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A Parametric Investigation on the Bearing Capacity of Reinforced Granular Soil, Overlying Clay

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Abstract: In the present study, an attempt has been made to comprehensively investigate the bearing capacity characteristics of shallow strip footing, placed on a geogrid reinforced granular soil and underlain by a soft clay deposit. A finite element limit analysis (FELA)approach has been used to obtain the upper bound value of the true collapse load. Investigation of several critical parameters, such as thickness of the sand layer, friction angle of the sand, and number of geogrid layers are investigated under a parametric framework and the results are presented in the form of charts. Based on the results obtained, the efficacy of installation of geogrids has been established and subsequently, their optimal spacing has been obtained. Present study would be highly beneficial to the practicing civil engineers while designing a shallow foundation over a granular soil, underlain by a weak clay soil layer.

Keywords: Bearing Capacity,FELA, Geogrids, Soft Clay

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1. INTRODUCTION

Classical bearing capacity theories developed in the literature makes an inherent assumption of assuming the underlying soil to be homogeneous and uniform. Several theories are available in the literature which address the problem of bearing capacity of shallow strip footing under a deterministic framework, assuming the mean value of the engineering properties of the underlying geomaterials under dry [1,2,3,4] and partially saturated conditions [5,6]. However, in general practices, the soil layer underlying a shallow footing is not homogeneous and may contain layers of weak soils as well. When a shallow foundation is constructed over a weak and soft clay deposit, it undergoes an excessive and long-term settlement. Additionally, the bearing capacity of footing, placed over such a weak clay deposit is substantially low and therefore, some ground improvement techniques have to be sought off while designing a foundation over such a weak clay layer deposit.

In literature, several ground improvement techniques, such as installation of stone columns [7,8] addition of admixtures [9,10,11] and installation of vertical drains [12] to enhance the bearing capacity have been adopted and are still being studied with certain possible modifications. Additionally, replacement of weak clay soil layer with sand or other suitable geomaterials, has also gained attention of the researchers in the past. The replacement of the weak soil is often accomplished by placing sand with higher shear strength values. This replaced soil layer is then compacted to achieve the desired compactness and thus the overall bearing capacity and stiffness characteristics of the ground increases.

However, as the natural sand is a very expensive geomaterial and is not available easily in several locationstherefore, providing a large thickness of sand layer above the weak clay layer, may not be a sustainable solution. Additionally, due to large depth of the sand layer, the vertical stress on the underlying clay layer would further increase and the weak clay layer may fail due to the overburden pressure coming from the sand layer only.

Therefore, in the present study, the influence of inclusion of geogrids, as an alternative to reduce the thickness of the sand layer, has been investigated based on a finite element limit analysis (*FELA*) technique. The numerical analyses have been performed using commercially available software package *OPTUM*G2. The efficacy of FELA in solving the complex problems of geomechanics, has already been well established in the literature [13,14]. The influence of several critical parameters, such as thickness of sand layer (H), Friction angle of sand (ϕ'), undrained cohesion of clay (c_u). number of reinforcement layers (N) and their spacings (λ), on the bearing capacity of the footing has been reported.

2. PROBLEM DEFINITIONS AND MATERIAL PROPERTIES

The schematics of the problem considered in the present study has been shown in Fig. 1. The finite element mesh has been shown in Fig. 2. The lateral and vertical boundaries are chosen as $20B$ and $10B$ respectively (where B = footing width). Based on a sensitive study, it was found that for the range of boundaries considered, all the failure mechanisms are confined well within the boundary zones and hence is suitable to carry out the analysis. For the numerical analysis, lateral boundaries were restrained for horizontal movement whereas both, vertical and horizontal movements were restricted for the bottom boundary. The footing was assumed to be rigid and rough and having a width of 1.0m. The geotechnical properties of both, sand and clay considered in the present study have been shown in Table 1.

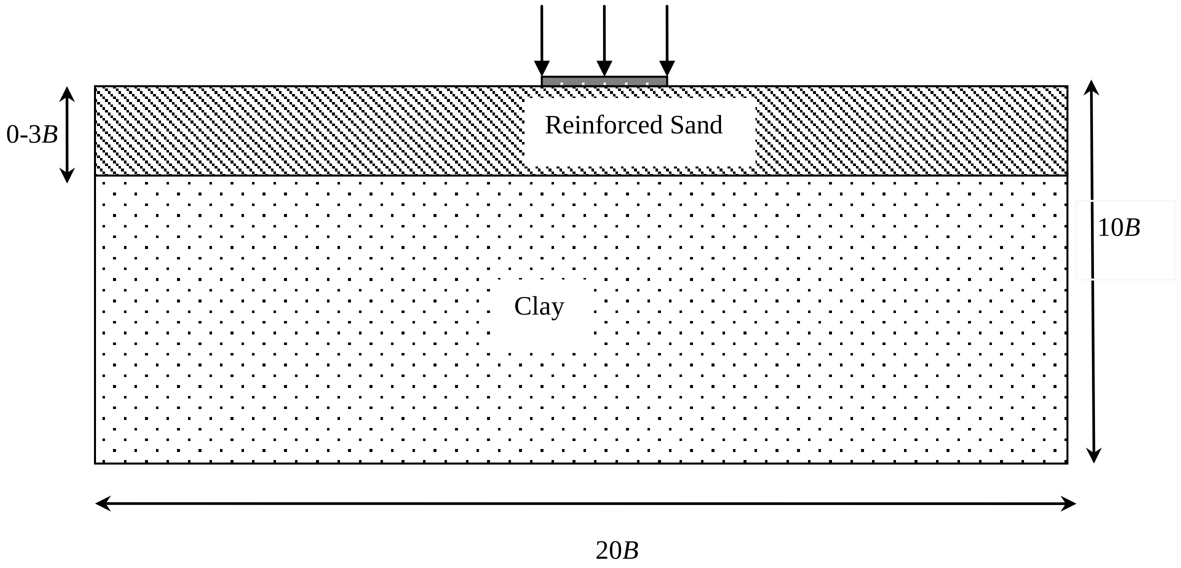

Fig. 1. Schematics of the problem considered in the present study

In the present study, footing width (B = 1.0m) has been considered for all the analyses. For the geogrid, the stiffness and yield force values are adopted as 450 kN/m and 45 kN/m respectively. A typical FELA model, with boundary conditions, has been shown in Fig. 2. A total number of 10000 elements were adopted with mesh adaptive technique to obtain the failure load and the yield mechanism.

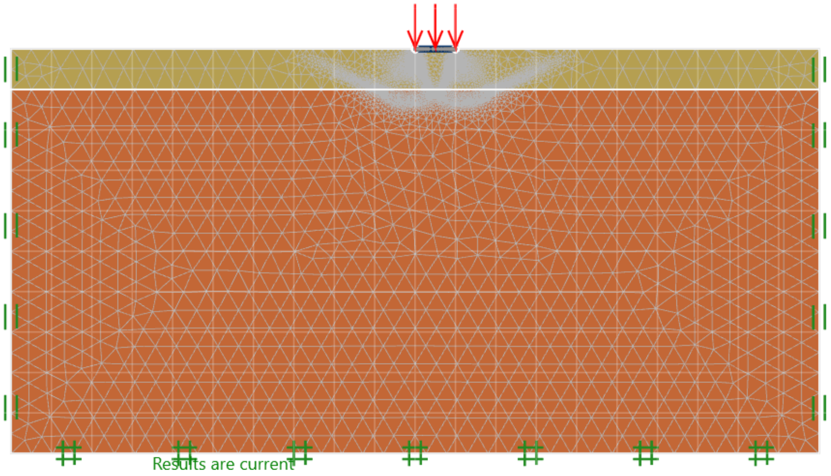

Fig. 2. Typical mesh and boundary conditions considered in the present study

3. RESULTS AND DISCUSSIONS

This section presents the results obtained through the numerical analysis for the bearing capacity of the footing, with and without geogrid reinforcement. Also, results obtained through parametric study have also been presented to quantify the influence of parameters, such as thickness of sand layer (H), friction angle of sand (ϕ'), undrained cohesion of clay (c_u), number of reinforcements and their spacings (λ). All the results are presented in dimensionless forms of bearing capacity ratio (BCR) defined as

$$BCR = \frac{p}{\gamma B} \tag{1}$$

Where, p = ultimate bearing capacity, γ = unit weight of sand.

3.1. Influence of Thickness Ratio (*H*/*B*) of Sand

In the present section, the influence of thickness ratio (*H*/*B*) of the top sand layer on the BCR has been discussed with and without reinforcement. The variation of BCR with H/B has been shown in Fig. 3.

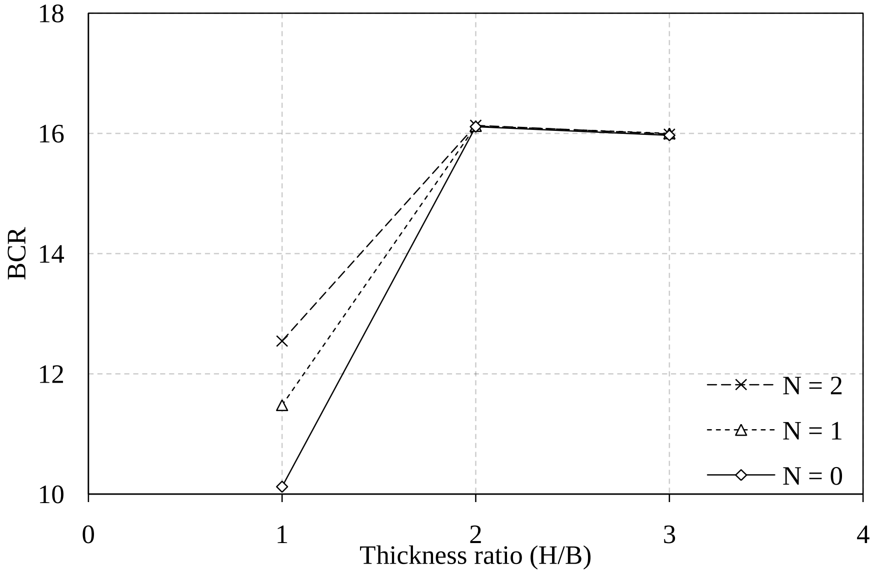

Fig. 3. Variation of *BCR* with *H*/*B* for different number of geogrid layers (*N*)

It could be seen from Fig. 3 that with increase in *H*/*B*, *BCR* increases initially and then becomes constant for *H*/*B* value more than 2. This is primarily due to the fact that for larger thickness of sand, the failure mechanism does not propagate deep within the clay layer and the shear strength characteristics of sand governs the failure mechanism of the footing.

3.2. Influence of friction angle (ϕ') of sand

To investigate the influence of angle of internal friction of sand on the BCR of the footing, analyses were carried out for four different friction angle values (ϕ' = 25°, 30°, 35° and 40°). Variation of BCR with ϕ' has been shown in Fig. 4. For the analysis, *H*/*B* = 1 and *N* = 1 has been assumed. It could be seen from Fig. 4 that with an increase in the angle on internal friction value of the sand, BCR increases. However, BCR is very small when the friction angle of the sand is 25°, even with the inclusion of a single layer of geogrid. Therefore, while replacing the soft and weak clay layer with sand, adequate compaction should be provided to enhance the effective friction angle of the sand.

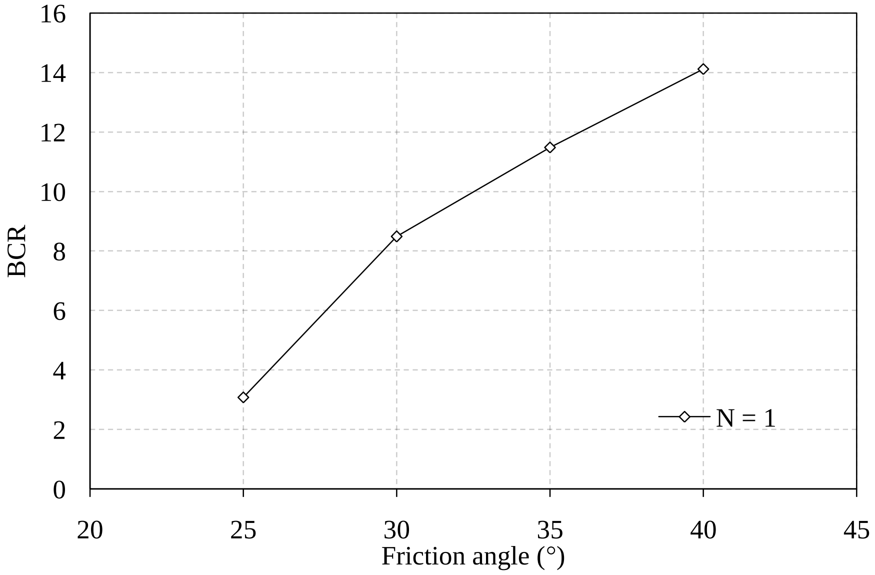

Fig. 4. Variation of *BCR* with ϕ'for (N = 1) and (H/B = 1)

3.3. Influence of undrained cohesion (c_u) of clay

As already mentioned in section 3.1 that the influence of underlying weak soil diminishes for a thickness of more than 2B of the overlying sand layer. When the thickness of the overlying sand layer is lesser than 2B, the failure mechanism penetrates deep into the underlying soil, and therefore, the bearing capacity is governed by the shear strength parameters of the underlying soil as well. To investigate the influence of shear strength of underlying soil on the BCR, four different undrained cohesion values of underlying clay layer (i.e.,c_u = 7, 14, 28 and 56 kPa) have been considered in the present study. For all the analyses, $H = 1B$,$N = 1$ and ϕ' (sand) = 35° have been considered. The variation of BCR with c_u has been depicted graphically in Fig. 5.

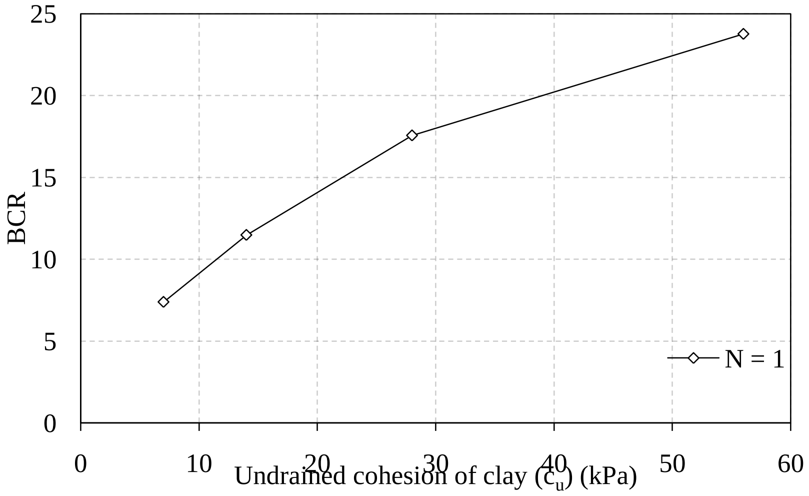

Fig. 5. Variation of *BCR* with undrained cohesion of clay (c_u) for N = 1 and H/B =1

It could be seen from Fig. 5 that the BCR increases monotonically with an increase in the undrained cohesion of the underlying clay layer for H/B =1. This is predominantly due to the fact that for $H/B = 1$, the failure mechanisms are developed within the clay layer as well and therefore the shear strength, and consequently the BCR, increases with increase in the magnitude of undrained cohesion of the clay layer. Therefore, while designing footing over a weak clay layer, the replacement thickness of the overlying soil should be more than 2*B.*

3.4 Influence of number of geogrids (*N*)

In the present section, the influence of number of geogrids (*N*), on the *BCR* have been presented. Geogrids possess high tensile strength and with proper bonding with the granular soil, enhances the bearing capacity of the reinforced soil. In the present study, geogrid reinforcement up to a maximum of 4 nos. are considered and their influence on the BCR has been presented. For all the analysis, the length of the geogrid reinforcement has been kept as 4*B*. Variation of BCR with N has been shown in Fig. 6 for H/B = 1, ϕ' (sand) = 35° and c_u (clay) = 14 kPa.

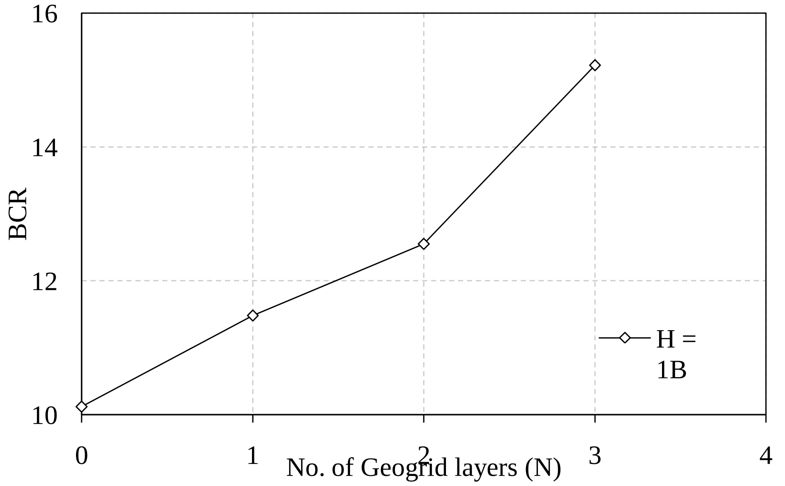

Fig. 6. Variation of BCR with number of geogrid layers (N) for H/B = 1

As could be seen from Fig. 6 that with an increase in the number of geogrid layers, BCR increases monotonically. The increment in BCR is more pronounced when the Number of geogrid layers increases from 2 to 3. Therefore, it could be seen that with inclusion of 3 layers of geogrids is equivalent to providing a sand thickness of 3*B*. Therefore, to conserve the natural soils, geogrid reinforced sand layers should be overlain a weak clay layer deposit.

4. CONCLUSIONS

In the present study, the efficacy of providing geogrid reinforcement to improve the bearing capacity of weak clay layer soil has been investigated. Based on the results obtained through the numerical investigations, the following major conclusions are withdrawn from the study

- Influence of weak underlying soil, on the BCR diminishes for a thickness ratio (*H*/*B*) of more than 2*B*. Therefore, for an unreinforced fill, the thickness of sand layer provided should be more than 2*B*.
- For reduced thickness (H/B <2), BCR increases monotonically with friction angle of sand.
- For H/B = 1, BCR is substantially affected by the undrained shear strength of clay deposit.
- With provision of 3 or more number of geogrids, the required thickness of sand layer could be minimized, and thus saving a huge amount of useful sand.

5. ACKNOWLEDGEMENTS

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