Study of Prestressed Geotextile Reinforced Sand Supporting an Embedded Square Footing

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Abstract. The use of geosynthetics for the improvement of sandy soil is widely acknowledged. However, the effect of using geosynthetics is negligible for the small settlement of foundation resting over it. Therefore, prestressing the geotextile has a beneficial effect on the performance of the foundation even for the small settlement. In this study, the behavior of the square footing resting on the prestressed geotextile-reinforced sand is carried out through both laboratory model test and numerical analysis. The experimental study is performed using 100 mm × 100 mm ($B \times B$) square footing embedded at a depth of 50 mm, resting on unreinforced sand and sand reinforced with both geotextile and prestressed geotextile. It is found that placing the geotextile at 0.2*B* depth below the footing gives the maximum improvement. The improvement of the study is reported in terms of bearing capacity ratio and settlement reduction ratio. Prestressing of the geotextile shows 73% reduction in the settlement and 261% increment in the bearing capacity in comparison to footing resting on unreinforced sand**.** The results of the numerical analysis using Plaxis 3D is found to be in good agreement with the experimental study

Keywords: Ground-Improvement, Geotextile, Prestressed, Plaxis 3D.

1 Introduction

The development of a country is highly dependent on various infrastructures to support it. The infrastructure projects like roadways, railways, and earthen dams require a robust, stable, and economically viable foundation system. However, when one encounters problematic soil, its improvement is crucial from a stability point of view. The use of geosynthetics in improving the problematic soils has been proved extremely beneficial and is highly appreciated. Geosynthetics serve various functions like separations, reinforcement, filtration, protection, barrier, and drainage during its interaction with the soil. Geosynthetic used under the foundation can be geogrid, geotextile, geocell, or other of their family.

The use of geosynthetic materials for improving the bearing capacity and reducing the settlement has been studied in detail. The studies have been conducted both experimentally and numerically in the last two-three decades [1-3]. Ghosh et al. [4] reported the influence of footing shape and load eccentricity on load-settlement behavior.

Most of the reported studies have focused on either different kind of geosynthetic [4], or type of the soil [1, 2, 4-8], or shape of the footing [9-12] or loading type [13, 14]. However, in the previous studies, it has become indisputable that the geosynthetics show their actual tensile strength only after undergoing a substantial amount of settlement, which is neither desirable nor acceptable in case of many structures. This settlement is required to mobilize the tension in the reinforcing geotextile. The concept of prestressing the geotextile to mobilize the desired tension in geosynthetic layer was pioneered by Shukla and Chandra [15]. In the seminal study, the authors analytically demonstrated the effect of the amount of prestress on different parameters such as settlement response, the width of reinforcement zone and interface friction coefficient, etc. Chew et al. 2005 [16] used prestressed geotextile to stabilize a part of the driving circuit for the armored training school of Singapore armed force. Lovisa et al. [17] studied the effect of prestressing on a geotextile-reinforced sand bed supporting a loaded circular footing on an experimental basis and compared the results with Plaxis-2D analysis. Similarly, Shivashankar and Jayaraj [18] studied the influence of parameters like the strength of underlying weak soil, the magnitude of prestressing and thickness of sand bed on the behavior of square footing resting on it. Shukla and Kumar [19] studied the effect of prestressed geotextile on the factor of safety of the embankment.

In the present study, laboratory model tests and finite element model (*FEM*) analyses on embedded square footing resting on the unreinforced sand and sand reinforced with both geotextile and prestressed geotextile, have been carried out. The depth of placement of geotextile has been varied, and the effective depth is determined and is used to study the effect of prestressed geotextile. The FEM analysis is conducted using the FEM program Plaxis 3D, and results are compared with those obtained from the model test.

2 Experimental Investigation

The experimental study reported here includes small scale model tests carried out at the Geotechnical Laboratory of Applied Mechanics Department of SVNIT, Surat, India. The details of the material used, experimental setup, testing procedure, and its details are presented below.

2.1 Materials

Clean beach sand (locally called Panna sand) dried at 1.55 g/cc density is used as a sand bed in the laboratory model tests. The soil is tested as per IS specifications. Table 1 summarizes the basic properties of the sand, along with the properties required for numerical studies. The sand is classified as poorly graded sand (*SP*) as per the IS Classification System.

The Garware Wall Ropes Ltd. Pune has provided the geotextile used in the experiment. The property of geotextile is determined using the research facility of

MANTRA Laboratory, Surat, India. The tests are carried out as per ASTM standards and mentioned in Table 2.

Table 1. Properties of sand used in the model test

Property	Value
Specific gravity	2.60
Maximum dry unit weight (kN/m^3)	17.3
Minimum dry unit weight (kN/m^3)	14.2
Dry unit weight during the test (kN/m^3)	15.5
Relative density (%)	46.8
Effective Grain Size	
D_{10} (mm)	0.14
D_{60} (mm)	0.19
D_{30} (mm)	0.25
Coefficient of uniformity(C_u)	1.36
Coefficient of curvature(C_c)	2.35
Friction angle (ϕ°)	32°
Cohesion (kPa)	0

Table 2. Properties of geotextile used in the model test

Property	Value	Standard
Mass per unit area (g/m^2)	147	[24]
Thickness (mm)	1.35	[25]
Tensile strength, *MD** (kN/m)	30	[26]
Tensile strength, *CD***(kN/m)	29	[26]
Tearing strength, *MD* (kN/m)	612	[27]
Tearing strength, *CD* (kN/m)	475	[27]
Burst strength (N)	290	[28]

**MD*= Machine Direction, ***CD*= Cross Machine Direction

2.2 Test setup

Model tests were carried out on a square rigid footing fabricated from mild steel having a dimension of 100 mm × 100 mm with a thickness of 10 mm. The embedment of the footing is 50 mm and loaded with a hand-operated gear system, as shown in Fig. 1. The test tank was made of mild steel having dimensions of 1.2 m × 0.5 m in plan and 0.5 m in depth. For unreinforced and geosynthetic reinforced test without prestressing, the entire tank was used. However, for the prestressed geogrid reinforcement setup, the only one portion of the tank (500 mm × 500 mm × 500 mm) was used so that anchorage can be done properly. The arrangement of prestressing was designed according to reported literature [17, 20, and 21]. The instruments used during the experiment to measure the load-deformation parameters were LVDT for measuring displacement and load cell transducer to measure the load.

Strain-controlled loading was applied using a hand-operated gear system whose reaction is resisted by a load frame as shown in Fig 1. The rate of loading was maintained at 1 mm/minutes throughout the experiment, and it was applied by rotating the loading device mounted at the top with a speed of 13 revolutions per minute.

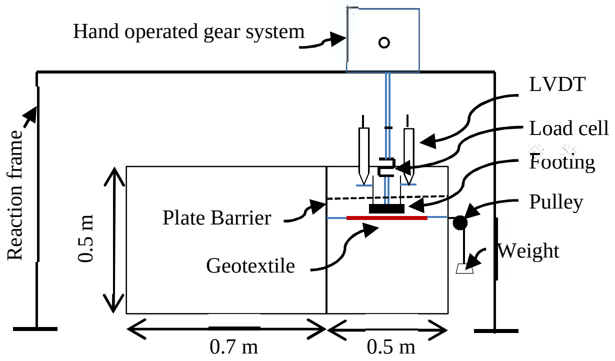


Fig. 1. Schematic diagram of the test set up

2.3 Test detail and sample preparation

Bi-axial prestressing was applied for the present study in order to achieve better improvement. The detail-testing program is explained in Table 3. The sand was filled in the tank through sand raining technique, i.e., Pluviation technique in order to achieve the desired density. It was filled with the layers of 5 cm, and for achieving a density of 1.55 gm /cc in 5 cm layer, 20.15 kg of the sand is used. The height of fall was maintained at 5 cm throughout the test. Frequent monitoring of the density was done using sand pouring measuring device, which was used to measure the density of the sand sample in sand replacement method test as per relevant Indian standards.

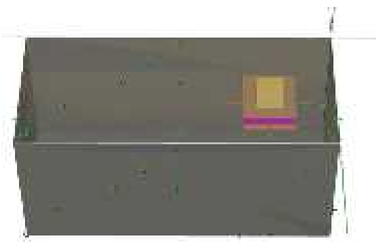


Fig. 2. Prestressing of geotextile bi-axially in Plaxis-3D

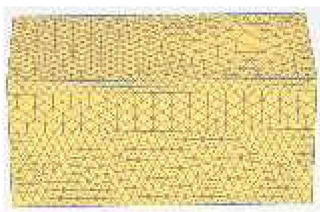


Fig. 3. Generated connectivity plot of medium fineness in Plaxis-3D

3 Numerical analysis

The finite element analysis is carried out using the software PLAXIS-3D [22], which is a three dimensional *FEM* package intended for the stability and deformation analysis of geotechnical problems. The footing is assumed to be rigid as the experimental footing is assumed to be rigid as well. In this case, the central deformation due to the rigid footing subjected to compressive loading has been simulated using non-zero prescribed displacement (maximum 25% of footing width) instead of modeling the footing itself (Fig. 2). The dimension of the tank is such that the lateral walls have no impact on the deformation of the footing under the action of loading. The bottom boundary of the tank is restricted to move in all the directions, whereas the lateral boundaries can move only in the vertical directions.

The interface strength (R_{inter}) value is assumed to be unity considering the gap closure at the geosynthetic-soil interface. Two interfaces have been placed at the top and the bottom of the geotextile layer to ensure for realistic interaction with the granular sand layer. The prestressing force is then applied by using the fixed end anchors available in Plaxis 3D in both *X* and *Y* directions, which amounted to 1% of the maximum tensile strength of the geotextile layer. In the current study, medium size-mesh analysis, having 36407 elements and 48096 nodes is used to achieve faster convergence. Figure 3, shows a typical connectivity plot for a mess of medium fineness. Mesh quality check is also performed to ascertain that no unwanted meshing remains in the model. In order to make the analysis more realistic, the stage construction process has been adopted. This is crucial because the reinforcement should be prestressed before filling soil above it; otherwise, the friction between soil and reinforcement layer will prevent the extension of reinforcement due to prestressing and subsequently the mobilization of tension is hindered.

Table 3. Detail-testing program

Series	Type	u/B#	b/B##	Prestress
A	*UR*	-	-	-
B	*GR*	0.1 to 0.5	2	-
C	*PGR*	0.2	2	1 %

#Depth below which geotextile is placed ##Size of geotextile

4 Results and Discussions

Tests have been performed on the sand with relative density 46.8%, dry density 1.55 g/cm^3 and with footing embedded at depth of 50 mm for the *UR*, *GR* and *PGR* soil.

4.1 Validation of numerical analysis

The present numerical study is validated with the experimental results of Kumar et al. [9] for the unreinforced soil. Figure 4, below shows that the *FEM* result obtained from the Plaxis-3D is in close agreement with the experimental result. There is a slight variation in response after the settlement of 20 mm, which may be due to different errors associated with the experiment.

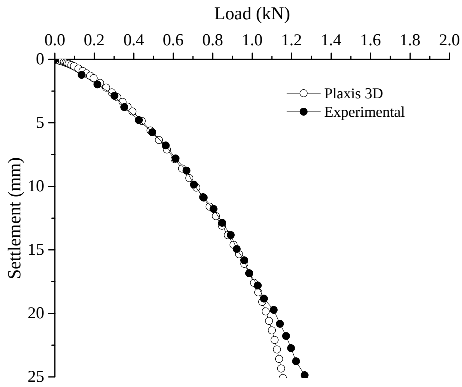


Fig. 4. Validation of Numerical study with the experimental data for unreinforced sand

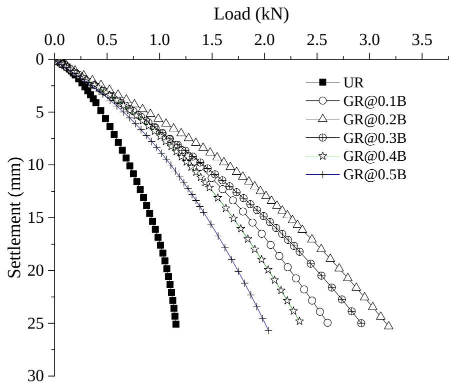


Fig. 5. Load-settlement behavior of UR and GR in Plaxis-3D

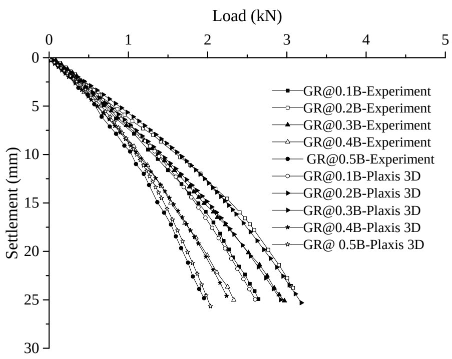
4.2 Finite element analysis and comparison with an experimental study

The numerical studies performed on the unreinforced sand and reinforced sand with geotextile reinforcement placed at different depths (u) viz. 0.1*B*-0.5*B* has been presented in Fig. 5. Figure 5, shows that placing geotextile at a depth of 0.2*B* gives the maximum improvement [18]. Also, it is also observed that the placement of geotextile does not show any improvement until the settlement reaches 4 mm. This is attributed to the fact that some settlement is required to mobilize the tension in the geotextile layer. Only after this, the geotextile can show its advantageous effects as reinforcement. The graph also shows that the numerical study shows a similar trend as observed in the experimental study, thus ensuring proper modeling in Plaxis 3D. The response of the *GR* soil for both experiment and *FEM* analyses have been shown in Fig. 6 with footings placed at different depths. The numerical results show good agreement with the experimental results for all the cases with overestimation for some of the cases.

4.3 Effect of prestress on the load-deformation behavior

As mentioned earlier, geotextile shows its strength only after undergoing a certain amount of settlement, which may not be desirable in many circumstances. Therefore, prestressing the geotextile provides a solution to this problem by mobilizing the required tension beforehand. Figure 7, shows that prestressing facilitates the mobilization of tension in the reinforcement without allowing excessive settlements, unlike the geotextile reinforced soil. In order to quantify and compare the improvement of *PGR* and *GR* sand w.r.t. *UR* sand, the authors have used two improvement ratios namely *BCR* and *SRR*. The ratio of bearing capacity of improved soil to that of original soil is termed as bearing capacity ratio (*BCR*). The *BCR* values at 10 mm settlement are determined for various cases from load vs. settlement curves and are shown in Fig 7.

Similarly, the ratio of the settlement of original soil to that of improved soil for the same loading is defined as settlement reduction ratio (*SRR*). The *SRR* value for 0.98 *kN* load is calculated from the load vs. settlement curve, as shown in Fig 8. From Fig. 8. it is clear that due to prestressing, the *BCR* of the experimental *PGR* is found to be 2.61 times higher than the *UR* sand. It is also noticed that experimental *BCR* is 5.4% lower from the value of the numerical study. From Fig. 9, it is also observed that there is a 73 % reduction in the settlement of *UR* soil w.r.t. *PGR* soil. The settlements were calculated just below the footing in order to achieve the maximum effect of prestressing following the argument given by Shukla and Chandra [15]. The *SRR* value for *PGR* soil w.r.t. *GR* soil comes out to be 1.28 which gives a settlement reduction of 23 % for *PGR* soil w.r.t. *GR* soil. Shukla and Chandra [15], in their analytical study, have also observed almost similar (27.65%) settlement reduction for *PGR* soil w.r.t. *GR* soil is below the center of the footing. Thus, the present study is not only validated experimentally and numerically but also, follows the analytical outcome given by Shukla and Chandra [15]. The numerical analysis, however, shows 4 % higher value in comparison to experimental *SRR* results which may be attributed to the various environmental factors during experiments.



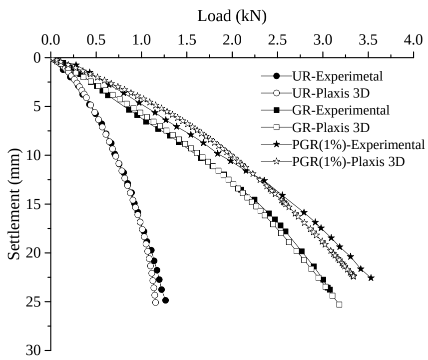


Fig. 6. Comparison of experimental and numerical studies.

Fig. 7. Load settlement Behaviour of UR and GR and PGR soil using Plaxis-3D

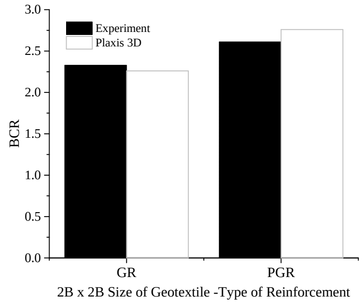


Fig. 8. BCR comparison for GR and PGR sand for numerical and experimental analysis.

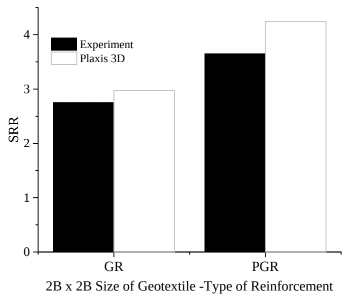


Fig. 9. SRR comparison for GR and PGR sand for numerical and experimental analysis

5 Conclusions

From the experimental and numerical study, it is concluded that by using prestressed geotextile, the contribution of reinforcement is significantly increased for small settlements. Following are the necessary conclusions from the study:

- For the 2*B* × 2*B* size of geotextile, the adequate depth of placement of geotextile for both experimental and numerical study is 0.2*B* below the footing.
- The maximum improvement in *BCR* for geotextile placed at 0.2*B* depth is 2.33 times and 2.61 times for *GR* and *PGR*, respectively, as obtained from the experimental study.
- The *BCR* value from the numerical study is found approximately 5.5 % higher than the experimental value.
- The maximum improvement in *SRR* for geotextile placed at 0.2*B* depth is 2.75 times and 3.65 times for *GR* and *PGR*, respectively, as obtained from the experimental as well other analytical studies.
- The *SRR* value from the numerical study is found approximately 4% higher than the experimental value.

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