Transportation Geotechnics 10 (2017) 73–84

Contents lists available at ScienceDirect

Transportation Geotechnics

journal homepage: www.elsevier.com/locate/trgeo

Experiment and 3D-numerical studies on soft clay bed reinforced with different types of cellular confinement systems

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ARTICLE INFO

Article history:
Received 25 September 2015
Revised 2 October 2016
Accepted 4 January 2017
Available online 13 January 2017

Keywords:
Geocells
Soft soil
Bamboo
Bearing capacity
Tensile strength
Surface roughness

ABSTRACT

The manuscript deals with the experimental and 3-dimensional numerical studies carried on the soft clay bed reinforced with three different types of 3D-cellular confinement systems. The geogrid cells, commercial geocells and the bamboo cells are the three different types of 3D-cells used in the study. First, laboratory plate load tests were performed on the soft clay beds. Subsequently, numerical simulations were carried out to compliment the experimental findings. The numerical simulations were carried out in 3-dimensional framework using FLAC^{3D} by considering the actual honeycomb shape of the geocells. The foundation soil, infill soils and the cell materials were modeled with three different material models, namely, modified Cam-clay, Mohr Coulomb and the linear elastic models. The maximum bearing capacity was observed in the case of foundation bed reinforced with the bamboo cells due to its higher stiffness, higher tensile strength and the higher surface roughness values. Using the validated numerical model, the effect of tensile strength and the surface roughness of the geocell on the performance of the reinforced soft clay beds were quantified. The tensile strength of the geocell material found to have a more pronounced influence than the surface roughness. In addition, a hypothetical case of the prototype foundation on the soft clay has been analyzed and results of the model and prototype cases were found to be in accordance with each other.

Introduction

Nowadays, the 3-dimensional cellular confinement systems are being widely used in geotechnical engineering to strengthen the soft soil. These are expandable panels made of high density polymers. The 3D cellular confinement systems are popularly known as geocells. General geotechnical applications of geocells include pavements, foundations, and embankments. By virtue of its 3-dimensional box like structure, geocells provide additional confinement to the soil. The geocells offers faster, cheaper, sustainable, and environmentally friendly solutions to many complex geotechnical problems (Sitharam and Hegde, 2014).

Geocell was originally developed by the US army corps of engineers in the early 1970s for military applications. Afterwards, many researchers have carried out the studies and highlighted the beneficial use of geocells in civil engineering applications (Rea and Mitchell, 1978; Mitchell et al., 1979; Bush et al., 1990; Rajagopal et al., 1999). Interestingly, the geocells used by the different researchers are not made from the same material. Rea and Mitchell (1978) used the paper made geocells in their studies. Mandal and Gupta (1994) have used the geocells made from geotextiles. In the recent past, geocells used in the laboratory studies were prepared from the biaxial geogrids (Dash et al., 2001, 2003; Sitharam and Sireesh, 2005). Madhavi

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http://dx.doi.org/10.1016/j.trgeo.2017.01.001
2214-3912/

Latha and Somwanshi (2009) used the geocells made from geonets. Similarly, the geocell prepared from HDPE were used by various researchers in their studies (e.g. Emersleben and Meyer, 2008, 2009). Nowadays, with the development of materials science and technology, the geocells are being made from the materials with higher strength and stiffness. The present day geocells are manufactured from Neoloy, a novel polymeric alloy (NPA), which provides a higher modulus, creep resistance and tensile strength to geocells than commonly available HDPE (Pokharel et al., 2009). The advantages of Neoloy geocells were highlighted by many researchers (Yang et al., 2012; Thakur et al., 2012; Hegde and Sitharam, 2013; Hegde et al., 2014; Kief et al., 2014; Hegde and Sitharam, 2015a, b). Recently, Hegde and Sitharam (2015c) reported the use of geocells prepared from bamboo known as bamboo cells. Due to the use of different types of the geocells, the quantification made by the different researchers on the performance of the geocell is also different. None of the researches in the past have compared the performance different type of geocells.

The performance of the geocell varies significantly with the material with which it is made. The two main material properties, which significantly influence the performance of the geocell are the tensile strength and surface roughness. Bathurst and Karpurapu (1993) observed that, with the increase in the tensile strength of the material, the confinement offered by the geocell increases. The increase in the confining pressure ($\Delta\sigma_3$) on the soil due to the presence of geocell is given by Eq. (1).

$$\Delta\sigma_3 = \frac{2M}{d_0}\left[\frac{1-\sqrt{1-\xi_a}}{1-\xi_a}\right] \quad (1)$$

where, M is the secant modulus of the geocell material calculated corresponding to the axial strain of ξa in the tensile stress–strain response; d_0 is the equivalent diameter of the geocell pocket opening. Similarly, the positive influence of the surface roughness on the load carrying capacity was highlighted by the few researchers in the past (Koerner, 1998; Sitharam and Hegde, 2013). Koerner (1998) attributed the improvement in the load carrying of the geocell reinforced foundation bed (ΔP) to the lateral resistance effect.

$$\Delta P = 2P_r \tan^2(45-\varphi/2)\tan\delta \quad (2)$$

where P_r is the applied vertical pressure on the bamboo cell, φ is the friction angle of the infill material and δ is the angle of shearing resistance between the geocell wall and the soil contained within. The angle of shearing resistance is also called as interface friction angle and is the indirect measure of the surface roughness of the geocell material. Generally, it is determined from the modified direct shear test.

While using the geocells in a project, it is very essential for the engineers to understand the type of geocells being used and the performance associated with it. The aim of the present research is to quantify and compare the performance of the different type of geocells. Out of all the different types of geocells reported in the literature, the three most relevant types of geocells, which suits to the present day scenario, have been selected in the present study. The three types of geocells considered in the present study are geogrid cells, Neoloy based commercial geocells and the bamboo cells. Fig. 1 shows the photographs of the different geocells used in the study. Geogrid cells were prepared in the laboratory using the biaxial geogrids. The bodkin joints were formed by inserting the Perspex sticks. Similarly, the bamboo cells were also prepared in the laboratory from locally available bamboo. The bamboo was procured from the Belgaum region in Karnataka, India. The bamboo belongs *Bambusa bambos* species. The relatively fresh green bamboo was cut into pieces to obtain a strip of 20 mm. Then the strips were woven together to form a grid. These grids were tied together using galvanized steel wire to form a shape which resembles the geocells. The joint distances were maintained so as to give the pocket size of the bamboo cells equivalent to that of commercial geocells used in the study.

The laboratory plate load tests were performed on the soft clay bed reinforced with three types of geocells. Subsequently, numerical simulations were carried out using FLAC^{3D} to compliment the experimental findings. The geocell was modeled realistically by capturing the actual honeycomb shape of the geocells. The foundation soil, infill soil and the geocell materials were assigned with different material models to simulate a real case scenario. Further, using the validated numerical model, the effect of tensile strength, and the surface roughness of the geocell were quantified.

Experimental studies

Fig. 2 shows the schematic representation of the test setup used in the laboratory studies. A cast iron test tank of size 900 mm in length, 900 mm in width and 600 mm in height was used. The tank was connected to the loading frame and which was attached to manually operated hydraulic jack. A steel plate of square in shape with 20 mm thickness and 150 mm sides was used as the footing. The bottom of the footing was made rough by coating a thin layer of sand with epoxy glue. According to Selig and Mckee (1961) and Chummar (1972), the failure wedge below the strip footing on the sand bed will be extended up to a distance of 2–2.5B on either side of the footing and 1.1B (B is the width of footing) below the footing. Similarly, 3-dimensional numerical simulations conducted by Hegde and Sitharam (2015d) have shown that the stresses below the footing are confined to 1.5–2B along the width and about 2B along the depth in the clay beds. Hence, from these observations, it is evident that the tank used in the current investigation is sufficiently large and is not likely to interfere with the failure zones and the experimental results.

Natural clayey soil with specific gravity 2.66 was used to prepare the foundation bed. The liquid limit and the plastic limit of the clayey soil were 40% and 19% respectively. According to Unified Soil Classification System, the soil was classified as clay with low compressibility (CL). Dry sand was used to fill the geocell pockets. As per Unified Soil Classification System, the sand was classified as poorly