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Direct shear tests on geosynthetic-encased granular columns

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ABSTRACT

The behaviour of geosynthetic-encased granular columns (EGC) under vertical loads is reasonably well understood. To date, very little research has been done to understand the behaviour of EGCs subjected to lateral loads. The main objective of this paper is to quantify the effect of encasement on the lateral load capacity of EGCs. Several direct shear tests are performed on granular columns with and without encasement in a shear box having plan dimensions of 305 × 305 mm. Tests are conducted at different normal pressures varying from 15 kPa to 75 kPa. Two different diameters of columns, three types of encasements and three different plan configurations are studied in this research work. The results from these tests are discussed in terms of the increase in the shear strength due to geosynthetic encasement and the strength envelopes for understanding the influence of the encasement. Different types of failures observed in the granular columns (with and without encasement) subjected to lateral load are also discussed.

1. Introduction

In recent times, granular columns have found wide applications for the construction of various rigid and flexible structures like buildings, embankments and oil storage tanks over soft clay (e.g., Murugesan and Rajagopal, 2006, 2007, 2008; Gniel and Bouazza, 2009, 2010; Ali et al., 2012; Shahu and Reddy, 2014). The ground reinforced with granular columns behaves as a composite with higher strength and stiffness compared to virgin soils (Alamgir et al., 1996; Murugesan and Rajagopal, 2010). In addition to improving the bearing capacity of the foundation soil, granular columns also reduce the time taken to post-construction ultimate settlements by accelerating the rate of consolidation of soft clay. It is well understood that granular columns derive their load carrying capacity by relying on the lateral confinement provided by the surrounding soil (Hughes and Withers, 1974; Hughes et al., 1975). However, sufficient lateral confinement may not be available in the case of very soft clays having low undrained shear strengths ($c_u < 15$ kPa) (Raithel et al., 2002; Murugesan and Rajagopal, 2007). Due to lateral flow in soft clays (Barksdale and Bachus, 1983), support for the granular column from the surrounding soil reduces, leading to the bulging of granular columns at shallow depth and resulting in higher settlement for overlying structures (Murugesan and Rajagopal, 2006; Black et al., 2007). Lateral flow of the foundation soil leads to shear failure of the columns (Fig. 1). Clogging of the granular column from the surrounding soft clay is also a major issue, which reduces the discharge capacity of the column (Murugesan and Rajagopal, 2008; Weber et al., 2010; Castro and Sagaseta, 2011; Indraratna et al., 2012).

The above-mentioned problems with granular columns can be effectively overcome by using a geosynthetic encasement to the granular column, which provides additional confinement, leading to mobilization of higher shear resistance.

Although the behaviour of ordinary and encased granular columns under vertical loads is reasonably well understood; (e.g., di Prisco et al., 2006; Murugesan and Rajagopal, 2006, 2007, 2010; Yoo and Kim, 2009; Gniel and Bouazza, 2009, 2010; Lo et al., 2010; Khabbazian et al., 2010; Pulko et al., 2011; Elsawy, 2013; Ali et al., 2012, 2014; Keykhosropur et al., 2012; Dash and Bora, 2013;

Abbreviation: A_r, Area replacement ratio; E1, Woven geotextile encasement; E2, Socks encasement; E3, paper towel encasement; EGC, Geosynthetic Encased granular Column; LDS, Large direct shear (305 mm × 305 mm); σ_n, Applied normal pressure; OGC, Ordinary granular column (without any geosynthetic encasement); 50C, Single 50 mm diameter granular column at centre of shear box; 100C, Single 100 mm diameter granular column at centre of shear box; 50T, 50 mm diameter granular columns in triangular arrangement (three columns); 50S, 50 mm diameter granular columns in square arrangement (four columns).

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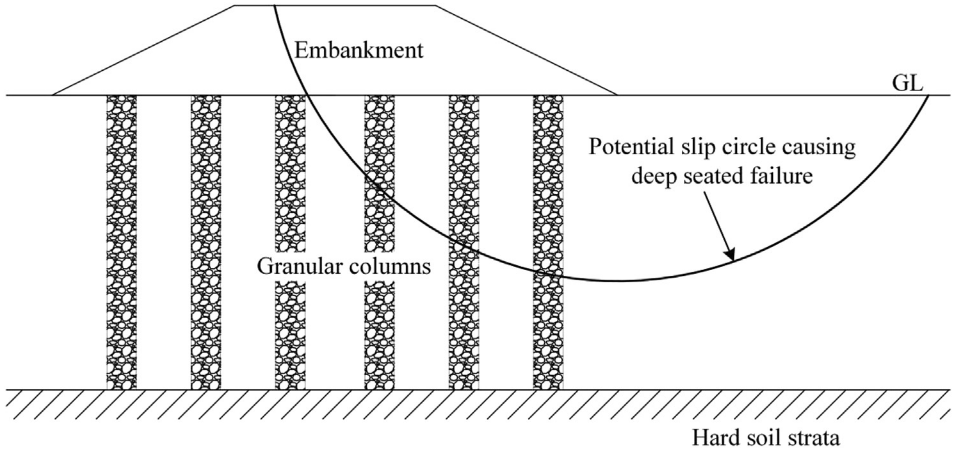

Fig. 1. Embankment on granular column improved soft foundation soil.

Ghazavi and Afshar, 2013; Hosseinpour et al., 2014; Zhang and Zhao, 2015), there have not been many studies on their behaviour under lateral loading. Murugesan and Rajagopal (2008) carried out plane-strain laboratory model tests to understand the behaviour of OGC and EGC subjected to shear loading and reported significant improvement in the shear resistance of granular columns due to encasement. Schnaid et al. (2014) carried out field tests on geosynthetic-encased sand columns and concluded that due to geosynthetic encasement, horizontal earth pressure on adjacent foundation decreases significantly. Chen et al. (2015) carried out physical model test and 3-dimensional numerical modelling to understand the behaviour of embankment loading on geosynthetic-encased stone columns in soft soils and reported that encased stone columns fail in bending instead of shear. However, the effects of variation of column diameter and stiffness of encasement were neglected. Almeida et al. (2015) carried out field study by constructing a 5.35-m-high trial embankment on soft foundation improved by EGCs and observed that the rate of radial strain of geosynthetic encasement reduced progressively with the consolidation of foundation soil. The lateral deformation of soft soil observed at the toe of the embankment for the case of EGCs was observed to be four times lower than that for an unimproved soft ground.

It is evident from the above discussion that EGCs provide increased resistance to lateral loading compared to OGCs; however, there have been no previous studies on the effect of size of columns and the stiffness of geosynthetic encasement on the shear resistance of EGCs. Additionally, there have been no previous studies on the group effect of EGCs under lateral loading. These effects should be quantified in order to have a more complete understanding of the behaviour of EGCs.

This paper focuses on understanding the behaviour of OGC and EGC under lateral loading by conducting large direct shear tests. Three different types of encasement materials were used. The tests were carried out using single granular columns with two different diameters and also with groups of three or four granular columns in triangular and square arrangements, respectively. From the experimental results, qualitative and quantitative improvement in lateral load capacity of soil due to the inclusion of OGCs and EGCs were observed.

2. Materials and methods

The laboratory model studies on lateral load capacity of granular columns were carried out using a large direct shear box having plan size of 305 mm × 305 mm and a depth of 140 mm. The dimensions of the test set-up are fairly small compared with typical dimensions of full-scale granular columns; however, the tests have been conducted at normal stress levels that are typical of full-scale embankments. As such, issues, such as too much dilation of the granular material in small-scale laboratory tests, have been avoided and the stress-strain behaviour of both the sand and the granular column has been simulated appropriately in the test set-up.

All the tests were performed in dry conditions. The details of laboratory tests are given in the subsequent sections.

2.1. Material properties

2.1.1. Sand and aggregates

Poorly-graded fine sand (effective particle size D_{10} of 0.24 mm) was used for the laboratory tests. The peak and critical state friction angles of the sand measured from large direct shear tests are 36° and 29°, respectively. Two types of crushed granular aggregates were used for forming the granular columns.

Two different diameters of granular columns – 50 mm and 100 mm – were used for the laboratory tests. The 50-mm-diameter granular columns were formed using aggregate passing through a 4.75 mm sieve and retained on a 2 mm sieve. The 100-mm-diameter granular columns were formed using aggregate passing through a 9.5 mm sieve and retained on a 2 mm sieve. Smaller aggregates were used for the 50-mm-diameter stone columns and larger aggregates were used for 100-mm-diameter stone columns to achieve the same diameter to aggregate size ratio of nearly 10. A value of 10 for this ratio was considered adequate based on the works of Fox (2011) and Stoeber (2012) wherein a ratio of around 6 for the triaxial specimen diameter to maximum particle size was found to be satisfactory for mine waste rock, which is similar in mechanical behaviour to the aggregates used in granular columns. Table 1 shows the different properties of sand and aggregates used in large-scale direct shear tests.

2.1.2. Geosynthetic encasement

Three different types of encasement materials - a woven geotextile (E1), cotton socks (E2) and paper towel (E3) - were used to study the effect of variation of encasement properties (ultimate tensile strength, initial and secant modulus and failure strain). All the properties of the three different encasement materials are listed in Table 2. The encasement material E1 had the highest ultimate tensile strength and modulus value compared to the other two materials. The initial modulus of E3 is higher than that of E2 but its