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Study of Strip Footings Resting on Granular Bed Overlying Weak Soil

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Abstract: This paper presents results of a series of finite element analyses carried out to determine the behaviour of a Reinforced Granular Bed (RGB) overlying clayey soil. The beneficial effects of prestressing the reinforcement is also studied. The interface shear parameters under various conditions were determined by carrying out large scale direct shear tests on Geogrid Reinforced Sand using a shear box of size 300 x 300 x 200mm. It is observed that the beneficial effects of prestressing the reinforcement also depends upon the geometric parameters of the RGB.

Keywords: Finite element analyses, shear strength parameters, shear box, reinforced granular bed, strip footing.

I. INTRODUCTION

Increase in demand of construction site due to various aspects results in choice of soils with marginal soil properties. Construction in such soils require deep foundation techniques which prove uneconomical and unsustainable. An alternative solution to this is to construct shallow footing on geosynthetic embedded granular beds. The technique of reinforcing soil, which in its present form owes its origin to Vidal (1969), is one of the more recent and fast-growing techniques of soil improvement in the field of geotechnical engineering. In many cases of construction, shallow foundations are built on top of existing cohesive soils of low to medium plasticity, resulting in low bearing capacity and/or excessive settlement problems. An economical treatment method is the use of reinforced granular bed (RGB). This can be done by either reinforcing cohesive soil or replacing the poor soils with stronger granular fill, in combination with geosynthetics. Geosynthetics are extensible materials and will require some elongation to mobilize tensile stress in it. The strains occurring during initial settlements are insufficient to mobilize significant tensile load in the geosynthetic and hence the improvement in bearing capacity will occur only after considerable settlements. This is not a desirable feature for foundations of certain structures, since their permissible values of settlements are very small. Thus there is a need for a technique which will allow the geosynthetics to increase the load bearing capacity of soil without the occurrence of large settlements. In the past 30 years, a significant amount of research efforts, including experimental, numerical, and analytical studies, has been made to investigate the behavior of the RGB for different soil types. An early study conducted by [15] with discrete inclusions in the granular bed. Since then, several experimental studies on the bearing capacity of footings on reinforced soil have been reported [1], [2], [3], [4], [5], [6], [9], [10], [12], [13], [14]. One promising technique is to pre-stress the geosynthetic layers before implementing them as reinforcement in various foundation engineering applications [7], [8], [11], [16]. Further in the investigation presented by some researchers the concept of an innovative system called prestressed reinforced soil developed at Graz University of Technology, Austria [7]. This concept was to improve the load-displacement behaviour of the geogrid reinforced soil structure. In order to prestress the geogrid in a reinforced soil structure, three different methods where developed.

They proposed three possible modes of prestressing, viz. Prestressed Reinforced Soil by Compaction (PRSC), Permanently Prestressed Reinforced Soil (PRSP) and Temporarily Prestressed Reinforced Soil (PRST). They further conducted a series laboratory model tests and finite element analyses to find the load-settlement behaviour of tested soil specimen and concluded that bearing capacity of soil increasing with prestressing. Also [8] carried out a series of about 60 path controlled static load displacement tests and 80 cyclic load displacement tests on beach sand 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. This paper depicts the results of a series of finite element analysis carried out to determine the behaviour of reinforced granular bed overlying clayey soil. The interface shear parameters were determined using large scale direct shear tests that facilitates prestressing and values obtained were given accurately to the software in order to carry out model simulations. Effect of geometric parameters of the granular bed along with the beneficial effects of prestressing the geosynthetics is studied using PLAXIS 2D.

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II. STRESS TRANSFER BETWEEN GEOGRID AND SAND AT INTERFACE

In order to find out the stress transfer between geogrid and sand at their interface, large scale direct shear tests are carried out in a shear box of dimensions 300 x 300x 200mm. The strength reduction factor Rinter required for finite element analyses is obtained from the results of large scale direct shear tests.

A. Materials

The material used for granular bed is well graded medium sand and underlying weak soil is locally available clay. The properties of both soils are given in Table 1 and 2 respectively. The reinforcement used is Geogrid and its properties are given in Table 3. The tensile strength of geogrid was tested with the help of ASTM D6637 (2001).

TABLE I
PROPERTIES OF SAND USED AS FOUNDATION BED

Sl No:	Property	Value
1	Specific gravity	2.657
2	Effective Grain size D10 (mm)	0.15
3	D60 (mm)	0.60
4	D30 (mm)	0.30
5	Coefficient of Uniformity Cu	2.0
6	Permeability (m/s)	1.07x10-4

TABLE II
PROPERTIES OF WEAK SOIL

Sl No:	Property	Value
1	Specific Gravity	2.57
2	Optimum moisture content (%)	18
3	Maximum Dry Density (kN/m^3)	15.61
4	Liquid Limit (%)	58
5	Plastic Limit (%)	22
6	Plasticity index	36
7	Permeability (m/s)	$3.03x10^{-6}$

TABLE III
PROPERTIES OF GEOGRID USED

Sl No:	Property	Value
1	Colour	Black
2	Coating Type	PVC
3	Textile Type	High Tenacity Low Shrinkage Polyester Yarn
4	Tensile Strength (kN/m)	12.9
5	Aperture Size (MD x CMD in cm)	26 x 20
6	Mass per Unit Area (g/m^2)	225
7	Roll size (m x m)	100 x 2.40
8	Pull-out Interaction Coefficient, Ci	0.8

B. Large Scale Direct Shear Tests

The geogrid was tested for its maximum tensile strength in both machine and cross machine direction as shown in Fig.1. Ultimate strength of the geogrid is considered for designing the prestressing weights in the new apparatus. As per ASTM D6243 (2013) a large scale direct shear apparatus of shear box size 30cm x 30cm x 20cm is designed and fabricated as shown in Fig. 2. ASTM procedure for direct shear tests is adopted to determine the shear parameters of soil and the interface shear parameters between soil and geogrid for various magnitudes of prestress. The results of large scale direct shear tests are shown in Table 4. The prestress is applied as horizontal tensile load to the geogrid through a system of pulleys and weights.

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Fig. 1 Tensile testing of geogrid

Fig. 2 Modified direct shear apparatus

TABLE IV
RESULTS OF LARGE SCALE DIRECT SHEAR TESTS

Sl No:	Specimen Description	Angle of shearing resistance	Cohesion	R inter
1	SandAlone	45.7˚	0	NA
2	Sand + Geogrid	39.7˚	0	0.81
3	Sand + Geogrid with 1% prestress	42.8˚	0	0.904
4	Sand + Geogrid with 2% prestress	44.4˚	0	0.957
5	Sand + Geogrid with 3% prestress	44.9˚	0	0.972

III. FINITE ELEMENT ANALYSIS

Finite element analyses are carried out with the FE software PLAXIS 2D. For simulating the behaviour of soil, different constitutive models are available in the software. In the present study Mohr-Coulomb model is used to simulate soil behaviour. This non-linear model is based on the basic soil parameters that can be obtained from direct shear tests; internal friction angle and cohesion intercept.

Since strip footing is used, a plain strain model is adopted in the analysis. The settlement of the rigid footing is simulated using non zero prescribed displacements. The displacement of the bottom boundary is restricted in all directions, while at the vertical sides; displacement is restricted only in the horizontal direction. The initial geostatic stress states for the analyses are set according to the unit weight of soil. The soil is modelled using 15 noded triangular elements.

TABLE V
OBSERVATIONS FROM LARGE SCALE DIRECT SHEAR TESTS

Sl No:	Type	Size of GB	Thickness of GB	Magnitude of Prestress
1	Clay	--	--	--
2	Unreinforced GB	5B, 4B, 3B, 2B, B	0.25B, 0.5B, 0.75B, B	--
3	Reinforced GB	5B, 4B, 3B, 2B, B	0.25B, 0.5B, 0.75B, B	--
4	Prestressed RGB	5B, 4B, 3B, 2B, B	0.25B, 0.5B, 0.75B, B	1%,2% & 3%

The reinforcement is modelled using the 5-noded tension element. To simulate the interaction between the reinforcement and surrounding soil, an interface element is provided on both upper and lower surface of reinforcement. The interaction between soil and reinforcement is simulated by choosing an appropriate value for strength reduction factor Rinter at the interface. The parameters studied in FE analyses is given in Table 5.

Mesh generation can be done automatically. 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, self-weight of soil was assigned and 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

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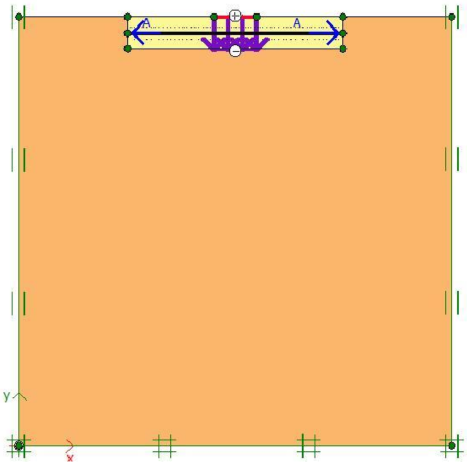
simulated as in Fig. 3. Such a staged construction procedure is necessary because the reinforcement should be prestressed before filling soil above it, otherwise the friction between soil and reinforcement will prevent the elongation of reinforcement due to prestressing. The modelled mesh after carrying out analysis is shown in Fig. 4.



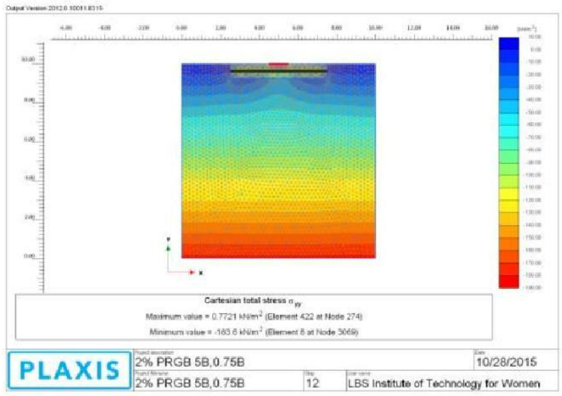


Fig. 3 Geometric model for finite element analysis   Fig. 4 Stress distribution after giving prescribed displacements

IV. RESULTS AND DISCUSSIONS

A. Improvement in Load Settlement Behaviour

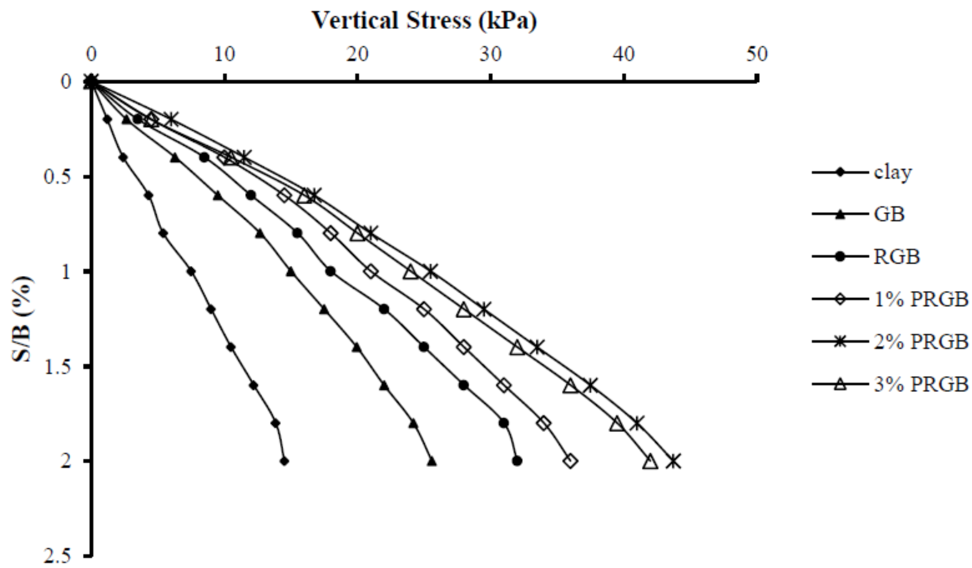


Fig. 5 Stress versus normalized settlement curves for foundation bed of size 3B and thickness 0.5B with various magnitudes of prestressing.

From Fig. 5 which shows the variation of bearing pressure with footing settlement of uniaxially prestressed granular bed of thickness 0.5B where B is the width of footing, 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. Initially as the prestress is applied, the bearing capacity will improve due to increased mobilized tensile stress in the reinforcement. The results of finite element analyses indicated that as the prestress increases, the friction at the interface between reinforcement and surrounding sand reduces. This will cause a reduction in bearing capacity. Hence there will be no improvement in load-settlement behaviour when the prestress in increased beyond the optimum value.

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B. Distribution of Normal Stress at the Interface between Geogrid and Granular soil

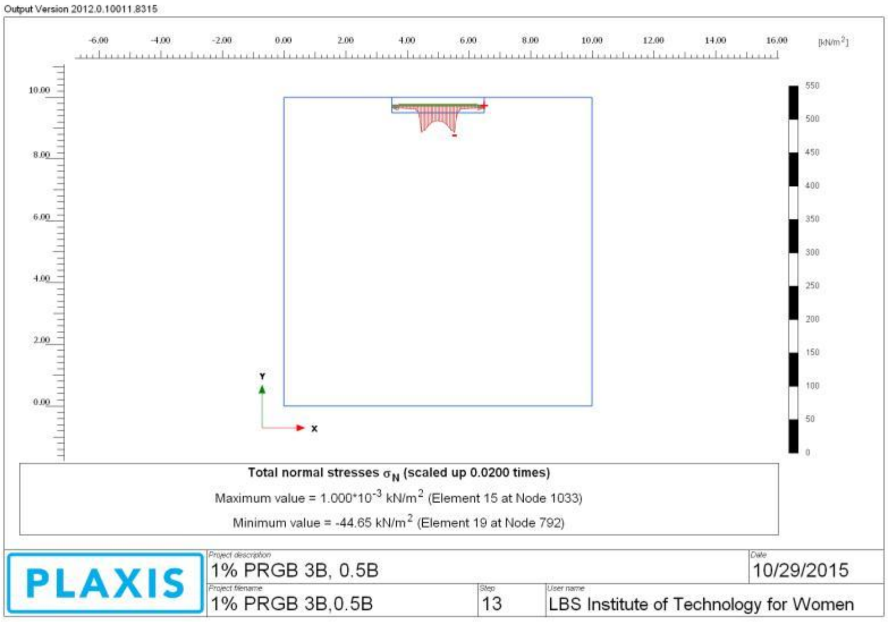

Fig. 6 Typical distribution of normal stress on reinforcement during loading

The typical distribution of normal stress on reinforcement during loading is shown in Fig.6. It is observed that maximum normal stress on reinforcement develops beneath the edges of footing. The effect of thickness of RGB on the normal stress acting on reinforcement is presented in Fig. 7. It is observed that the stress distribution becomes more uniform with the increase in magnitude of prestressing. This is because, with the application of prestress in the reinforcement, the mobilized tensile stress increases. This starts distributing the normal stress evenly along the length of reinforcement.

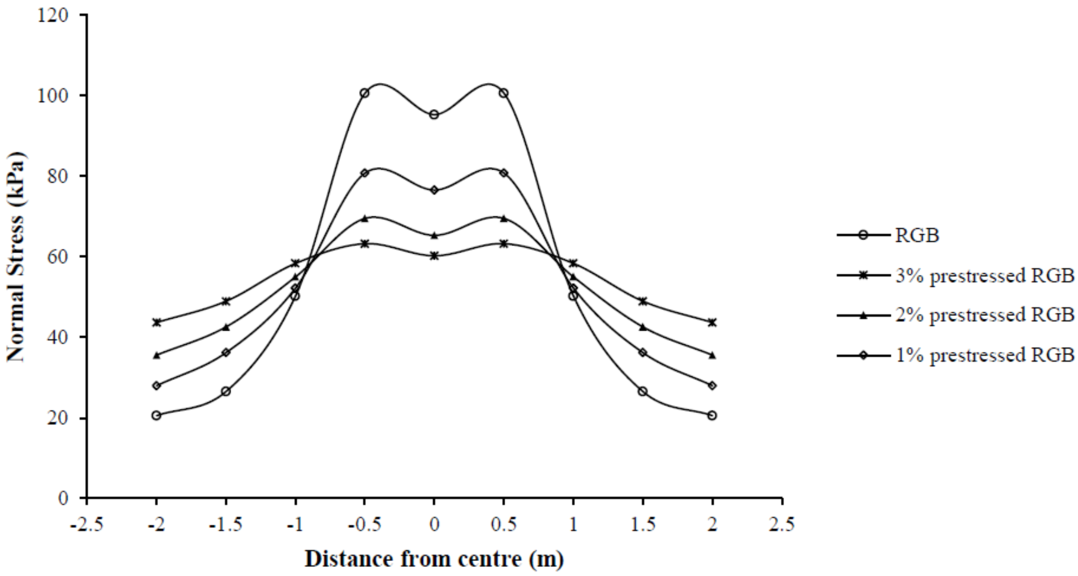

Fig. 7 Distribution of normal stress on reinforcement for various magnitudes of prestressing

C. Effect of Thickness of Granular Bed

The effect of thickness of RGB is studied by varying the thickness as indicated in Table 5. Bearing Capacity Ratio for 2% settlement vs magnitude of prestressing curves, from finite element analyses, for RGB of size 3B, with various thickness of RGB are presented in Fig.8. The bearing capacity increases with the thickness of RGB and the optimum thickness is observed to be 0.75B beyond which the increase is only marginal.

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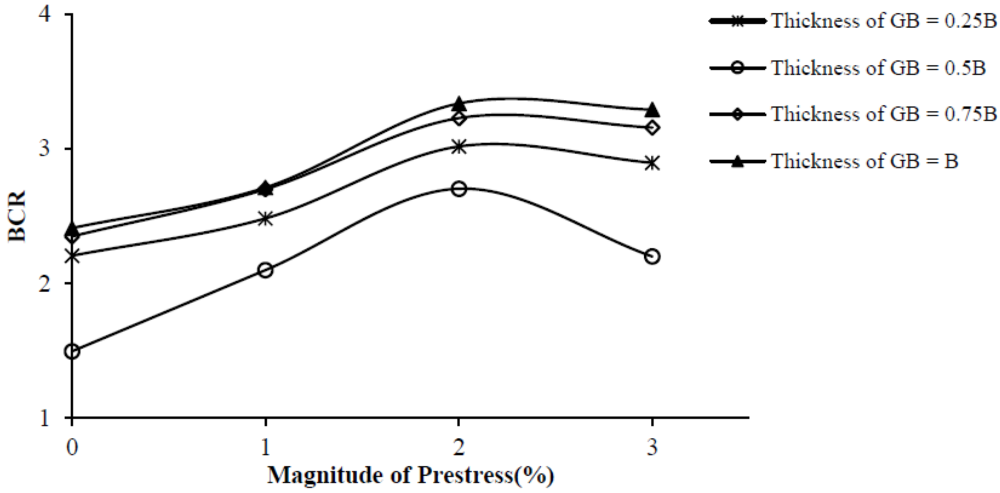

Fig. 8 Variation of BCR with prestress in granular beds overlying weak soil for size of GB = 3B

D. Effect of Width of Granular Bed

Finite element analyses are carried out with reinforced foundation bed of width B, 2B, 3B, 4B, and 5B, where B is the width of footing. Bearing Capacity Ratio for 2% settlement vs magnitude of prestressing curves, from finite element analyses, for RGB of thickness 0.5B with various width of RGB is presented in Fig. 9. It is seen from the figure that the bearing capacity increases with the size of RGB as the stress distribution in the weak soil becomes more uniform with the increase in width of granular layer.

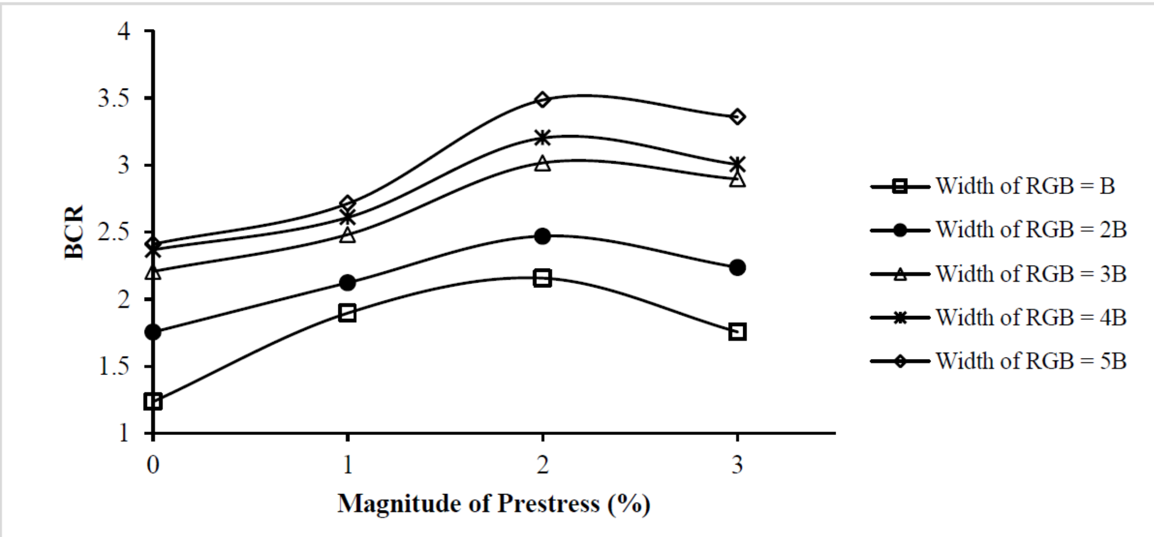

Fig. 9 Variation of BCR with prestress in granular beds overlying weak soil for thickness of GB = 0.5B

V. CONCLUSION

From the results of finite element analyses, the following conclusions are made on the behaviour of strip footing resting on Prestressed Reinforced bed overlying clay.

1. Prestressing the geosynthetic reinforcement in RGB considerably improves load-settlement behaviour.
2. It is seen that the optimum value of prestress is equal to 2% of the tensile strength of geogrid, beyond which there is no further improvement.
3. The normal stress distribution at the interface between reinforcement and granular soil widens with increase in magnitude of prestress.
4. The optimum thickness of RGB is found to be 0.75B.
5. The bearing capacity ratio of soil increases with width of granular bed.

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