BEARING CAPACITY OF CIRCULAR FOOTING RESTING ON GEOGRID-REINFORCED GRANULAR FILL OVERLAY ON SOFT SOIL

[1]Disha M. Patel, [2]Priti J. Mehta

[1]PG Student, [2]Associate Professor
[1] Applied Mechanics Department,
L D College of Engineering, Ahmedabad, India

Abstract: In many cases of construction, shallow foundations are built on top of existing cohesive soils, resulting in low bearing capacity and/or excessive settlement problems. An economical treatment method is the use of reinforced soil foundation (RSF). This can be done by either reinforcing cohesive soil directly or replacing the poor soils with stronger granular fill, in combination with reinforcement. In the present study, the bearing capacity of circular footing resting on multilayer geosynthetic-reinforced granular fill overlying soft soil is investigated by performing load settlement test. Series of tests are carried out to evaluate the effects of replacing soft soil with granular fill layer. To achieve soft soil condition in laboratory environment, unconfined compressive strength (UCS) tests were performed for various water content. Variable parameters include thickness of granular fill and number of geogrid layers into granular fill below circular footing. Thickness of granular fill (H) layer varied as 0.5B,0.75B and 1B, where B is width of footing. Soil is reinforced with horizontal layers of reinforcement ranging from one layer to three layers in the top layer of soil only. Circular footing of diameter10 cm and thickness of 1cm is used. The test results indicate that substantial improvement in terms of increase in bearing capacity ratio and reduction in the footing settlement due to provision of granular fill overlay on soft soil is observed. For unreinforced granular fill, maximum bearing capacity is observed in case of granular thickness of 0.75B. Also, as the number of geogrid layer increases bearing capacity increases and settlement decreases.

Index Terms - **Bearing capacity, Circular footing, Multilayer soil, Load settlement test, Geogrid**

I. INTRODUCTION

It is very difficult to construct any structure with a shallow foundation directly on soft soil due to its low bearing capacity and excessive settlement. Thus, it is necessary to treat the soft soil (for use as foundation soil) by improving its bearing capacity. The conventional method to improve the bearing capacity of soft soil is replacement of the existing soil up to the influence depth (the depth of the shear failure zone developed below the shallow foundation) of the shallow foundation by a strong granular soil. The replacement of soft soil by granular soil is a huge task and uneconomical. Hence, granular fill containing one or more horizontal layers of geosynthetic reinforcement is placed over the soft soil in many practical cases to improve the bearing capacity of the soft soil. This practice of soil improvement is commonly known as a geosynthetic reinforced granular fill-soft soil system. The composite behaviour between reinforcement and granular fill improves the load-carrying capacity of the soil. Geogrid made from polypropylene is widely used as the soil reinforcement material. Several numerical studies and laboratory and large-scale tests have been conducted to determine the ultimate bearing capacity of shallow foundations resting on reinforced granular fill over soft soil (Giroud and Noiray 1981; Love et al. 1986; Madhav and Poorooshasb 1988; Das 1989; Ghosh and Madhav 1994; Shukla and Chandra 1995; Khing et al. 1994; Yin 1997; Lee et al. 1999; Deb et al. 2005, 2007; Demir et al. 2013, 2014; Shivashankar and Jayaraj 2014; Saha Roy and Deb 2017).

Most of the studies reported are performed on strip footings with a single layer of reinforcement either placed at the interface of soft soil and granular fill or embedded in the granular fill. Alenowicz and Dembicki (1991) introduced a second layer of reinforcement within the granular fill and found a significant improvement in the load-carrying capacity. Deb et al. (2005) developed a nonlinear lumped parameter model to study the settlement response of a multilayer geosynthetic-reinforced granular fill-soft soil system. It is suggested that the use of a multilayer geosynthetic-reinforced system is more effective at higher load intensities, and it reduces both total and differential settlement of the loaded area. Deb et al. (2007) numerically analyzed the response of multilayer geosynthetic reinforced granular fill placed over a soft soil deposit and found good agreement with the lumped parameter model (Deb et al. 2005) and finite-element analysis (Yin 1997). Analytical and experimental studies are also reported highlighting the bearing capacity of square footing on the multilayer-reinforced granular fill of limited thickness over soft soil (Demir et al. 2013, 2014; Shivashankar and Jayaraj 2014). Omar et al. (1993b) performed a series of model tests on different shapes of rectangular footings resting on multilayer geogrid-reinforced sand beds. Thus, most of the available studies for multilayer-reinforced soil are conducted on sandy soil. Studies are required for circular footing resting on a multilayer geosynthetic-reinforced granular fill-soft soil system. The effect of thickness of granular fill (H) and number of reinforcement (n) on the bearing capacity improvement of multilayer reinforced granular fill over soft soil should also be studied.

Fig. 1 shows a schematic diagram of a circular footing resting on a reinforced granular fill of thickness H over soft soil. The top layer of reinforcement is placed at a depth u from the bottom of the footing. The vertical spacing between consecutive reinforcement layers is h. The primary objective of this work is to conduct laboratory-scale plate-load tests to evaluate the performance of geogrid reinforcement layers for improving the bearing capacity and settlement behavior of circular footings resting on reinforced granular fill of limited thickness over soft soil. The parameters varied in this study are thickness of granular fill to width ratio (H/B = 0.5, 0.75, and 1.0), number of reinforcement layers (N = 1, 2, and 3) when two layers of geogrid reinforcement are used with one layer kept at the interface.

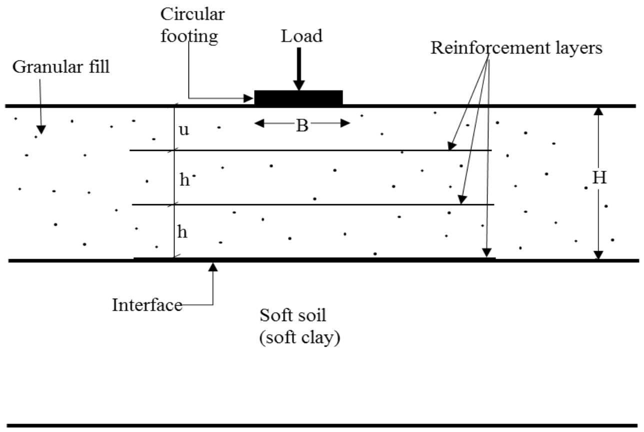


Fig. 1 Geometrical parameters of the multilayer-reinforced granular fill-soft soil system

II. EXPERIMENTAL STUDY

2.1 Material collection and properties

In this study, clay was used to prepare the soft soil bed. The soil contained 60% silt and 31% clay. In this study, soil was used in the soft state. To evaluate the soft state of the clayey soil, a series of unconfined compressive strength (UCS) tests were performed on cylindrical samples (38 mm in diameter and 76 mm in height) prepared at various moisture contents. Negligible variation of strength was observed due to the variation of moisture content in between 32 and 36% (i.e., the variation of UCS value is minimum in this range of moisture content), as shown in Fig. 2. Hence, 34% moisture content was chosen to obtain the soft state of soil for the present experimental study. The average UCS value and bulk unit weight at 34% water content were found to be 15.62 kN/m^2 and 16.46 kN/m^3, respectively. Similar UCS tests were also conducted by various researchers on soft clay with a UCS value of 14.0 kPa, or close to that, to determine its strength.

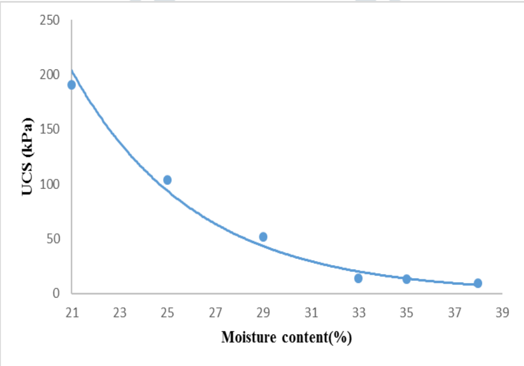


Fig. 2 Variation of UCS using moisture content

Table 1 Properties of Clay

Properties	Quantity
Specific gravity	2.60
Liquid and plastic limit	41.54% & 21.78%
Optimum moisture content (OMC)	21%
Maximum dry density (MDD)	16.84%
UCS at 34 % water content	13.62 kN/m^2
Bulk unit weight at 34 % water content	16.46 kN/m^3
Classification based on plasticity characteristics (IS Classification)	CI

Table 2 Properties of Sand

Properties	Quantity
Uniformity coefficient(C_u)	2.86
Coefficient of curvature (C_c)	1.09
Classification as per IS	SP
Maximum & Minimum dry unit weight	19.10 & 16.95 kN/m^3
Angle of internal fraction(Φ)	34^0

Table 3 Properties of Biaxial Geogrid

Properties	**Quantity**
Aperture size	20 × 20 mm
Ultimate tensile strength	40 kN/m
Creep reduction factor	1.49
Partial factor-installation damage	1.11
Partial factor-environmental effect	1.15
Pull-out interaction coefficient	0.8

The sand used in this investigation was collected from local supplier and dried completely in air for the model tests. Properties of sand are presented in Table 2. A biaxial geogrid made from high-density polyethylene (HDPE) was used as a reinforcing layer. The physical and strength properties of the geogrid are presented in the Table 3.

2.2 Experimental setup

Fig. 3 shows the schematic diagram of model plate load test setup. The test tank of steel with inside dimensions of 600 mm diameter, 650 mm height was used for performing the model test. A rigid circular steel plate of 100 mm diameter, and 10 mm thickness was used as model footing. Mechanical jack-frame arrangement was used to apply load on the soil stratum through the footing plate, magnitudes of applied loads were recorded with the help of sensitive proving ring of 1 ton capacity and Settlements of the footing were measured with dial gauges.

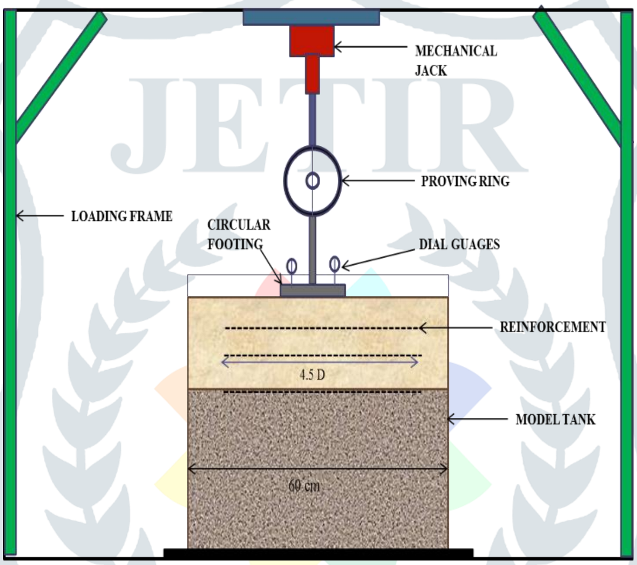


Fig. 3 Schematic diagram of the test setup

2.3 Preparation of clay bed

The clay bed was prepared by compacting locally available silty clayey soil in the soft state. Initially, the soil was air dried and pulverized with a wooden mallet and passed through a 4.75-mm sieve. Then air-dried clay was thoroughly mixed with predetermined amounts of water to achieve the desired water content, i.e., 34%. To achieve similar properties, soft clay was compacted in layers. Each layer was compacted uniformly to attain a uniform density in all the test beds. After completion of the top layer of the clay bed, it was levelled to make a smooth finished surface, and the level was checked by a spirit level.

2.4 Preparation of sand bed

Completely dry sand was used as the granular fill and placed in the test tank up to the required depth on the clay surface by the weight volume method. A predetermined amount of sand (for a particular volume) was allowed to fill the test tank. The quantity of sand was calculated by multiplying the unit weight of sand with volume. For each lift, the amount of sand required to produce the desired unit weight (18.17 kN/m^3) was weighed and compacted and gently levelled using a flat-bottomed wooden block. In each lift, the thickness of sand was checked from the depth difference (inside the tank) with the help of steel scale.

2.5 Placement of Geogrid Reinforcement

The geogrid layers (one or two) were placed inside the sand layer based on the desired values of u/B and/or h/B, and one geogrid was laid at the sand-clay interface for all tests. Geogrid layers were placed with their centre exactly beneath the jack. Some weights were kept at the four corners of the geogrid when it was placed on the soil surface to ensure flat and horizontal placement of the reinforcements. The weights were removed gently after the placement of the next layer of sand.

Table 4 Details of Test Program and Variables

Foundation Medium		Depth of layer		Geogrid (Reinforcement)	
Top	Bottom	Top	Bottom	No.of layer	Depth of layer
Sand (D_r=60%)	Sand	6B		-	
Clay	Clay	6B		-	
Sand (D_r=60%)	Clay	0.5B	5.5B	1	0.5B
				2	0.25B,0.5B
		0.75B	5.25B	1	0.75B
				2	0.375B,0.75B
				3	0.25B,0.5B,0.75B
		B	5B	1	B
				2	0.5B, B
				3	0.3B,0.6B, B

III. RESULT AND DISCUSSION

In the present research, a dimensionless parameter called bearing capacity ratio (BCR), is used measure the effect of improvement utilizing reinforcement layers on increasing the bearing capacity. This parameter is defined as ratio of the ultimate bearing capacity in reinforced soil to that in unreinforced soil condition.

$$BCR=\frac{q_u\,(reinforced)}{q_u\,(unreinforced)}$$

To determine the bearing capacity of the layered soil, load test with 10 cm diameter circular plate is conducted in tank with different layered condition. The results of the tests plotted as load-settlement curves are shown in Figure 4. The ultimate bearing capacity was calculated using double tangent method. Where N is number of reinforcement used in tests.

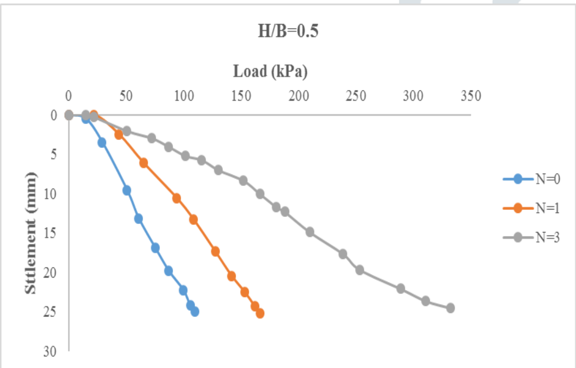


Fig. 4 Load v/s graph of H/B= 0.5

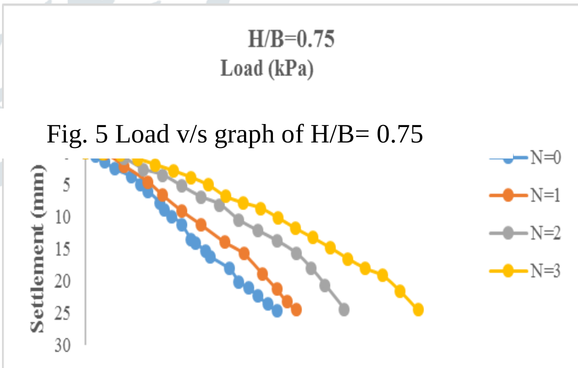


Fig. 5 Load v/s graph of H/B= 0.75

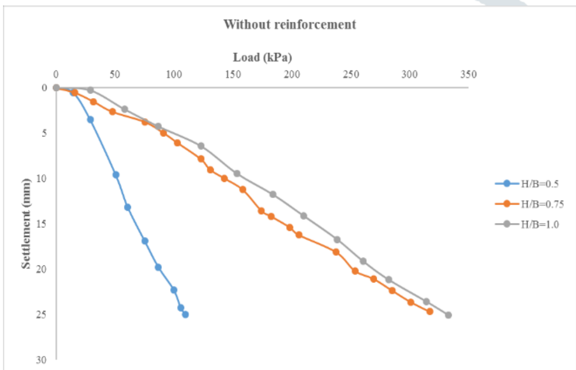
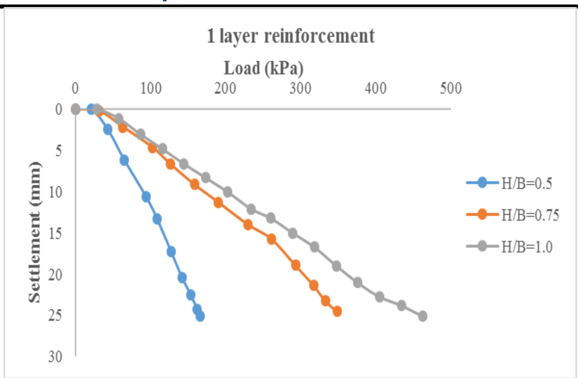
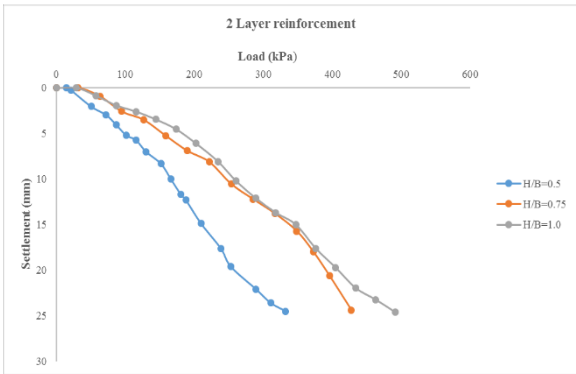


Fig. 6 Load v/s settlement graph of H/B = 1

Fig.7 Comparison of variation in granular fill for N=0





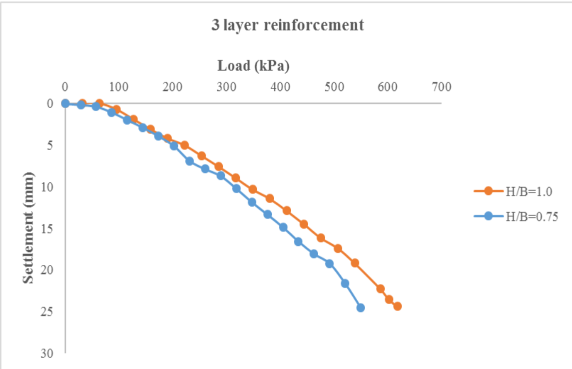


Fig. 8 Comparison of variation in granular fill for N = 1

Fig. 9 Comparison of variation in granular fill for N=2

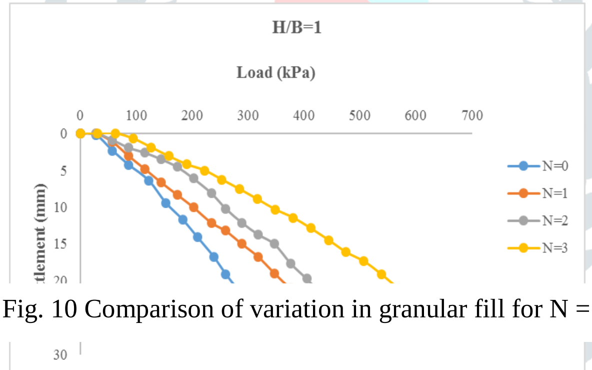


Fig. 10 Comparison of variation in granular fill for N = 3

IV. CONCLUSION

Based on the experimental results the following conclusions can be drawn:

- The degree of improvement of bearing capacity is related to the thickness of granular fill layer.
- BCR increases from 2 to 2.5 with increase of H/B ratio from 0 to 0.75. Further increase of H/B does not show significant increase and becomes nearly constant.
- For ratio of H/B = 0.75 three number of geogrid layers has been observed as optimum number of layers.
- For granular fill on soft clay to get the maximum improvement benefit, the optimum thickness of granular fill at 0.75 times the width of the footings for a circular footing.
- Due to provision of reinforcement in layered soil settlement is reduce.

V. ACKNOWLEDGEMENT

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