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Technical note

Effects of prestressing the reinforcement on the behavior of reinforced granular beds overlying weak soil

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ABSTRACT

The effects of prestressing the reinforcement on the strength improvement and settlement reduction of a reinforced granular bed overlying weak soil are being investigated through a series of laboratory scale bearing capacity tests. The influences of parameters such as strength of underlying weak soil, thickness of granular bed, magnitude of prestressing force, direction of prestressing forces and number of layers of reinforcement are being examined. Finite element analyses are carried out using the FE program *PLAXIS* to study the effect of prestressing the reinforcement. Results obtained from finite element analyses are found to be in reasonably good agreement with the experimental results.

1. Introduction

The use of geosynthetics to improve the bearing capacity and settlement performance of shallow foundations has proven to be a cost-effective foundation system. In marginal ground conditions, geosynthetics enhance the ability to use shallow foundations in lieu of the more expensive deep foundations. This is done by either reinforcing cohesive soil directly or replacing the poor soils with stronger granular fill in combination with geosynthetics reinforcement. In low-lying areas with poor foundation soils, the geosynthetic reinforced granular bed can be placed over the weak soil. The resulting composite ground (reinforced granular 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. During the past 30 years, the use of reinforced soils to support shallow foundations has received considerable attention.

Many experimental and analytical studies have been performed to investigate the behavior of reinforced foundation beds for different soil types (eg. Binquet and Lee (1975), Shivashankar et al. (1993); Deb et al. (2011); Demir et al. (2013)). 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); Boushehrian et al. (2011); Bai et al. (2013) etc).

It is now well established that geosynthetics demonstrate their beneficial effects only after considerably large settlements which may not be a desirable feature for shallow footings, pavements, embankments, etc. In fact, for the initial settlements, the strains in the soil are insufficient to mobilize significant tensile load in the geosynthetic. 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. Lovisa et al. (2010) conducted laboratory model studies and finite element analyses on a circular footing resting on sand reinforced with geotextile to study the effect of prestressing the reinforcement. The magnitude of prestressing force applied was equal to 2% of the tensile strength of the geotextile. It was found that the addition of prestress to reinforcement resulted in 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 behavior of prestressed reinforced soil structures. They also conducted a detailed meoscopic analysis using particle image velocimetry method. They proposed

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three possible modes of prestressing, viz. Prestressed reinforced soil by compaction (PRS_C), Permanently prestressed reinforced soil (PRS_P) and Temporarily prestressed reinforced soil (PRS_T). They concluded that prestressing the reinforcement improves the load-displacement behaviour of reinforced soil structures. They observed that in static tests the highest increase in bearing capacity was attained by temporarily prestressed reinforced soil (PRS_T).

A possible method of improving bearing capacity of footings is to provide a geosynthetic reinforced granular bed over the weak soil. Also rather than a circular footing; square or rectangular footings are commonly used. Hence in this investigation an attempt is made to evaluate the effects of prestressing the reinforcement in further improving the bearing capacity of square footings supported on geosynthetic reinforced granular beds overlying weak soil. In this technical note the results of laboratory model tests and finite element analyses on a square footing supported by a prestressed reinforced granular bed (PRGB) overlying weak soil are presented. The parameters considered in the study are strength of the underlying weak soil, thickness of granular bed, magnitude of prestress, direction of prestress and number of layers of reinforcement. An elasto-plastic finite element analysis is conducted using the FE program *PLAXIS* version 8 and the results are compared with those obtained from the model tests.

2. Laboratory model tests

The experimental programme reported herein, that involves a series of laboratory scale load tests on model footings resting on prestressed reinforced granular beds, was carried out using the test facilities in the Structural Engineering Laboratory of Civil Engineering Department at the National Institute of Technology Karnataka, India. Details of the experimental programme, test procedures and analysis of test results are presented below.

2.1. Materials

The material used for granular bed is well graded medium sand and locally available soil termed as 'Shedi soil' is used as weak soil and properties of both soils are given in Table 1. The Shedi soil is used in two conditions namely moist condition (termed as moist soil or weak soil 1) and also used in submerged condition (termed as submerged soil or weak soil 2). The reinforcement used is Geogrid and its properties are given in Table 2. The geogrid used is a somewhat weak geogrid with a tensile strength of only 7.68 kN/m, for purpose of laboratory scale model tests.

Table 1
Properties of sand and weak soils used in the model tests.

Property	Value		
	Sand	Weak soil 1 (moist soil)	Weak soil 2 (submerged soil)
Specific gravity	2.61	2.32	2.32
Average dry unit weight during model test (kN/m^3)	16.60	16.00	16.00
Void ratio during model test	0.54	0.42	0.42
Water content during model test (%)	0	10	31.5
Effective grain size D_{10} (mm)	0.50	0.11	0.11
D_{60} (mm)	1.30	0.155	0.155
D_{30} (mm)	0.80	0.125	0.125
Coefficient of uniformity C_u	2.60	1.41	1.41
Coefficient of curvature C_c	1.00	0.92	0.92
Friction angle Φ (degrees)	31.0	12	6
Cohesion (kPa)	0	10	5.5

Table 2
Properties of geogrid used in the model tests.

Property	Value
Mass per unit area (gm/m^2)	730.00
Aperture size (mm)	8 × 6
Thickness (mm)	3.30
Tensile strength (KN/m)	7.68
Extension at maximum load (%)	20.20
Color	Black
Polymer	HD-Polyethyelene

Shedi soils are dispersive soils and are predominantly found in the western coast of peninsular India, which receives heavy rainfall during monsoon. Their strength reduces drastically under saturation condition.

2.2. Test setup

The load tests are conducted in a combined test bed and loading frame assembly. The test beds are prepared in a ferrocement 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 tank are 750 mm length × 750 mm width × 750 mm depth. The model footing is a rigid mild steel plate of 100 mm × 100 mm size and 20 mm thickness. The footing was loaded by a hand operated Jack of 10 kN capacity supported against a reaction frame. The load is measured using a proving ring and deformation using two dial gauges placed diametrically opposite to each other.

2.3. Preparation of test bed

At first the weak soil is filled in the ferrocement 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 were compacted are indicated in Table 1. The compactive effort required to achieve the required density of both the soils is determined by trial and error. Preparation of underlying soil in all the tests involved compaction of soil using a rammer. In the preparation of granular bed, the sand was compacted using a small plate vibrator.

Tests are carried out with single layer and double layer of reinforcement. In the literature, it is reported that optimum depth of placement of the first layer of reinforcement is 0.2*B* to 0.5*B* (*B* is the width of footing) (Sharma et al., 2009). The depth of reinforcement from the base of footing is adopted as 0.5*B* for all the

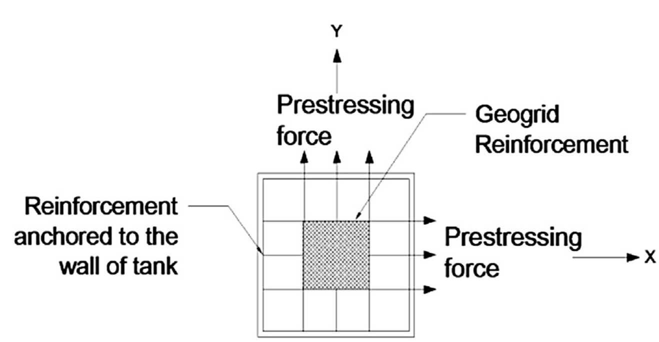

Fig. 1. Directions of prestress.