A Study on the Load Carrying Capacity of Shallow Foundation on Reinforced Sandy Soil

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1 Introduction

The foundation transfers the load from the structure to the soil. To stand the vertical load transfer, the bearing capacity of the soil needs to be strong enough. To increase the bearing capacity and to minimize the settlement, reinforcement is given to the soil either by mixing the soil with additives like cement, natural fibers or synthetic fibers, etc. or with geotextile, geogrid, geocell, etc.

Some researchers have shown the effect of reinforcement on soil and also illustrated the influence of reinforcement like geotextile or geogrid with the embedded depth-to-breadth ratio and the numbers of the reinforcement layer**.** Kolay et al. [1] concluded that the bearing capacity of the soil increased when reinforcement was provided. They showed the bearing capacity for two-layered soil using one geogrid layer at the interface of soils in which the ratio embedded depth (u) to the width of footing (B) is 0.667 and had an average increase of 16.67%, and for one geogrid in the middle of the sand layer with u/B equal to 0.33, the bearing capacity increased with an average of 33.33%. Chakraborty and Kumar [2] also illustrated an increase in bearing capacity after the soil was reinforced and also showed that the critical position of reinforcements lay between 0.29 B and 0.57 B for single layer reinforcement, which would give the maximum bearing capacity of a strip footing placed over granular and cohesive-frictional soils. Chakraborty and Kumar [3] also stated that for circular footing on the sand, the embedment depth of the circular reinforcement sheet within 0.15 diameter of footing (D) to 0.43 D had maximum bearing capacity. Shirazi et al. [4] reviewed the effectiveness of the ratio of first geotextile depth to footing width (d/B), the ratio of geotextile spacing to footing width (S/B), ratio of geotextile length to footing width (L/B), and reinforcement layers number (N) on the bearing capacity.

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Roy [5] reviewed different reinforcement types, like natural and synthetic fibers, and concluded that the reinforcement fiber increased the bearing capacity and reduced settlement. Omar et al. [6] concluded that in the case of geogrid, the effect of reinforcement lay within 1.4B for square foundations on sand. From the literature, it could be concluded that the optimum effect of the reinforcement could be achieved if the reinforcement lay within 0.6B. However, the influence of reinforcement with the embedded depth differs with different types of soil and type of reinforcement used.

In this paper, two different embedment depths were considered, and fiberglass mats were used as the reinforcement. The load test of shallow foundation models was performed in different soil bedding conditions, i.e., plain soil, fiberglass mat embedded at 7.5 cm (embedment depth/ breadth of the foundation ratio is 0.5) depth soil below the ground level and fiberglass mat embedded at 15 cm (embedment depth/ breadth of the foundation ratio is 1) depth below the ground level. The influence of the fiberglass mat on the soil bed and foundation model was also studied.

2 Experimental Process

The experimental process is categorized, namely (i) materials used and (ii) test box set up along with soil bedding.

2.1 Materials

The soil sample was collected from Dhansiri River bank, Dimapur, Nagaland. The detailed characteristic properties of the soil sample are shown in Table 1. Direct shear test was performed to find the shear strength parameters as per IS:2720 (Part 13)-1986 [7]. The particle grain size distribution and normal-shear stress graph are given in Figs. 1 and 2, respectively. The soil sample is classified as well-graded sand (SW), and effective diameter is 0.2 mm. The fiberglass mat used was a double-layer 200 gsm non-woven fabric and had a cross section of 60 cm $\times$ 50 cm.

The concrete of M25 grade, which has a ratio of 1 cement:1 fine aggregate:2 coarse aggregate, was used for the preparation of the foundation model. Since the models have a 2.5 cm thickness, the coarse aggregate of size ranging from 4.75 mm to 10 mm is employed. The fine aggregate has been classified as Zone-II as per IS:383–1970 [8]. The cement is 53-grade ordinary Portland cement having a consistency of 32%, an initial setting time of 2 h 9 min, and a final setting time of 4 h 30 min. The compressive strength of the concrete at 7 and 28 days is 20 MPa and 33 MPa, respectively.

Table 1 Characteristic properties of the soil sample

Characteristic property	Value
Gravel (greater than 4.75 mm)	2.8%
Sand (ranging between 4.75 and 0.75 mm)	97.2%
Silt (ranging between 0.75 and 0.002 mm)	0.8%
Clay (smaller than 0.002 mm)	Nil
Specific gravity	2.63
Liquid limit (LL)	N/A
Plastic limit (PL)	Non-Plastic
Co-efficient of uniformity (Cu) Co-efficient of curvature (Cc) Bulk density	4 1 1.6 g/cm^3
The angle of internal friction Cohesion	29.73° 2.336 kPa

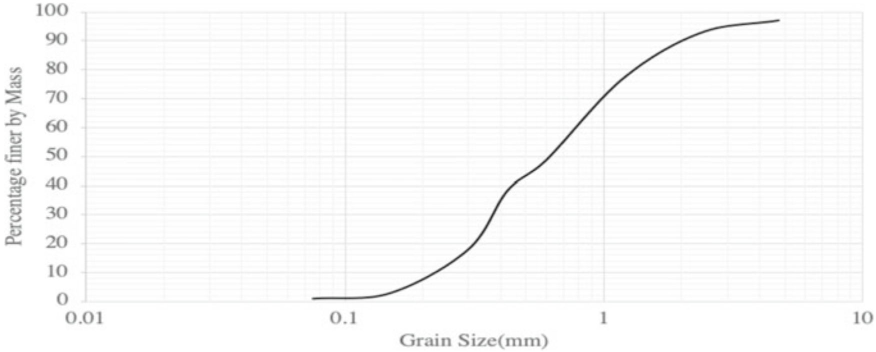

Fig. 1 Particle size distribution of the soil sample is shown

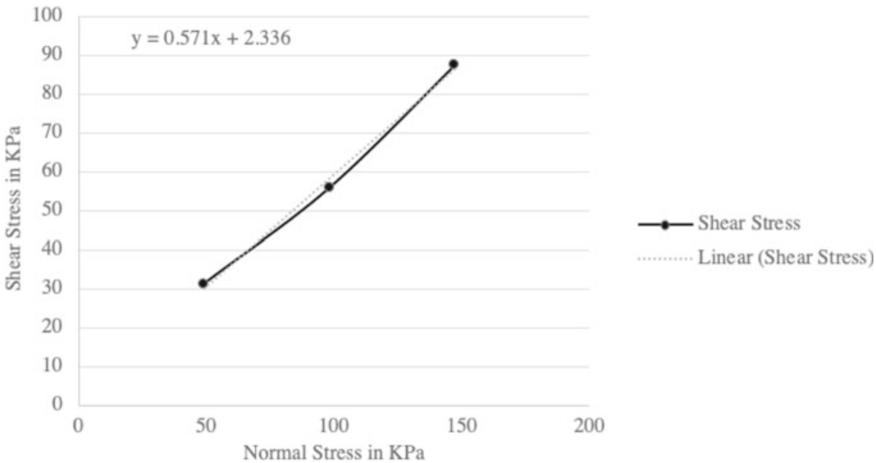

Fig. 2 Normal stress–shear stress graph gives the shear strength parameter values of the soil sample

2.2 Test Box Along with Soil Bed Preparation

The thickness of the foundation model was made at 2.5 cm, and the ratio of the thickness of the foundation model to the test box was 1:40. The length and breadth of the model were 150 mm (15 cm) × 150 mm (15 cm). The test box was made of 4 mm thick steel. The internal dimensions of the box were 1000 mm in length, 1000 mm in breadth, and 1000 mm in height. The test box was made rigid in such a way that there would be less plain displacement in all directions. The soil was poured uniformly by pluviation method as in Vaid and Negussey [9] in five layers from constantly changing the pouring trip to have constant the height of drop 0.5 m into the testing box so that the relative density of 22.22% was maintained. The soil bed was again compacted with a plyboard placed over the surface of the bed to give a uniform surface. The procedures were repeated when the soil was disturbed for fiberglass embedment. The soil bed was arranged for three series. The first series is only plain sand without any reinforcement. For the second series, the fiberglass double-layered mat was embedded at a depth of 7.5 cm, in which the ratio of embedment depth/ breadth of the foundation (*u/B*) is 0.5. Finally, for the third series, the fiberglass double-layered mat was embedded at a depth of 15 cm, where the embedment depth/ breadth of the foundation ratio (*u/b)* is 1.

At the top frame of the test box, a hydraulic jack was attached, which was connected to a proving ring of 25 kN load capacity. The hydraulic jack produced downward displacement when pressure was applied. The proving ring reads the load applied to the foundation model through the hydraulic jack. A dial gauge was fixed with the help of an iron beam. The dial gauge was later kept in contact with the foundation model to measure the displacement/ settlement when the vertical load was applied to the foundation model. Three test series of models for each different soil bedding were carried out. When the load was applied through the hydraulic jack, the readings of both the proving ring and the dial gauge were taken. The load was applied till the foundation failed (Figs. 3 and 4).

3 Results and Discussion

The bearing pressure-settlement curves of the foundation of all three series were analyzed, and the effect of the reinforcement sheet along with embedded depth was considered. The compared bearing pressure-settlement curves are shown in Fig. 5. The breaking pressures of the foundation models vs settlements are given in Table 2.

From Fig. 5, the bearing pressure of the foundation, which has reinforcement at 7.5 cm, has the highest value when the double tangent method is used. From Table 2, the foundation model on the sandy soil without reinforcement has a maximum settlement compared to the other two conditions. The foundation models break at nearby

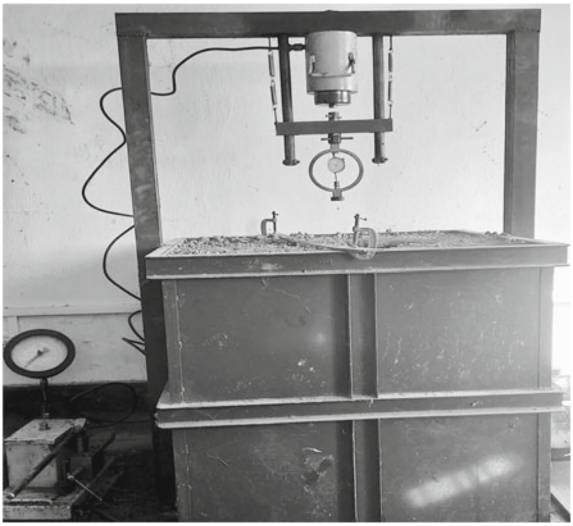

Fig. 3 Experimental test box set up for the load-settlement test

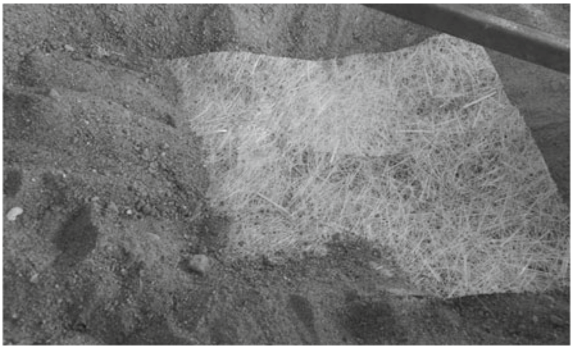

Fig. 4 Fiberglass mat embedded inside the soil

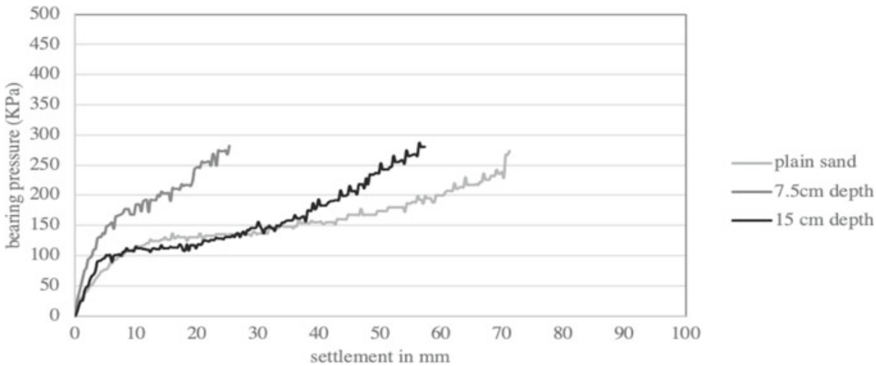

Fig. 5 Comparison of bearing pressure-settlement curves of the shallow foundation models

Table 2 Breaking pressure of the shallow model foundation in different soil bedding conditions

Soil bed condition	Breaking pressure in KPa	Settlement in mm
Plain soil	273.78	71.1
7.5 cm depth fiberglass mat embedded	281.24	25.2
15 cm depth fiberglass mat embedded	280	57.3

values of breaking pressure. However, there are significant differences in the settlement values. The results show that the reinforcement increases the ultimate bearing capacities of the foundation model and decreases the settlement.

Moreover, the soil with reinforcement at 0.5 B embedded depth has less settlement than the other two conditions. This shows the influence of the reinforcement's embedded depth. Similar findings were found in [1–3] and [6]. As the reinforcement's embedded depth increases, the bearing capacity decreases and settlement increases.

4 Conclusion

The study concludes that the fiberglass mat as reinforcement to the soil improves bearing capacity and strengthens the soil. The foundation model, placed on the soil with the fiberglass mat at 7.5 cm, has the highest bearing pressure/ load carrying capacity with less settlement. In both conditions of reinforcement with fiberglass mat, the values of settlement of the foundation model decrease as compared to the unreinforced soil. The settlement of the foundation model, which was embedded at a depth of 7.5 cm below the ground level (ratio of embedment depth to width of the model as 0.5), has 64.55% less settlement than the plain soil and 56% less settlement than the plain soil which was embedded at a depth of 15 cm below the ground level (the ratio of embedment depth to width of the model as 1). Moreover, it can be concluded that load carrying capacity and settlement depend on the depth of the fiberglass embedment. As the *u/B* ratio increases, the contribution of the fiberglass reinforcement sheet gets lesser, and the bearing capacity decreases, which leads to an increase in settlement.

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