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Numerical Analysis of Bearing Capacity of Loose Sand overlying Clay

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Abstract: ***Soils are often deposited in layers. Within each layer the soil may be assumed homogeneous, although the stress-strain characteristics of the stratified layers are different. The present paper aims to study the behavior of strip footing placed on the surface of sand overlying clay under a vertical central load. The study has been carried out for the bearing capacity of loose sand layer overlying clay soil for the case where the thickness of the sand layer is comparable to the width of a rigid footing. A detailed parametric study was carried out on the bearing capacity of sand layer overlying clay under prototype footings. This study is based on a careful assessment of appropriate combinations of soil properties. The results of the parametric study are used to illustrate the mechanics of the system and also to develop charts that may be used directly in the design. The results are presented in terms of non-dimensional relationships to show the effect of sand thickness to footing width ratio, H/B, and the undrained shear strength of clay layer, $c_u /\gamma B$. In addition, the modes of failure of the foundation soils system are also presented.***

Keywords: bearing capacity, sand overlying clay, sand thickness ratio; mode of failure

1. Introduction

Several important examples exist for foundation engineering problems where it may be necessary to include the effect of soil layers in the assessment of bearing capacity. Shallow offshore foundations and raft foundations, for example, generally have large physical dimensions; potential failure surfaces may therefore extend to a significant distance below the soil surface. It is expected that any soil layer within the depth of these failure surfaces would be influenced by the failure load. Other examples include structures placed on engineered fill layers as oil storage tanks, which may be founded on a thin layer of granular fill and unpaved roads built on soft clay where a layer of compacted fill is used to spread the load applied by the passing vehicles. A very common kind of soil non-homogeneity is that of distinct soil layers of different strength and approximately constant thickness. The simplest situations that can be considered would be those of a two-layer profile. Extensive research work has been done for the behavior of the sand overlying clay [1-16]. Most of the available design methods are analytical approaches based on experimental work. In the present study, numerical analysis were carried out using the finite element program PLAXIS 3D Tunnel to investigate the actual behavior and mode of failure of sand overlying clay under a vertical central load.

2. Numerical Model

In all cases, the footing width was 1 m with thickness 0.5 m to attain the rigid footing condition. The soil system in all cases of study is sand overlying clay with various conditions. Figure (1) shows the problem notation to clarify the factors affecting the problem. Only one quarter of the model was solved due to symmetry. The dimensions of the model were selected to get suitable number of elements without any confinement for soil system.

The boundary conditions for strip footing cases have been considered at a distance of 40 times the footing width in (x) direction and 15 times the footing width in (y) direction as concluded from Brocklehurst [17]. The boundary conditions in (z) direction have been considered at a distance of 5 times the footing width although plane strain condition is applied to (xy) plane. The mesh used for a specified ratio, H/B was the same in all Groups irrespective of clay strength. Generally, the mesh dimensions in different cases were carefully chosen to be sure that no confinement for soil system will happen near boundaries.

The selected input parameters of both soil model and footing model in case of strip footing are shown in Tables (1) and (2).

Both the modulus of elasticity of soil and Poisson's ratio were selected according to the suggested values from both Bowles [18] and Budhu [19]. For footing model, the value of the modulus of elasticity and Poisson's ratio was selected as for reinforced concrete. The values of cohesion of sand were calculated from the values of $c_u/\gamma B$ suggested by Michalowski and Zhu [13] according to different values of ϕ. For all types of clay, the value of undrained shear strength, c_u, was selected according to Bowles [18]. For plane strain condition, the value of cohesion was calculated as suggested by Budhu [19].

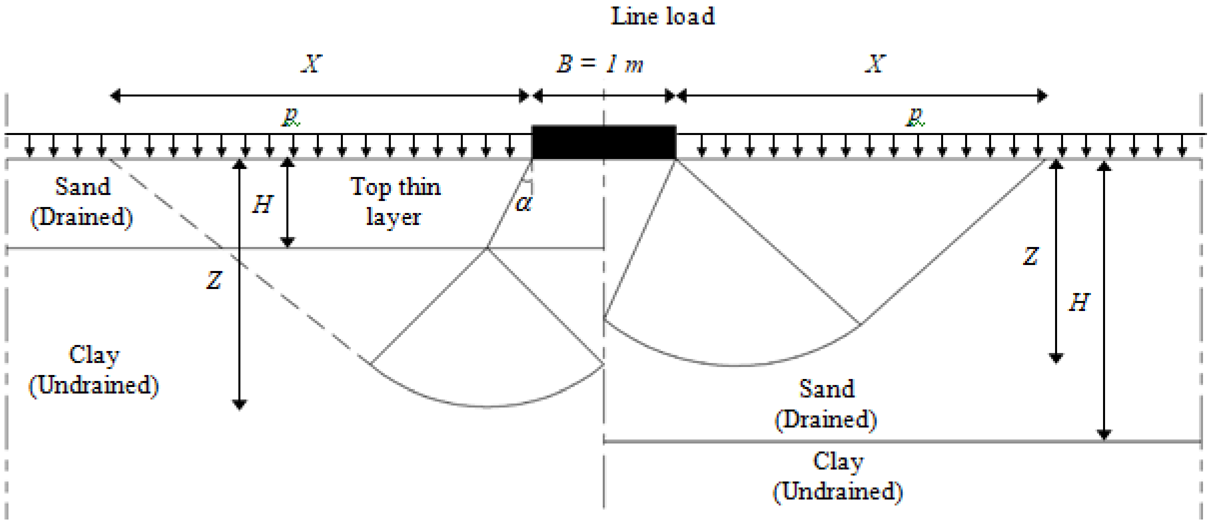

Figure 1: Problem notations and potential failure mechanisms

Table 1: Input parameters for plane strain condition of the FEM program

Parameter	Loose Sand	Soft Clay	Medium Clay	Stiff Clay	Footing (Concrete)	Units
Material model	Mohr-Coulomb	Mohr-Coulomb	Mohr-Coulomb	Mohr-Coulomb	Linear Elastic	__
Material behavior	Drained	Undrained	Undrained	Undrained	Non-porous	__
Unit weight, γ	16.30	16.80	17.90	18.50	24.0	kN/m^3
Young's modulus, E	20,000	15000	30,000	60,000	2.1 x 10^7	kN/m^2
Poisson's ratio, ν	0.20	0.40	0.35	0.30	0.20	__
Cohesion, c_u	1.0	17.0	36.0	85.0	__	kN/m^2
Friction angle, ϕ	39.70	0	0	0	__	°
Dilatancy angle, ψ	0	0	0	0	__	°
Interface strength reduction, R_{inter}	0.67	__	__	__	1.0	__

The angle of internal friction ϕ was selected as suggested by Budhu [19]. For plane strain condition, both the values of cohesion and ϕ_{ps} was calculated as suggested by Budhu [19].

3. Results and Discussions

The bearing capacity for the two-layer soils system can be represented as:

$$\frac{q_u}{\gamma B} = f\left(\frac{c_u}{\gamma B}, \frac{H}{B}\right) \quad (1)$$

In case of the presence of overburden pressure at the foundation level, p as shown in Fig. (1), the term $p/\gamma B$ will be added to Eq. (1) as a dimensionless factor affects the bearing capacity analysis.

3.1 Effect of sand layer thickness ratio

It can be observed from Fig. (2) that only in case of loose sand overlying soft clay, the rate of increase of bearing capacity with increasing of H/B is slow. This is as both soils are weak and the soft clay is relatively weaker than the loose sand. So, at high thickness of sand layer the soft clay has an effect on settlement and consequently on the bearing capacity. While in case of loose sand overlying medium clay, high rate of increase of bearing capacity can be observed until reaches almost a constant value at H/B ≥ 3.

In case of loose sand overlying stiff clay, the stiff clay layer can be considered as a rigid base. The bearing capacity at H/B = 1 is less than that of stiff clay and by increasing H/B to H/B = 2 the bearing capacity reaches its maximum value and then decreases by increasing H/B until the effect of stiff clay layer vanishes and the bearing capacity reaches to that of loose sand only. This behavior can be interpreted as the stiff clay layer at H/B = 1 and 2 confines the loose sand layer and general shear failure in sand occurs. By increasing H/B the effect of stiff clay layer decreases and local shear failure occurs in loose sand.

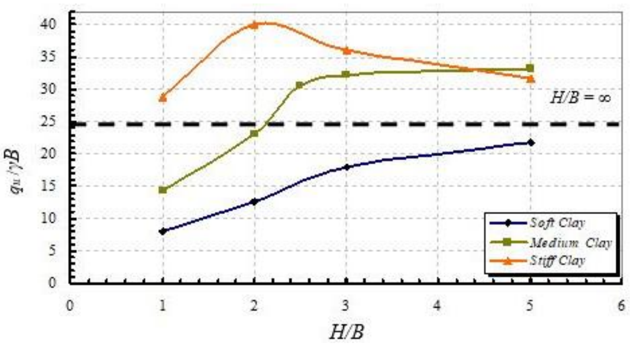

Figure 2: Bearing capacity of strip footing of loose sand overlying clay

3.2 Effect of clay undrained shear strength

It can be observed that the bearing capacity increases obviously with increasing undrained shear strength, $c_u/\gamma B$ for case of H/B = 1 and 2 as the clay layer is effective in decreasing the settlement, Fig. (3). While in case of H/B > 2 the effect of clay layer vanishes when the undrained shear strength, $c_u/\gamma B > 2$ and the settlement is limited in loose sand.

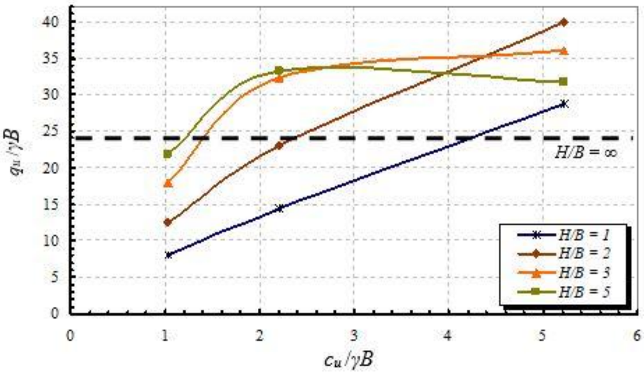

Figure 3: Bearing capacity of strip footing of sand overlying clay for various clay shear strength

3.3 Modes of failure and deformations

It should be noted that the definition of weak or strong soil layer does not depend on the bearing capacity value of the soil layer but on the modulus of elasticity, which control the settlement of the soil layer and consequently the modes of failure of the soil layers system. In case of loose sand overlying soft clay, it can be concluded that punching shear failure occurs in loose sand layer and local shear failure in soft clay up to H/B = 2. For 2 < H/B ≤ 5 the failure zone is limited in the loose sand layer and local shear failure occurs in this layer. This also can be concluded where the depth of the failure zone ratio, Z/H ≈ 1 at H/B =3 and decreases gradually until reaches Z/H ≈ 0.85 at H/B = 5 which means that local shear failure has occurred in loose sand layer.

4. Conclusions

It can be concluded from the present paper that bearing capacity of layered soil is totally different from that of homogeneous soil. In case of loose sand overlying clay with different undrained shear strength, c_u, the bearing capacity of strip footing on a two-layer soil system increases with increasing the sand thickness ratio, (*H/B*). The undrained shear strength of the clay play the main role in defining the bearing capacity of two-layer soils system. By decreasing the undrained shear strength of the clay layer, the sand layer is more effective in transmitting the load to the clay layer. This means that the clay layer will control the settlement and consequently the bearing capacity and mode of failure of the soil system. in case of loose sand overlying clay for different H/B, the mode of failure changes from punching and local shear failure in loose sand to punching and general shear failure in loose sand..

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Mohamed Ramadan received the B.S. and M.S. degrees in Civil Engineering from Assiut University in 2002 and 2006, respectively.

In 2007, he started his PhD studies at Memorial University of Newfoundland, Canada. He performed hid PhD research in offshore geotechnical engineering. In 2011, he obtained his PhD in geotechnical engineering. He is currently working as Assistant Professor at King Abdulaziz University, KSA.