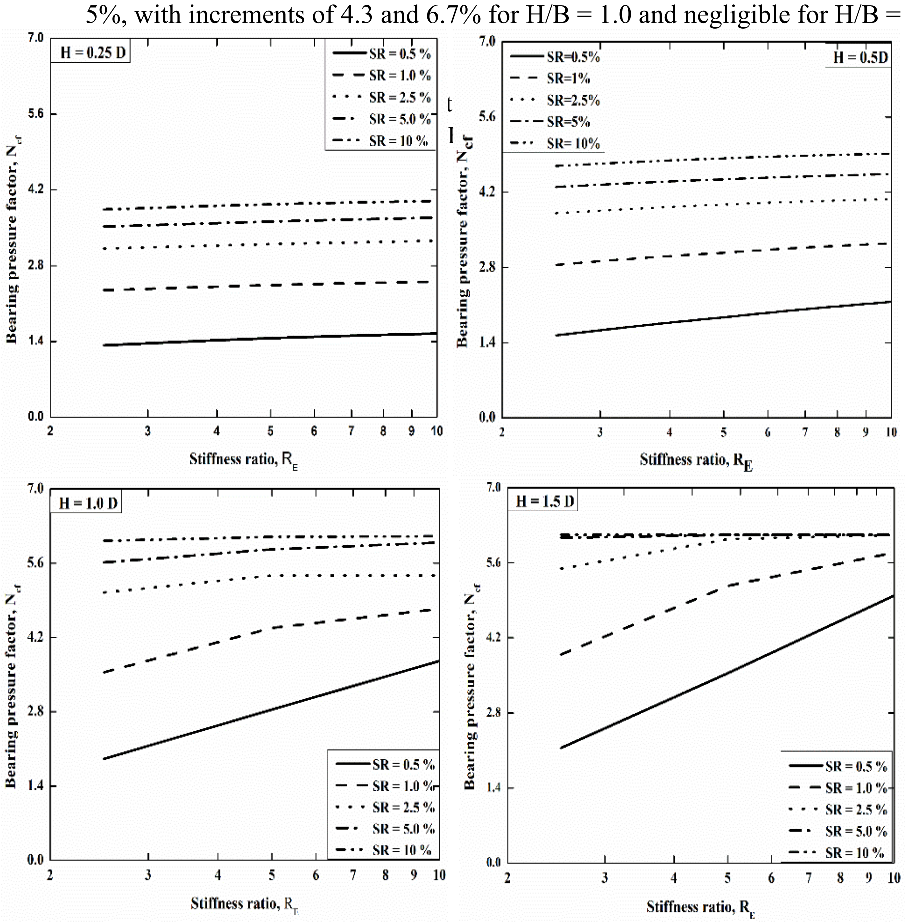
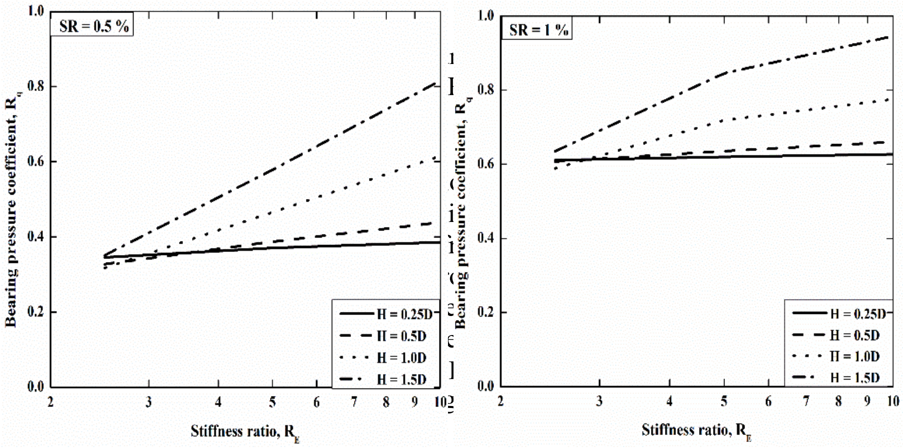


Figure 4 shows the variations of N_{cf} with R_E plotted on a logarithmic scale (Fig. 4) for different normalized thicknesses and settlement ratios of 0.5%, 1.0%, 2.5%, 5.0% and 10%. N_{cf} increases linearly to marginally bilinearly with stiffness ratio. For H/D = 0.25, N_{cf} increases from 1.33 at R_E = 2.5 at SR = 0.5% to 1.54 at R_E = 10; similarly for a settlement ratio of 10%, N_{cf} increases from 3.84 for R_E =2.5 to 4.0 for R_E = 10. For a normalized thickness of 1.5 and at a settlement ratio of 0.5% and 5%, the values of N_{cf} are 2.15 & 5.0 and 6.07 & 6.12 for R_E = 2.5 and 10 respectively (Fig. 4d) implying the effect of compressibility on bearing pressure to be minimal or negligible at higher settlements.



…tor, N_{cf} to … 0.5% and … and 1% … e stiffness … nificant at … at larger … % are … .5 and 10. … ng layer.

5 Conclusions

Circular footing resting on strong stiff clay layer overlying weak soft soil is analyzed for different thicknesses of the top layer and different modular ratios. Bearing pressure

– settlement responses are obtained for different compressibility of the upper layer. Bearing pressure coefficients at specific settlement increase with increase in stiffness ratio of clay layers. For H/D = 1.5, R_q at SR = 0.5% increases from 0.35 to 0.82 as R_E increased from 2.5 to 10. Bearing pressure coefficients also increase with increase in thickness of top strong and stiff layer. For $R_E = 5$, R_q at SR = 0.5% increases from 0.37 to 0.58 as H/D increased from 0.25 and 1.5. Effect of compressibility is significant at smaller settlements and larger thicknesses of the layer beneath the rigid footing.

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