Influence of prestress on the behaviour of footings resting on reinforced foundation beds

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ABSTRACT: Geosynthetics in foundation beds demonstrate their beneficial effects only after considerable settlements, since the strains occurring during initial settlements are insufficient to mobilize significant tensile load in the geosynthetic. Prestressing the reinforcement is a promising technique to overcome this shortcoming. This paper presents results from a series of finite element analyses carried out to investigate the improvement in bearing capacity of a footing resting on geogrid reinforced foundation bed overlying weak ground due to prestressing the reinforcement. The results of finite element analyses are validated by carrying out a series of laboratory scale loading tests. The parameters varied are magnitude of prestress, relative density of foundation bed etc. The effects of prestressing on the interface shear strength between geogrid and granular soil are studied by carrying out large scale direct shear tests in a shear box of dimensions 300 x 300 x 200 mm. It is observed that the bearing capacity and settlement behaviour of footings can be considerably improved by prestressing the geosynthetic reinforcement in the foundation bed. The interface shear strength between geogrid and granular soil is considerably influenced by the magnitude of prestress.

Keywords: Prestress; Foundation Bed; Geosynthetic; Large Scale Direct Shear Tests

1 INTRODUCTION

Reinforcing Soil with geosynthetics has proven to be a cost-effective method for improving bearing capacity of low-strength soils. Single or multiple layers of geosynthetic reinforcement are placed in a controlled granular material and placed beneath foundations to improve the strength and reduce settlements. The resulting composite ground (reinforced foundation bed) will improve the load carrying capacity of the footing and provide better pressure distribution on top of the underlying weak soils, hence reducing the associated settlements. A number of studies carried out by researchers have expanded the knowledge on the potential failure mechanisms and improvement in bearing capacity of shallow foundations (eg. Binqet and Lee 1975, Shivashankar et al. 1993, Mitchell 1981). Several experimental and analytical studies were conducted to evaluate the bearing capacity of footings on reinforced soil (eg. Shivashankar et al. 1993, Shivashankar and Reddy 1998, Madhavilatha and Somwanshi 2009, Alamshahi and Hataf 2009, Vinod et al. 2009, Deb et al 2006, Deb et al 2007 etc).

The strains occurring in the reinforcement during initial settlements are insufficient to mobilize significant tensile load in the geosynthetic and hence even though bearing capacity gets improved; settlements occurring are quite high. This is not a desirable feature, since for foundations of certain structures; the values of permissible settlements are low. Thus there is a need for a technique which will allow the geosynthetic to increase the load bearing capacity of soil without the occurrence of large settlements. Prestressing the Geosynthetic Reinforcement is a promising technique to reduce settlements, which is yet to be comprehensively studied. Lovisa et al 2010 conducted laboratory model studies and finite element analyses on a circular footing resting on sand reinforced with prestressed geotextile. It was found that the addition of prestress to reinforcement resulted in a significant improvement in the load bearing capacity and reduction in settlement of foundation. Lackner et al 2013 conducted about 60 path controlled static load displacement tests and 80 cyclic load displacement tests to determine the load-displacement behaviour of prestressed reinforced soil structures. They concluded that prestressing the reinforcement improves the load-displacement behaviour of reinforced soil structures.

It has been proved from Experimental and Analytical studies that prestressing the geosynthetic reinforcement in the foundation bed can improve bearing capacity and reduce settlement (Jayamohan et al 2013, Shivashankar and Jayamohan, 2013)

The purpose of this investigation is to study the effects of prestressing the geosynthetic reinforcement, on the load-bearing capacity and settlement response of a reinforced foundation bed overlying weak soil. The study involved laboratory scale load tests on model strip footings of width 100mm and large scale direct shear tests in a shear box of dimensions 300 x 300 x 200 mm. Nonlinear finite element analyses are carried out using the FE software *PLAXIS 2D* and the results are compared with those obtained from the model tests. The effects of prestressing the reinforcement on the stress distribution at the interface between foundation bed and weak soil, axial stress distribution in the reinforcement etc. are particularly studied. The parameters varied are magnitude of prestress, relative density of granular soil etc.

2 EXPERIMENTAL PROGRAMME

The laboratory scale load tests reported in this paper are carried out at the Geotechnical Research lab of LBS Institute of Technology for Women, Thiruvananthapuram, India.

2.1 *Materials used*

Locally available clay and sand are used in this investigation. Biaxial Geogrid is used as reinforcement. The properties of clay, sand and geogrid are presented in tables 1, 2 and 3 respectively.

Table-1 Properties of Clay

Properties	**Clay**
Specific Gravity	2.63
Optimum Moisture Content (%)	18
Dry Unit Weight (kN/m^3)	15.6
Liquid Limit (%)	58
Plastic Limit (%)	22
Plasticity Index	36
Permeability (m/sec)	3.03×10^{-6}
IS Classification	CH
Friction angle (ϕ °)	5
Cohesion (KPa)	25

Table-2 Properties of Sand

Properties	**Sand**
Specific Gravity	2.65
Friction angle (ϕ °)	31.2
Cohesion (kPa)	0
Dry Unit Weight (kN/m^3)	16
Effective Grain Size D10 (mm)	0.15
D60 (mm)	0.60
D30 (mm)	0.30
Coefficient of Uniformity C_u	4.00
Coefficient of Curvature C_c	1.00
Permeability (m/sec)	1.07×10^{-4}

Table-3 Properties of Geogrid

Property	Value
Colour	Black
Type	Biaxial
Tensile Strength (kN/m)	13
Aperture Size (mm)	26x20
Mass per Unit Area (g/m^2)	225

2.2 *Laboratory scale load tests*

The load tests are conducted in a combined test bed and loading frame assembly. The test beds are prepared in a tank which is designed keeping in mind the size of the model footing to be tested and the zone of influence. The dimensions of the test tank are 1000 mm length x 750 mm width x 750 mm depth. An inverted Tee Beam of flange width 100 mm is used as the model strip footing. The web of the Tee Beam is stiffened using MS angle sections. The loading tests are carried out in a loading frame fabricated with ISMB 300. The load is applied using a hand operated- mechanical jack of capacity 50kN. The applied load is measured using a proving ring of capacity 10kN. The settlement of the model strip footing is measured using two dial gauges kept diametrically opposite to each other. The model strip footing is placed exactly beneath the centre of loading jack to avoid eccentric loading. The details of test setup are shown in Figure 1 and photograph in Figure 2

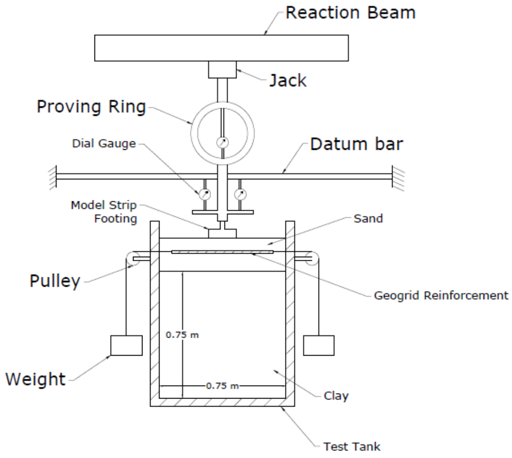

Figure 1. Test Setup.

Figure 2. Photograph of Test Setup

At first the weak soil is filled in the test tank to the required level with compaction done in layers, to achieve the pre-determined density. Then sand is filled up to the bottom level of reinforcement and compacted. The reinforcement is then placed with its centre exactly beneath the jack, and the prestress is applied. Then sand above the reinforcement is placed and compacted to the pre-determined density. The densities to which the soils are compacted are indicated in Tables 1 & 2. The compactive effort required to achieve the required density of both the soils is determined by trial and error. Preparation of underlying weak soil in all the tests involved compaction of soil using a rammer. In the preparation of foundation bed, the sand is compacted using a small plate vibrator.

The thickness of foundation bed adopted was B in all the cases, where B is the width of model footing. The depth of reinforcement from the base of footing is adopted as 0.5B for all the tests. The prestress applied is equal to 1%, 2% and 3% of the tensile strength of the geogrid and is distributed over five pulleys.

The size of reinforcement was five times the size of footing in all the tests. After preparing the bed, the surface is leveled, and the footing is placed exactly beneath the centre of the loading jack to avoid eccentric loading. The load is applied in small increments. Each load increment is maintained constant until the footing settlement is stabilized. The settlement is measured using two dial gauges kept diametrically opposite to each other and their average value is adopted. The test tank is emptied and refilled for each test to ensure that controlled conditions are maintained throughout the investigation. The details of testing programme are given in Table 4.

Table-4 Testing Programme

Series	Type	Magnitude of Prestress
A	Clay	--
B	Unreinforced Foundation Bed	--
C	Reinforced Foundation Bed	--
D	Prestressed Reinforced Foundation Bed	1%, 2% & 3%

2.3 *Large scale direct shear tests*

Large scale direct shear tests are carried out in a shear box of dimensions 300 x 300 x 200 mm, with facilities for prestressing the geosynthetic reinforcement. The photograph of the shear box is shown in figure 3. Tests are carried out with various magnitudes of prestress and relative densities of granular soil

Figure 3. Shear Box with attachment for prestressing the geogrid

3 FINITE ELEMENT ANALYSES

In the present study, loading tests on Reinforced Foundation Beds are also simulated numerically using the finite element software package *PLAXIS* 2D. The settlement of the rigid footing is simulated using non zero prescribed displacements. The soil is modeled using 15 noded triangular elements. The reinforcement is modeled using the 5-noded geogrid element. The prestress is applied as a horizontal tensile load to the reinforcement (Fig.4). Medium mesh size is adopted in all the simulations. To simulate exactly the testing procedure in the laboratory, staged construction procedure is adopted in the calculation phase. In the first stage, weak soil up to its top level is simulated. In the second stage, sand up to the bottom level of reinforcement is simulated. In the third stage the reinforcement with prestress is simulated and in the fourth stage sand above the reinforcement is simulated. In the final stage the footing with prescribed displacement is simulated. Such a staged construction procedure is necessary because the reinforcement should be prestressed before filling soil above it, otherwise the friction between soil and reinforcement will prevent the elongation of reinforcement due to prestressing. The deformed shape of soil after loading is shown in Fig. 5.

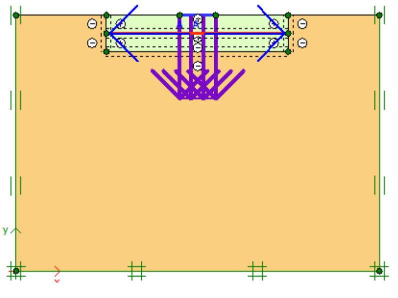

Figure 4. Geometric Model.

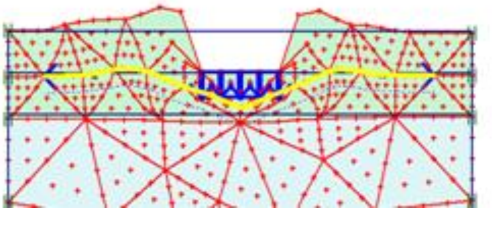

Figure 5. Deformed Shape after Loading

4 RESULTS AND DISCUSSIONS

4.1 *Effect of magnitude of prestress*

Figure 6 presents the variation of bearing pressure with footing settlement, obtained from laboratory scale load tests as well as from finite element analyses. It can be seen that maximum improvement is observed when the magnitude of prestress is equal to 2% of the tensile strength of reinforcement. Further addition of prestress did not show any improvement in settlement behaviour.

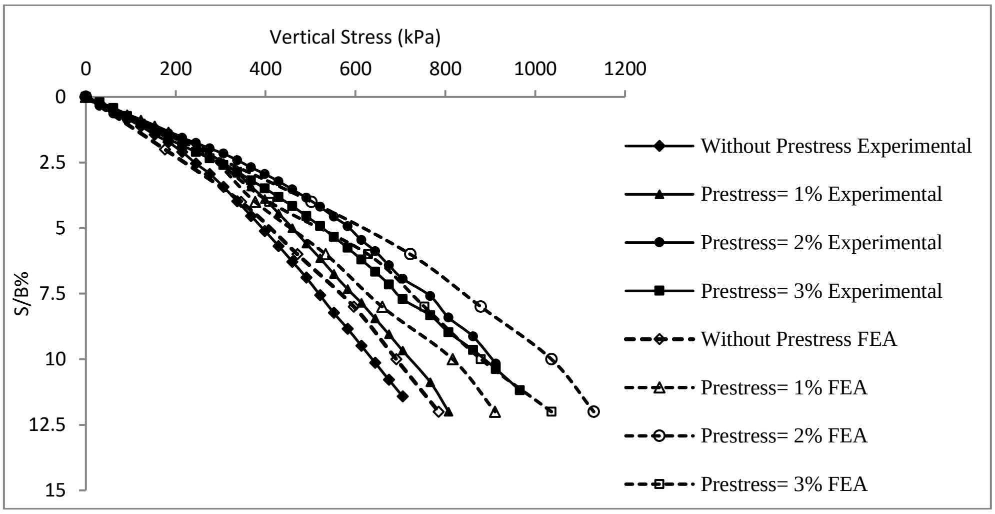

Figure 6. Vertical Stress vs Normalized Settlement Curves at various magnitudes of prestress

4.2 *Distribution of axial force along the reinforcement*

The distribution of axial force along the length of geogrid reinforcement, determined from finite element analyses, is presented in Fig. 7. It is observed that the mobilized tensile force in the reinforcement increases due to the applied prestress. When there is no prestress, the tensile force is mobilized only in the middle third portion of the geosynthetic reinforcement. As prestress is applied, tensile force starts getting mobilized in the outer portions of the reinforcement as well. The axial force distribution in the reinforcement becomes more uniform as the magnitude of prestress increases.

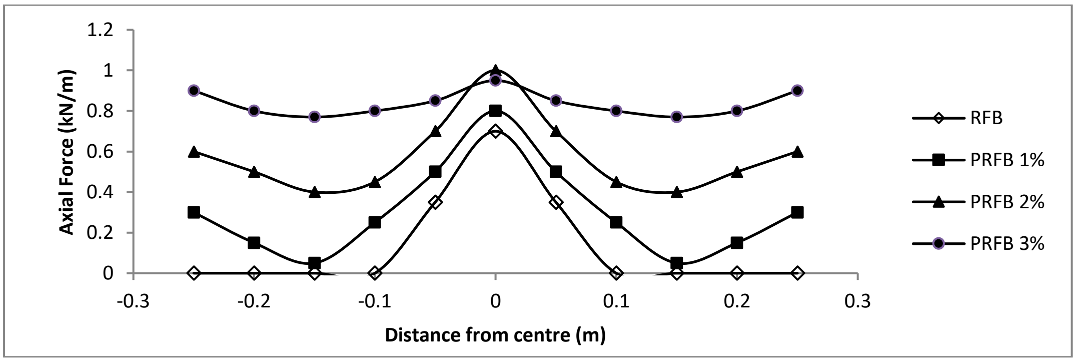

Figure 7. Axial Force Distribution in the Reinforcement

4.3 *Distribution of vertical stress at the interface between foundation bed and underlying weak soil*

Figure 8 presents the distribution of vertical stress at the interface between foundation bed and underlying weak soil. It is observed that prestressing the reinforcement results in distribution of the vertical stress at interface to a wider area. The peak stress at interface reduces with the increase in prestress.

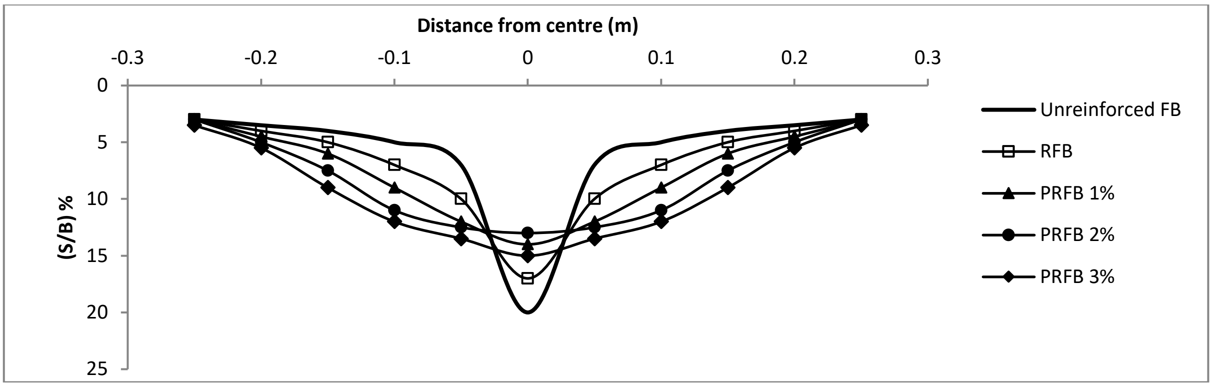

Figure 8. Distribution of vertical stress at the interface between foundation bed and underlying weak soil

4.4 *Effect of prestress on the mobilized shear stress at interface between reinforcement and surrounding granular soil*

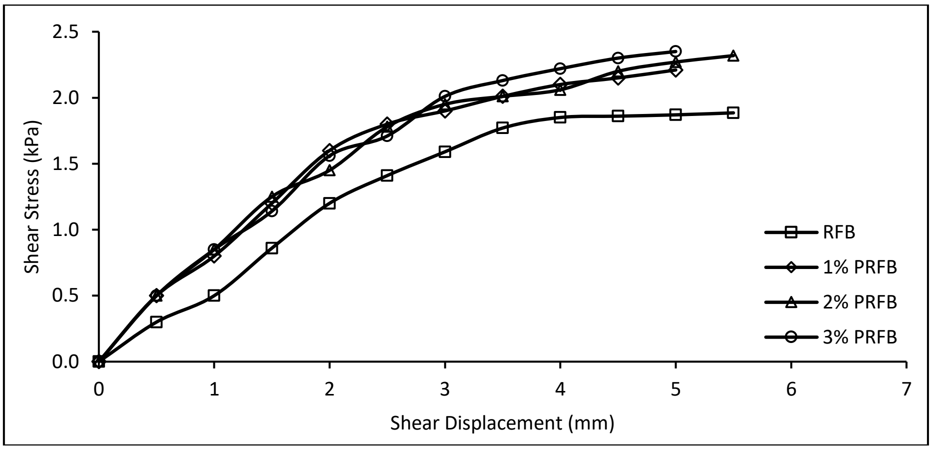

Figure 9. Shear Stress vs Shear Displacement curves at various magnitudes of prestress

Shear stress vs shear displacement curves obtained from large scale direct shear tests are presented in figure 9. It is seen that as the magnitude of prestress increases, the mobilized shear stress at the interface between reinforcement and surrounding soil increases.

4.5 *Effect of relative density of foundation bed*

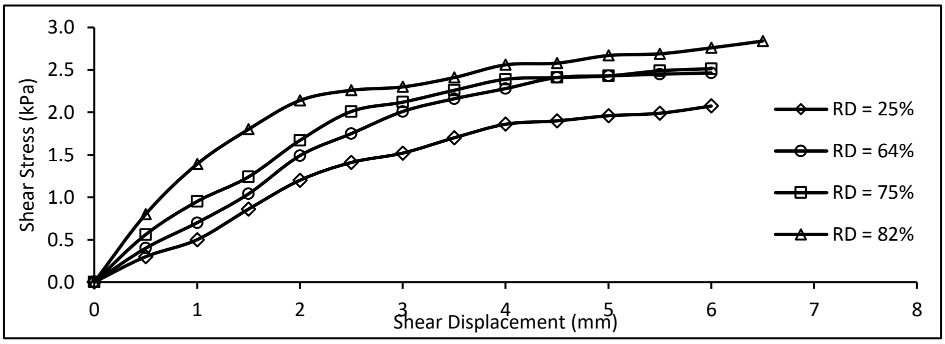

Figure 10. Shear Stress vs Shear Displacement curves at various relative densities of foundation bed

Figure 10 presents the shear stress vs shear displacement curves for various relative densities of foundation bed, determined from large scale direct shear tests. It is observed that as the relative density increases, the shear resistance of foundation bed increases.

5 CONCLUSIONS

Based on the results obtained from experimental studies and finite element analyses the following conclusions are made on the behaviour of prestressed reinforced foundation beds overlying weak soils.

1. The addition of prestress to geosynthetic reinforcement significantly improves the bearing capacity and settlement behaviour of the soil.
2. The stress, due to loading, on the underlying weak soil gets distributed to a wider area due to the addition of prestress to geosynthetic reinforcement.
3. The mobilized tensile force in the geosynthetic reinforcement increases with prestress.
4. The mobilized shear stress at the interface between reinforcement and surrounding soil increases with prestress
5. The shear resistance of foundation bed increases with an increase in its relative density
6. The results obtained from Finite element analyses are in reasonably good agreement with the experimental results.

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