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Technical note

Influence of relative density of soil on performance of fiber-reinforced soil foundations

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ABSTRACT

An experimental study has been carried out for studying the influence of combinations of relative densities of two layered soil system. The model tests have been performed for the case of circular and ring footings resting on randomly distributed fiber reinforced sand (RDFS) layer overlying unreinforced sand bed. The influence of relative density on, different type of footings i.e. circular and ring ($r_i/r_o = 0.3$, 0.4, 0.5, 0.6) footings; percentages of fiber in RDFS layer i.e. 0.5%, 0.75%, 1.00%, and 1.25%; and thickness of RDFS layer i.e. 0.5B, 0.75B, and 1.00B have been studied. Results have indicated that relative density, of both the RDFS layer as well as the bottom unreinforced sand layer, significantly influences the ultimate bearing capacity as well as the settlement. Improvement in terms of bearing capacity ratio (BCR) is more when top RDFS layer is compacted at 70% relative density with bottom unreinforced sand having 30% relative density. Moreover, in terms of settlement reduction, maximum improvement is observed when both the layers were compacted at 70% relative density.

1. Introduction

Improving the engineering behavior of soil has been a major concern for geotechnical engineers ever since the introduction of ground improvement techniques. There are many ways to improve the engineering properties of soil like, incorporation of reinforcements into the soil (say: geosynthetics; metal strips; discrete fibers which can further be randomly distributed or aligned in the direction of planes of weak zone of soil), replacing the weak soil with strong soil up to significant depth, and/or densifying the weak soil up to significant depth or in other words increasing the relative density of soil. Ring shear tests were carried out on sand both for unreinforced and fiber reinforced under large shear strains. It was observed that denser samples behaved more efficiently in increasing and maintaining the ultimate shear strains (Consoli et al., 2007). Plate load tests were conducted on unreinforced and fiber reinforced sand at low, medium and dense relative density of sand, respectively. It was found out that the effect of fiber inclusion was more pronounced for higher relative densities. Moreover, higher relative density suppresses the dilation which results in increase in effective stress and hence increases the strength and stiffness of the soil (Consoli et al., 2009). The influence of relative density of soil on the improvement in performance of geocell reinforcement by using model plate load tests was studied. It was concluded that for effective utilization of geocell reinforcement; the soil should be compacted to higher density (Dash, 2010).

Many researchers in the past have improved the soil properties by the introduction of reinforcement elements in the soil strata. Out of the reinforcement elements, randomly distributed discrete inclusions have been the main attraction of researchers in the past few years. A very major advantage of fibers as reinforcement elements among the other types of reinforcements is that; there are no weak zones left in the soil strata as in the case of other types of reinforcements. Researchers (Al-Refeai, 1991; Freitag, 1986; Gray and Al-Refeai, 1986; Gray and Ohashi, 1983; Maher and Ho, 1993) started the initial testing on fiber-reinforced soil. The pressure-settlement and stress-strain behavior of fiber reinforced soil was compared by conducting model plate-load tests and triaxial tests, respectively. Both the pressure-settlement and stress-strain behavior was improved by the introduction of randomly distributed fibers in soil (Consoli et al., 2003). Numerical as well as experimental study was carried out to understand the influence of randomly distributed fiber inclusions in sand through

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triaxial tests. Inclusion of fibers in the soil makes the stress concentrations more diffuse and restricts the formation of shear bands (Babu et al., 2008). Split tensile and unconfined compression tests were carried out to estimate the Mohr-Coulomb failure envelope of unreinforced and fiber reinforced artificially cemented sands (Consoli et al., 2013). In the recent past more studied were carried out on different types of geosynthetic inclusions to study their effect on geotechnical properties of soil (Ajayi et al., 2017; Chen et al., 2015; Choo et al., 2017; Consoli et al., 2017; Festugato et al., 2017; Harikumar et al., 2016; Huang, 2017; Khachan and Bhatia, 2016; Kumar and Gupta, 2016; Madhusudhan et al., 2017; Miranda Pino and Baudet, 2015; Sharma and Kumar, 2017). Researchers have studied the effect of ground improvement technique by conducting model as well as field plate load tests by using different types of reinforcements. Metal strips, bars, planar, 3-D (geocell) and fiber reinforcements are the major types of reinforcement elements, which are very useful in improving the bearing capacity of soil. Different shapes of footings have been considered in the past, but ring footings which are very useful for tall towers, silos, and chimney, etc. Have not gained much attention. Researchers (Egorov, 1965; Fisher, 1957) started working on studying the behavior of ring footings. Later field plate load tests were conducted on dense calcareous sand (Al-Sanad et al., 1993; Ismael, 1996) and concluded that circular and ring plates have same average pressure settlement curves. Other researchers (Hataf and Razavi, 2003; Laman and Yildiz, 2003; Naderi and Hataf, 2014; Ohri et al., 1997; Sawwaf and Nazir, 2012) conducted laboratory model tests on ring footings and reported that the optimum value (on the basis of ultimate bearing capacity) of radius ratio (r_i/r_o), for ring footing lies in the range of 0.2–0.4, where r_i and r_o are the internal and external radius of ring footing under consideration. Majority of the work, related to model tests on footings, has been carried out by considering a uniform relative density of soil (reinforced with geogrid/planar reinforcement) under the footing up to larger depths. Very limited efforts have been made in the past to study the behavior of model footings when placed as, (a) strong soil overlying weak soil or, (b) weak soil overlying strong soil (Brown and Meyerhof, 1971; Hanna and Meyerhof, 1979; Kumar et al., 2013; Kumar and Walia, 2006; Meyerhof, 1974; Michalowski and Shi, 1995). Moreover, no study has been carried out on ring footings resting on randomly distributed fiber reinforced sand. Considering these gaps in the literature, an effort has been made to study the behavior of ring and circular footings resting on randomly distributed fiber-reinforced sand. Moreover, three combinations of fiber-reinforced sand overlying unreinforced sand have been considered and they are; (a) top fiber-reinforced sand compacted at 50% RD, overlying sand compacted at 30% RD, (b) top fiber-reinforced sand compacted at70% RD and underlying sand compacted at 30% RD. and, (c) top fiber-reinforced sand compacted at70% RD and underlying sand compacted at 70% RD. Hence the aim of this paper is to study the effect of RD of sand, i.e., loose (30%), medium (50%) and dense (70%), on.

- Footing type i.e. circular, and ring footing with radius ratio (r_i/r_o) of 0.3, 0.4, 0.5, and 0.6;
- Different percentages of randomly distributed fibers, i.e. 0.5%, 0.75%, 1.00%, and 1.25% by dry weight of sand;
- Different thicknesses (h1) of fiber-reinforced sand layer, i.e., 0.5B, 0.75B, and 1.0B, where B is the outer diameter for ring, or, diameter for circular footing.

Moreover a numerical example has been solved, for the better understanding of the readers by clearly highlighting the influence of relative density, fiber percentage, and thickness of RDFS layer.

2. Test material

Sand used in the model testing was obtained from Nasrala, Punjab, India. According to Unified Soil Classification System, the sand was classified as poorly graded, SP. Specific gravity (G_s) of sand was found out to be 2.65. The maximum and minimum dry unit weights of sand were found out to be 16.8 kN/m^3 and 13.6 kN/m^3, respectively, and the corresponding values of minimum and maximum void ratios were 0.56 and 0.93, respectively. The effective size (D_{10}), mean size (D_{50}), coefficient of curvature (C_c) and coefficient of uniformity (C_u) for the sand were 0.150 mm, 0.290 mm, 0.97 and 2.21, respectively.

Fibers used as a reinforcing element for sand in the model testing were macro-synthetic and non-corrosive fibers as shown in Fig. 2. For the effective anchoring of the fibers into the sand matrix they have an engineered contoured profile which enhances its performance. Physical and chemical properties of fibers are presented in Table 1.

2.1. Experimental setup and test program

Total 190 model plate load tests were carried out as shown in Table 2. A testing-cum-loading frame assembly was used for conducting model tests. The soil bed was prepared in a testing tank with inside dimensions of 1.5 m long, 1.5 m wide and 1 m deep. The model footings were made from mild steel, and were corrected to the desired size, thickness (25 mm) and shape (ring and circular). One circular footing and four ring footings were used in this study. Diameter for circular footing was 0.3 m and, the ratio of inner radius to outer radius of ring footings (r_i/r_o) of 0.3, 0.4, 0.5, and 0.6, were used in the study by keeping the outer diameter of ring to be constant i.e. 0.3 m. The footing was loaded until the failure (large uniform settlement corresponding to very small increment in load) or fully extended manually operated hydraulic jack. Two 0.01 mm sensitivity dial gauges were placed on either and opposite side of the footing to calculate settlement for every equal increment of load.

It was not possible to place hydraulic jack directly on ring footings because it will slip through the opening of the ring footings. So, in order to avoid this, first a loading platform was placed on ring footing followed by the hydraulic jack. Then loading of ring footing was possible. Test setup and detail of loading platform is shown in Fig. 1.

2.2. Preparation of bed and test procedure

Bed consists of two layers of sand as shown in Fig. 1. First, bottom unreinforced sand layer is filled, by using sand raining technique, at a known and desired density followed by leveling after reaching desired height. Second, top randomly distributed fiber reinforced sand (RDFS) layer was filled. For laying top RDFS layer, first dry weight of fibers and sand was calculated using equation (1), and (2). This means that fibers were added as a replacement of sand.

$$W_{RDFS} = V \times \gamma_{RDFS} \tag{1}$$

$$W_{RDFS} = W_s + W_f = p_s W_{RDFS} + p_f W_{RDFS} \tag{2}$$

where, W_{RDFS}, W_s, and W_f is dry weight of, RDFS layer, sand and, fibers, respectively; γ_{RDFS} is dry unit weight of RDFS layer; V is the total volume of RDFS layer to be placed; p_s and p_f are the percentages of sand and fibers in RDFS layer, respectively.

For the preparation of RDFS layer, sand and fibers were hand

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