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Bearing capacity of circular footing resting on granular soil overlying soft clay

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KEYWORDS

Bearing capacity;
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Circular footing;
Foundation depth

Abstract The bearing capacity of footings constructed on soft clay soil is considerably governed by soil settlement. In practice, the bearing capacity of foundations on soft clay can be improved by a layer of compacted sand or gravel. In this study numerical analysis is performed using the Mohr Column model and some of the results are ensured by field plate loading observations. It is demonstrated that the ultimate bearing capacity is directly proportional to the angle of internal friction of granular soil "ϕ", the granular layer thickness "H", and the foundation depth "D", while at the same time it is inversely proportional to the footing diameter "B". The ultimate capacity of surface footings ($D/B = 0$ and $H/B > 2$) increases about 67% if the granular soil changes from medium to very dense. A significant enhancement in bearing capacity is achieved by increasing the ratio between the granular soil thickness and the footing diameter "H/B" up to four for surface foundations ($D/B = 0$) and up to six for deeper foundations ($D/B = 1.0$). The failure mechanism is characterized by punch shear failure in the granular soil and Prandtl[1] failure in the lower soft clay soil. The ultimate bearing capacity is also directly proportional to the extension "x" of granular soil measured from the footing edge up to a ratio equal to one ($x/B = 1$).

Introduction

The foundation on soft clay soil should achieve both safe shear stresses and safe settlement. Prandtl [1] studied surface strip footing over a perfectly plastic cohesive-frictional weightless half-space and found that failure under limited footings is characterized by punching shear failure. Reissner [2] extended the solution to include the effect of a uniform surcharge load on the resistance of penetration of the ultimate applied load. Terzaghi [3] introduced the concept of ultimate bearing capacity (q_u) and presented a comprehensive theory for the evaluation of such capacity under shallow foundations. For circular footings:

$$q_u = 1.3cN_c + \gamma_1 D N_q + 0.3\gamma_2 B N_\gamma [1.3] \tag{1}$$

where; N_c, N_q, N_γ, are functions of internal friction angle, ϕ.

D and B are foundation depth and footing diameter respectively.

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γ_1 and γ_2 are soil unit weight of fill and foundation soil respectively.

c is soil cohesion.

For surface foundation on undrained saturated clay, $N_c = 5.7$, $N_q = 1$ and $N_\gamma = 0$ and $q_u = 1.3cN_c$.

The general bearing capacity theories proposed by Meyerhof [4], Hansen [5], Vesic [6] and others are used in foundation design checking on critical bearing capacity in the presence of loose and soft layers. The effect of ground water table is considered by calculating the soil effective stresses within the soil surface and deeper layers that extend to a depth equals the footing width below the foundation level.

Vesic [7] classified the bearing capacity modes of failure into general, local and punch failure. If the soil is incompressible and has finite shear strength, a footing on this soil will fail in general shear, while if the soil is very compressible like soft clay it will fail in punching shear.

Meyerhof [8], studied dense sand overlying soft clay. The failure shape is a truncated pyramid pushed into clay. The friction angle "ϕ" and the soil cohesion "c" are both mobilized in the failure zone. The test results agree with field observations.

Cerato and Lutenegger [9], Dewaiker and Mohapatro [10] found that small-scale model footing test produces higher values of bearing capacities than theoretical equations. In practice, the bearing capacity of foundations on soft clay can be improved by a layer of compacted sand or gravel. Exact solutions introduced by Kenny and Andrawes [11] allow development of a simple method to solve this problem. They presented a theoretical model for footings on sand layer overlying clay deposits. Model tests were carried out in the laboratory to evaluate the stress-settlement relationship for sand alone, for clay sub grade alone, and for sand overlying clay. Results are compared with experimental data reported by other researchers and presented in a chart.

Bowels [12] expressed the thickness of subsoil below shallow foundation which influences the bearing capacity by

$$H = \frac{B}{2}\tan(45^0 + \frac{\phi}{2}) \tag{2}$$

where B is the width of shallow foundation, and ϕ is the angle of soil internal friction. In engineering practice, it is usually assumed that H = 2B (PN-81/B-03020 [13]).

Methods for calculating the bearing capacity of multi-layer soils range from averaging the strength parameters using limit equilibrium considerations to a more rigorous limit analysis approach (Michalowski and Shi [14]). Semi empirical approaches have also been proposed based on experimental studies (Meyerhof and Hanna [15]). The finite element method can handle very complex layered patterns, and has also been applied to this problem. (Burd and Frydman [16]).

Theory and test results show that the influence of the upper soil layer thickness beneath the footing depends mainly on the shear strength parameters and bearing capacity ratio of the layers, the shape and depth of the foundation, and the inclination of the load. Sand overlying clay is one of those problematic soil profiles indentified by Cassidy et al. [17] which may cause punch through. Madhav and Sharma [18] examined the bearing capacity of a footing resting on stiff upper layer overlaying soft clay. The stiff layer distributes the applied uniform stress on the soft soil over a much larger width. The loading on the clay soil is considered to be uniform (q_u) over a width, B and to decrease linearly or exponentially with distance. Hanna and Meyerhof [19] cover the case of footings on subsoil of dense sand overlying soft clay and presented the results in the form of design charts.

Oda and Win [20] investigated the ultimate bearing capacity of footings on a sand layer overlaying a clay layer. They concluded that plastic flow occurs in the lateral direction in the clay layer, exerts drag force on the upper sand layer which results in loss of bearing capacity.

AbdulhaHz O. et al. [21] calculated the bearing capacity of weak clay layer overlaid by a dense sand layer, based on the assumption that the pattern of the failure surface is a punching shear failure through the sand layer and Prandtl's failure mode in the weak clay layer as a function of the properties of soils, the footing width, and the topsoil thickness.

Murat et al. [22] found that there was no significant scale effect of the circular footing resting on natural clay deposits stabilized with a cover of compacted granular-fill layers.

The bearing capacity of granular soil overlying soft clay soil is still a great challenge due to comprehensive punching failure that takes place in soft clay and also due to the low bearing capacity. This paper focuses its study on variable factors which affect the global bearing capacity such as: granular soil thickness, relative density, foundation depth, footing size, and the extension of granular soil with respect to footing edge.

Material and methods

Fig. 1, shows a sketch of the studied case which consists of a rigid circular footing with diameter "B" constructed at foundation depth "D". The subsoil is a compacted granular sandy soil with extension "x" from the footing edge and thickness "H" underlain by saturated soft clay. The compacted granular soil is used to enhance the bearing capacity at the foundation level. The soil and the footing properties are shown in Table 1. Two series of soils are studied. In series 1 the granular soil chosen is medium to loose sand. In series 2 the granular soil chosen is very dense sand and in both series the subsoil is saturated soft clay.

Fig. 2 shows the field loading test which consists of a circular loaded rigid steel plate 10 mm thickness and diameter 0.2 m resting on the surface of ground pit. The pit is 2.5 m in diameter (> 12B) and its depth is 2.0 m (> 6B). The soil in the pit consists of either coarse dense graduated granular sandy soil or medium to fine sand with thickness "H" underlain by saturated soft clay with un-drained cohesion 21 kPa. The

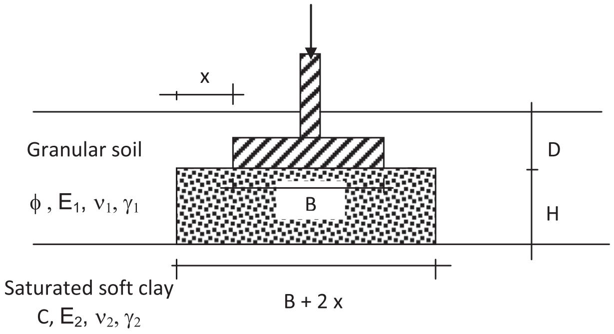

Fig. 1 Circular footing constructed on granular soil underlain by soft clay soil.