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Behaviour of model footing resting on sand bed reinforced with multi-directional reinforcing elements

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ABSTRACT

Laboratory plate load tests are conducted on a model footing resting on sand bed reinforced with plastic multi-directional reinforcements. The bearing capacity, settlement and heave are evaluated and the effect of depth to first layer, spacing between reinforcements in a layer, number of layers and spacing between layers are investigated. The bearing capacity at 25 mm settlement improved by almost 1.3 times for a single layer of reinforcement, placed at an optimum depth of 0.5B. An increase in number of layers beyond four resulted in a reduction in improvement of bearing capacity. Four layers of reinforcement, spaced vertically apart at 0.5B resulted in a maximum increase of 185% in the bearing capacity. For the same area, the multi-directional reinforcing elements provide additional confinement to the soil mass due to the three dimensional projections, compared to the conventional geosynthetic reinforcements such as geogrids. Even while comparing the economic aspects, the multi-directional elements prove to be a viable alternative to the conventional planar geosynthetics. An artificial neural network based model has also been developed, which would aid the engineers to effectively predict the ultimate bearing capacity and settlements of the model footing, resting on reinforced sand, before these reinforcing elements are actually applied in the field.

1. Introduction

The concept of mechanically stabilized earth has been widely used in various geotechnical applications such construction of embankments, pavements, bridge abutments, soft ground improvement and so on. Addition of reinforcements to soil have been performed by either incorporating continuous reinforcement inclusions such as sheet, bar or strip within a soil mass in a well-defined pattern, or by randomly mixing discrete fibres with a soil fill.

The effect of the conventional geosynthetic reinforcements on soil has been extensively investigated.(Fleming et al., 2006; Iizuka et al., 2004; Katarzyna, 2006; Latha and Murthy, 2006; Park and Tan, 2005; Patra et al., 2005; Varuso et al., 2005; Yetimoglu et al., 2005; Abu-Farsakh et al., 2015 and Davarifard and Tafreshi, 2015). Planar geosynthetic reinforcement layers substantially improved the strength and deformation characteristics of cohesionless soils (Chandrasekaran et al., 1989; Haeri et al., 2000 and Venkatappa Rao et al., 2005; Tafreshi and Dawson, 2010a; Tafreshi and Dawson, 2010b). Randomly oriented discrete geosynthetic fibres improved the strength, stiffness and reduced the post peak loss of shear in sands (Gray and Ohashi, 1983; Gray and Al-Refeai, 1986; Al-Refeai, 1991; Ranjan et al., 1994; Kaniraj and Gayathri, 2003; Yetimoglu and Salbas, 2003 and Park and Tan, 2005). Geogrid layers incorporated in soil fills improved the bearing capacity and reduced soil settlements (Alamshahi and Hataf, 2009; Mosallanezhad et al., 2008; Ghazavi and Mirzaeifar, 2010; El Sawwaf and Nazir, 2010; El Sawwaf and Nazir, 2012; Shin and Das, 2000; Sitharam and Sireesh, 2012 and Zidan, 2012).

The concept of three dimensional reinforcement was first introduced by Lawton et al. (1993), through laboratory investigations on sand reinforced with geo-jacks. Placing geo-jacks on top of geogrids substantially improved the performance of the soil bed. The combination of geogrid and geojacks performed better than the combination of geogrid and gravel. Zhang et al. (2008) investigated the use of three dimensional reinforcements in the form of rings with varying heights of vertical elements. In these investigations, the three dimensional elements were found to possess the inherent advantages of two dimensional

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reinforcements, along with the additional passive resistances introduced by the three dimensional components.

In this paper, results from laboratory plate load tests conducted on square footing resting on sand bed reinforced with single and multiple layers of multi-directional reinforcements are presented, in order to determine the feasibility of using multi-directional reinforcements to improve the bearing capacity of soil and to investigate the significance of parameters such as volume ratio of reinforcements, depth to first layer, spacing between reinforcements in a layer, spacing between layers and number of layers. An empirical model using artificial neural network modelling is also described, using which a field engineer can predict the improvement in strength parameters of reinforced soil, before the reinforcing elements are actually applied in the field.

2. Test materials

2.1. Sand

Locally available clean river sand obtained from the premises of NIT Calicut, Kerala, India was oven dried and was used for the present study. The engineering and index properties of sand used for the study are listed in Table 1. Under the USCS classification, sand is classified as poorly graded. The grain size distribution is described in Fig. 1.

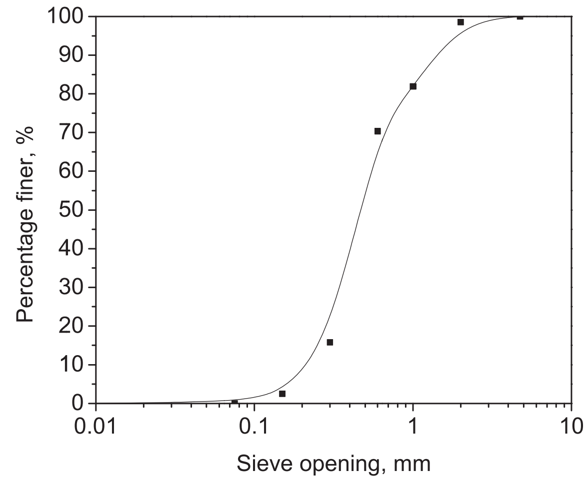

Fig. 1. Particle size distribution of sand used for the study.

2.2. Multi-directional reinforcements

Reinforcing elements were manufactured from injection moulding of Acrylonitrile Butadiene Styrene (ABS) plastic granules. ABS is derived from acrylonitrile, butadiene, and styrene. Acrylonitrile is a synthetic monomer produced from propylene and ammonia; butadiene is a petroleum hydrocarbon obtained from the C4 fraction of steam cracking; styrene monomer is made by dehydrogenation of ethyl benzene, which is a hydrocarbon. ABS combines the strength and rigidity of acrylonitrile and styrene polymers with the toughness of polybutadiene rubber. ABS has superior properties in terms of hardness, gloss, toughness, and electrical insulation. The reinforcements consisted of four legs or protrusions in a single plane (x–y) and two protrusions in plane perpendicular to this plane (z), with an average length of 30 mm and a diameter of 5 mm were used for the study, as shown in Fig. 2. The engineering properties of the reinforcing elements are explained in Table 2.

3. Test setup

The test setup for laboratory plate load test consists of the following:

a. Test tank of size 750 mm × 750 mm × 750 mm, made of mild steel sheets 1.5 mm thick and stiffened by horizontal and vertical bracings with mild steel angle sections on all faces.
b. MS plate 150 mm × 150 mm × 25 mm
c. Hydraulic jack, 50 kN capacity, with a ram diameter of 63 mm.
d. Dial gauges, 30 mm travel with 0.01 mm sensitivity

The test tank was fabricated keeping in mind the size of the model footing to be tested. As per Indian standards [IS:1888–1982], the width of the test tank should be five times the width of the model footing, to minimize scale effect. The sides and bottom of the tank were fabricated from 1.5 mm thick mild steel sheets. The sheets were screwed on to angle sections at the corners of the box structure. The box was stiffened by horizontal and vertical bracings to avoid yielding of the tank while being loaded, as shown in Fig. 3. The base of the plate was roughened by gluing on a thin layer of sand to it. A hand operated hydraulic jack of 50 kN capacity, abutting against a reaction frame was used to apply the required load to the system.

Table 1
Properties of sand used for the study.

Soil Parameters	Value
USCS classification	SP
Minimum Density, kN/m^3	12.75
Maximum Density, kN/m^3	15.7
D_{10}	0.25
D_{30}	0.38
D_{60}	0.5
Uniformity Coefficient, C_u	2.0
Coefficient of curvature, C_c	1.15
Angle of shearing resistance, φ	37.4

3.1. Preparation of test bed

Sand was poured into the tank using raining technique. In order to achieve a desired relative density, the corresponding height of fall required was determined, by performing trials with varying heights of fall. The densities were determined, in each trial by using steel containers of known volume. From the values of maximum and minimum dry densities, the relative density was calculated, in each trial. A curve was plotted between the height of fall and relative density, from which the height of fall required for filling sand at any given relative density could be obtained. For all tests, the relative density was maintained at 65%, consistent with the previous experimental investigations using multi-directional inclusions performed by the same authors (Harikumar et al., 2015). The sand bed prepared in the test tank at different levels is shown in Fig. 4.

4. Reinforcement configuration

The effect of parameters such as volume ratio of reinforcements, depth to first layer, intra and inter-layer between layers and number of layers are investigated in the test. Previous investigations conducted by Lee et al. (1999), Sitharam and Sireesh (2004), Bera et al. (2005) and Latha and Somwanshi (2009) on conventional