Kochi Chapter

Indian Geotechnical Conference
IGC 2022
15th – 17th December, 2022, Kochi

Undrained Bearing Pressure of Desiccated Nonhomogeneous Ground Accounting for Compressibility

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Abstract. Normally consolidated soils have strength increasing with depth and with a desiccated layer near the top due to diurnal variations of temperature and weathering effects. Desiccated depth usually has high stiffness and strength which reduce to those values that correspond to the normally consolidated lower depth whose undrained shear strength increases linearly with depth. In this study, Desiccated Normally Consolidated (DNC) ground was considered as a two-layer soil with non-homogeneities of these layers accounted for with decreasing and increasing rates of strength and stiffness with depth in top desiccated and the lower NC soil respectively. A circular footing resting on desiccated zone overlying compressible NC deposit was analyzed considering the compressibility of the soils in the form of rigidity index. Bearing pressure - settlement responses of DNC are obtained by numerical analysis. Parametric study was carried out to study the effect of desiccation on undrained bearing pressure of footing on DNC. Bearing pressure of footings DNC increase with increase in rigidity index and non-homogeneity of NC soil. Thickness and non-homogeneity of desiccated zone significantly affect the ultimate bearing capacity of footing resting on DNC ground.

Keywords: Compressibility, Circular footing, Desiccation, Non-homogeneity, Two-layered soil.

1 Introduction

Normally consolidated alluvial or marine soils, when exposed to atmosphere, are subjected to seasonal changes and form a crust or desiccated layer because of diurnal heating and cooling, lowering of water table, etc. [1]. Desiccated normally consolidated soils exhibit complex variations of strength with depth. Undrained shear strength of normally consolidated soil varies linearly with depth for a young normally consolidated deposit. With time, the deposit may gain in shear strength due to aging. Solutions for bearing capacity of strip footing resting on non-homogeneous aged clays with shear strength profile linearly increasing with depth given by Davis and Booker [2], is

$$q_{uf} = F_R\left[c_0 N_c + \frac{\rho B}{4}\right] \tag{1}$$

where $N_c = 5.14$; ρ - the rate of increase of shear strength with depth, c_o - undrained shear strength at ground level, B - width of the footing. $F_R = f(\rho B/c_o)$ - correction factor for roughness of the footing [2]. Shiva et al. [3] derived an equation for estimating the bearing capacity of footing resting on desiccated NC soil considering strength variation with depth. Desiccated normally consolidated soil (DNC) properties from few different locations are listed in Table 1 [4–6]. The thickness of the desiccated layer ranges from 1.5 m to 3.7 m, the rate of increase of undrained strength in NC layer from 1.0 to 4.5, the rate of decrease of undrained strength in the desiccated zone from 23 to 12, and the undrained strength at the top on NC layer from 16 kPa to 30 kPa, indicating large ranges in nature.

Table 1. Properties of desiccated normally consolidated ground

Parameter	Vankleek silo	Richmond silo	Bergado 2002	Bergado 2012
Unit weight of soil, γ (kN/m^3)	15	15	15	17
Thickness of desiccated zone, h_0 (m)	3.7	2.4	2.3	1.5
Rate of increase of shear strength, ρ, (kPa/m)	1.35	1	4	4.5
Rate of decrease of shear strength, κ, (kPa/m)	22.7	12.5	13.08	18.03
Undrained strength at the interface of desiccated and NC soil, c_{u0} (kPa)	16	30	16	16

Most of the bearing capacity theories consider the soil to be homogeneous and incompressible. Shear modulus of clays also has a significant effect on the undrained bearing pressure [7–9]. Based on the range of values from actual shear strength variations, a parametric study was carried out on the effect of desiccation on undrained bearing pressure of soft ground.

2 Problem Description

Rigid circular footing (diameter, D) located on desiccated layer of thickness, h_0 overlying normally consolidated soil was considered (Fig. 1). Desiccated normally consolidated (DNC) ground was considered as a two-layer soil whose undrained strengths vary linearly with depth, strength decreasing and increasing with depth in the two layers respectively. The rates of decrease in the top desiccated layer and increase in the lower NC soil layer of shear strengths with depth are denoted by κ and ρ respectively. The shear strength of the soil at the interface of the desiccated layer and NC soil was c_{u0}.

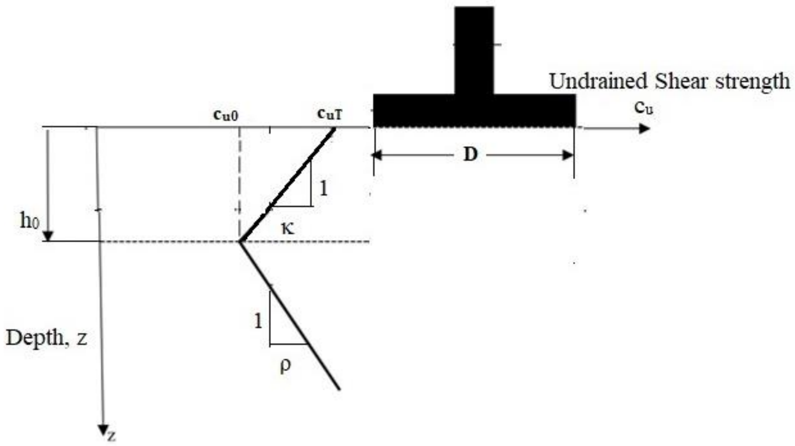


Fig. 1. Sketch describing the problem statement with parameters

Desiccated layer of thickness, h_0, with undrained strength c_{uT}, at the top deceasing to c_{u0}, the undrained strength at the interface with the NC soil was considered. Poisson's ratio of desiccated normally consolidated ground was taken as 0.495 to simulate the undrained behavior. Rigidity index, G/c_u, was assumed constant for both the layers by increasing the shear stiffness, G, at the same rate as that of undrained strength with depth. This study considers desiccation layer over NC soil as a two-layered system with the non-homogeneity and compressibility of the ground, in addition to the effect of desiccation on the strength profile.

3 Finite element model

Finite element software- PLAXIS 2D, 2020 was used to analyze the problem. A circular footing of 5 m diameter was considered. A vertical displacement was prescribed and the displacement-stress response was obtained. 15-noded triangular elements were used to discretize the geometry. The bottom boundary was fixed in both radial and vertical directions, while the side boundaries were fixed in the radial direction and the top boundary was free. The boundaries were fixed at 6 times the diameter in vertical and horizontal directions. Mesh convergence was checked and the mesh size was fixed as very fine.

The analysis was carried out in two stages – initially, the effect of desiccation on NC soil was studied considering the compressibility and later the heterogeneity of the ground is accounted for. The study was limited to a vertical displacement of 25 cm, i.e., 5% of diameter of the footing. Numerical model was validated with available literature for incompressible homogeneous ground. Parametric study was carried out on the results obtained from numerical modeling.

4 Results

The non-homogeneity (strength variation with depth) of DNC soil was considered alongside the desiccation effect in the top portion of the clay (Fig. 1). Obtained bearing pressure for a prescribed settlement was normalized with undrained strength at the interface and was defined as bearing pressure factor, N_{cf} $(= q/c_{u0})$.

Effect of compressibility on bearing pressure of desiccated NC ground

Rigidity index, G/c_u, was assumed constant for the two layers by increasing the shear stiffness, G, at the same rate as that of undrained strength. Rate of decrease in strength with depth, due to desiccation within top few meters, κ was taken as 10 kPa/m. Degree of non-homogeneity in desiccated portion, $\kappa D/c_{u0}$ was obtained as 5. Rigidity index of desiccated layer, I_r' was assumed as 200.

Rate of increase in strength with depth in NC soil, ρ was taken as 5 kPa/m. The degree of non-homogeneity, $\rho D/c_{u0}$, becomes 2.5. Rigidity indices, I_r of NC soil considered are 50 (soft), 100, 200, 500 and 1000 (rigid). Figure 2 presents the variation of bearing pressure factor with settlement ratio for different rigidity indices. N_{cf} increases with the rigidity of NC ground. N_{cf} for I_r = 500 soil increased 2.25 times that for I_r = 50 at SR = 1%.

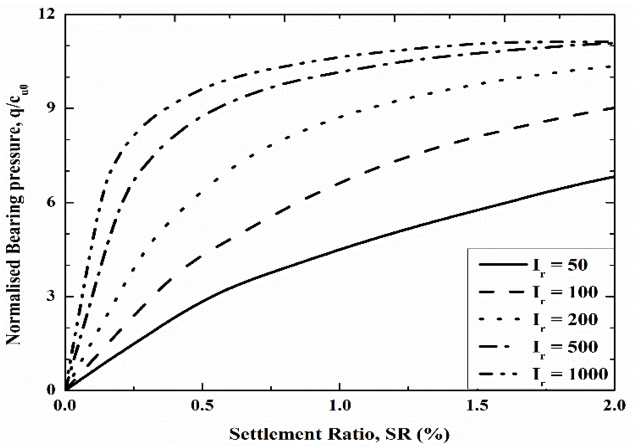


Fig. 2. N_{cf} versus SR curves for varying rigidity index, I_r

Effect of non-homogeneity of NC soil

The rate of increase in strength with depth, ρ, of NC soil was increased in steps from 0 through 5, keeping the undrained strength of 10 kPa at the top. The degree of non-homogeneity values are 0, 1 and 2.5. Assuming all the other parameters as constant, the effect of $\rho D/c_{u0}$ was evaluated in this section.

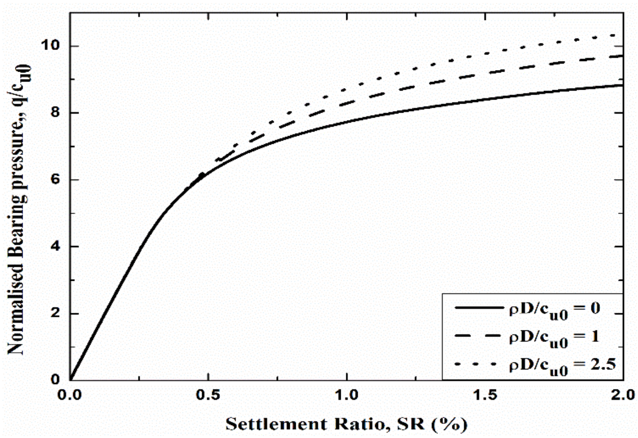


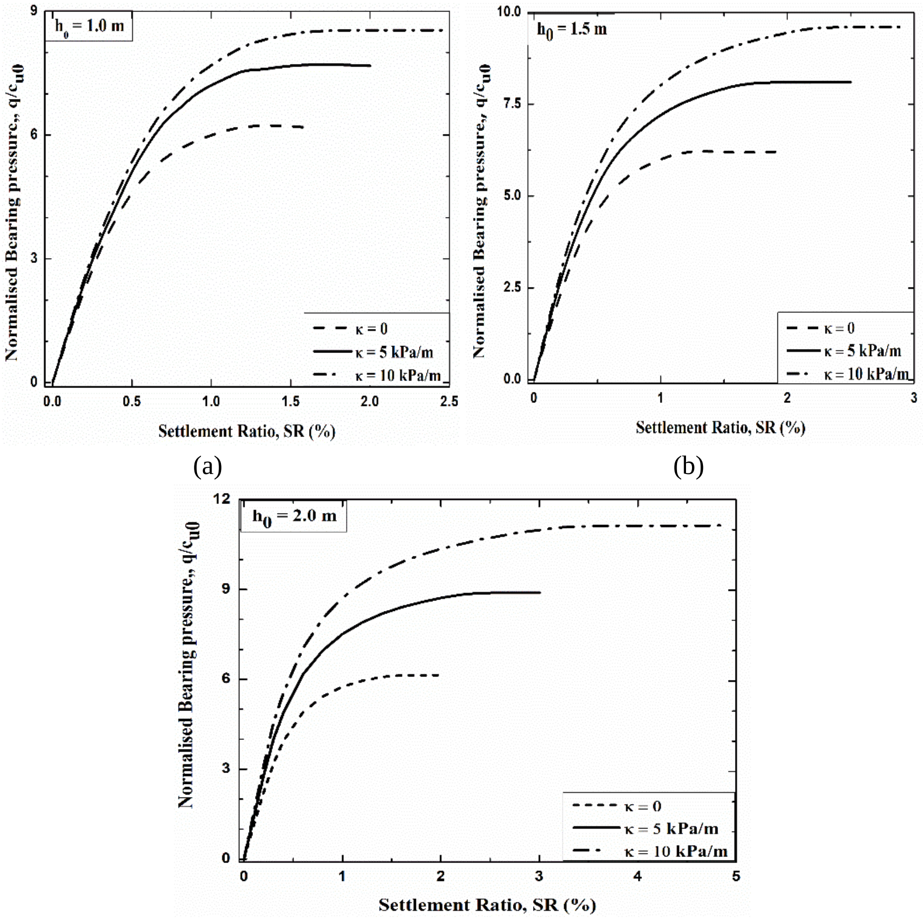
Fig. 3. N_{cf} versus SR curves for varying degree of non-homogeneity, $\rho D/c_{u0}$

Figure 3 shows the variation of bearing pressure factor with settlement ratio for different $\rho D/c_{u0}$. N_{cf} is nearly the same for settlement ratios, *SR*, less than about 0.6% for different $\rho D/c_{u0.}$ N_{cf} increases with $\rho D/c_{u0}$ for settlement ratios greater than about 0.6%. N_{cf} increased by 17% for ρ increasing from 0 to 5 kPa/m at SR = 2%.

Effect of non-homogeneity of desiccation zone

Degree of nonhomogeneity of NC ground, $\rho D/c_{u0}$ was kept constant at 5. Thickness of desiccation layer, h_0 was taken as 2 m. The rate of decrease in strength, *k* in the desiccated layer is varied from 0 through 10 kPa/m. Here $\kappa = 0$ represents a crust with strength constant with depth in the desiccation zone. Rigidity indices of both the layers are 200. Strength and stiffness decrease gradually with a rate of κ till the interface of desiccated and NC layers.

For $\rho D/c_{u0} = 2.5$, normalized bearing pressure - settlement ratio curves obtained for various κ are depicted in Fig. 4. Figures 4(a), (b) and (c) show the curves obtained for DNC ground with thickness of desiccation layer, h_0 = 1.0 m, 1.5 m and 2.0 m respectively. For a given thickness of desiccation layer, it is observed that DNC ground with higher rates of decrease in strength in desiccation zone resulted in higher bearing capacity. This is because of higher average undrained strength in the top desiccated zone, with a constant undrained strength of 10 kPa maintained at the interface of desiccation and NC layers.



(c)

Fig. 4. N_{cf} versus SR (%): Effect of κ for
(a) h_0 = 1.0 m (b) h_0 = 1.5 m (c) h_0 = 2.0 m

Effect of thickness on NBC

Normalized bearing capacity, NBC (= q_u/c_{u0}) of circular footing resting on DNC ground is plotted against the degree of non-homogeneity parameter in desiccation layer, $\kappa D/c_{u0}$ for different thicknesses, h_0 and presented in Fig. 5. It is seen that NBC increases linearly with increase in $\kappa D/c_{u0}$ for a given thickness of desiccation layer.

NBC increases 1.82 times for κ increasing by 5 times (strong and stiff desiccation layer) compared to an increase of 1.45 times for $\kappa D/c_{u0}$ of 2.5. The percentage of incremental variation in NBC is higher for higher $\kappa D/c_{u0}$. It is evident that the desiccated layer's degree of non-homogeneity and thickness correspond to the layer's strength in magnitude and depth of extent, respectively. As a result, the influence of desiccated layer thickness on undrained bearing capacity increases as the degree of non-homogeneity in the desiccation zone increases.

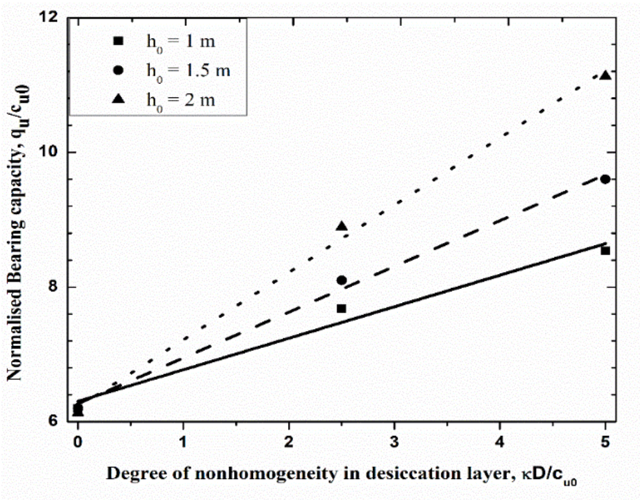


Fig. 5. NBC versus $\kappa D/c_{u0}$: Effect of h_0

5 Conclusions

Effect of desiccation on bearing pressure of footing resting on DNC soil considering the compressibility and non-homogeneity of the ground is studied. The present study quantifies the individual effects of compressibility, non-homogeneity and thickness of desiccation layer on bearing pressure factors. Bearing pressure factor increases with increase in rigidity index and degree of non-homogeneity for a specific settlement. Undrained bearing capacity increases with increase in degree of non-homogeneity for a given thickness of desiccation layer and its effect is more at higher values of non-homogeneity parameter in desiccation.

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