Journal of Rock Mechanics and Geotechnical Engineering xxx (2017) 1–8

Contents lists available at ScienceDirect

Journal of Rock Mechanics and Geotechnical Engineering

journal homepage: www.rockgeotech.org

Full Length Article

Utilization of soil nailing technique to increase shear strength of cohesive soil and reduce settlement

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ARTICLE INFO

Article history:
Received 1 March 2017
Received in revised form
28 April 2017
Accepted 25 May 2017
Available online xxx

Keywords:
Cohesive soil
Shear strength
Vertical inclusion
Stiffness
Settlement

ABSTRACT

This article deals with the assessment of the soil nailing technique with a vertical inclusion to improve the geotechnical parameters of cohesive soil. A series of unconfined compression tests and direct shear tests were carried out to establish the stress–strain relationship and strength characteristics of the reinforced clay sample by vertical steel nails. The shear strength performance of the new composite material was tested by varying the number of vertical inclusions, the embedment depth and the alignment radius. The results confirmed that the vertical bars/inclusions shared the vertical applied load with clay. Increase in the number of vertical inclusions significantly increases the shear strength and the stiffness with a remarkable reduction in settlement. When the clay samples were reinforced with six inclusions along the perimeter, the shear strength was increased to 231% for the embedment depth ratio equal to 0.85. To obtain the optimum effect in eliminating shear failure, the vertical inclusions should be extended to a deeper zone with sufficient numbers. It has been found that the vertical inclusions significantly influence the shear strength, and the brittle or general shear failure of the unreinforced sample can be diverted to partial/plastic shear failure.

1. Introduction

Soil nailing technique is one of the most suitable techniques for improving the cohesive soil condition. This approach is assessed as more practical and economical method than other improvement methods such as using modification of foundation aspect. Soil nailing is considered as a practical technique used in slope stabilization by reinforcing the soil with vertical elements. In general, soil effectively resists shear and compression; however, it is very weak against tensile loads. Using soil nailing technique for improving the shear strength of clayey soil has been investigated worldwide by using a variety of reinforced elements. These elements have been added to clay as a reinforced element with closely spaced steel bars, called nail as stated by many researchers (e.g. Maher and Ho, 1994; Indraratna, 1996; Dermatas and Meng, 2003; Casagrande et al., 2006; Freilich et al., 2010; Naeini et al., 2012; Azzam, 2014).

The soil nailing techniques are not suitable to soft clay due to the low cohesion of soft clay which leads to small friction between the ground and soil nails. Fracture grouting technique can be combined with the use of soil nailing technique to improve soft soil properties (Cheng et al., 2009, 2013, 2015). Several testing programs have been carried out to determine the effects of soil nailing on the performance of stabilized clayey soils. The focus was only on the shear strength of the stabilized soil. The scheme of using fibrous or steel bars in a soil skeleton to improve the mechanical properties of clayey soil has become a very accepted technique (Dasaka and Sumesh, 2011; Dutta et al., 2012). The idea of soil reinforcement by using a variety of reinforced elements is a very old procedure and confirmed in nature by the action of tree roots (Waldron, 1977). These elements can withstand tensile stresses that have developed within the soil mass, thus mitigating shear failure. Inclusions or reinforced elements behave as one unit with the soil during friction and adhesion. The used reinforced elements are employed to improve the subgrade soil below the structure and steep slopes and to reinforce the soil around the foundations (Mirzababaei et al., 2013; Chen et al., 2015; Abou Diab et al., 2016). Based on the above notions in the literature, the majority of the published researches about randomly oriented

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Peer review under responsibility of Institute of Rock and Soil Mechanics, Chinese Academy of Sciences.

https://doi.org/10.1016/j.jrmge.2017.05.009

fiber reinforced elements and other materials deal with the reinforcement of granular soil and remolded clay samples. Researchers have made numerous attempts with increasing such element sizes or contents to increase the peak unconfined compressive strength (UCS). In addition, all investigations dealt with improving the remolded clay with discrete reinforced elements which can significantly alter the clay characteristics. Therefore, in field application, using such technique is very costly and needs to excavate large quantities of soils. It is also difficult to remold and mix the resulting soil with proper types of reinforced elements or a given percentage of additives. Therefore, cost saving should be considered by using an alternative technique for improving the clay shear strength. Consequently, application of using contentious vertical inclusions with clay as a reinforced element similar to soil nailing cannot be scrupulously investigated in bulk behavior of the tested clay. Thus, the new suggested technique is based on using soil nailing in the vertical form as an inextensible reinforced element to improve the clay strength.

Soil nailing is a realistic and confirmed technique used in constructing excavations, reinforcing slopes and solving geotechnical foundation problems by reinforcing the ground with relatively small, completely bonded inclusions, typically steel bars (Stocker et al., 1979). The behaviors of slopes and excavations using the stabilization technique by soil nailing have been investigated using a small-scale model and full-scale analysis through case studies in the field or experimental tests (Turner and Jensen, 2005; Wang et al., 2010; Xue et al., 2013; Liu et al., 2014; Seo et al., 2014; Zhang et al., 2014). It is noticed from the results of these studies that installation of soil nails provides considerable changes in soil in the vicinity of nail and improves the shear strength within the soil mass. Dai et al. (2016) mentioned an alternative method using Moso bamboo. The bamboo elements were employed as soil nails and piles using laboratory and field studies. The tests showed that the load capacity of bamboo nails is significantly increased by 250% compared with steel-pipe nails. Garg et al. (2014) introduced a soft computing method called multi-gene genetic programming, which supports vector regression and artificial neural network. It can be used to predict the factor of safety for different soil properties of three-dimensional (3D) soil nailed slopes.

On the other hand, a further potential application of soil nails under foundation was modeled to control the settlement (Kul, 2003). This technique is new and different from the micro-piles utilization. In this application, nails were placed directly in the soil below the foundation without connection to foundation with different spacings and penetration depths. The new nail-soil system shares the load jointly with the foundation. Alternatively, geotechnical engineers face various problems during the installation of the foundations on compressible clayey soil due to lower shear strength and excessive settlement. For these reasons, new and conservative methods are highly needed and searching for innovative techniques is an important aspect in ground improvement. In this article, the application of the soil nailing technique in the vertical form is adopted to improve the shear strength of tested clay samples. This procedure is also considered as a cheaper approach to be used in geotechnical applications, because it does require neither a formwork nor a concrete work. Consequently, a series of both unconfined compression and direct shear tests at different nail/root element lengths and numbers are performed to investigate the mechanical characteristics of such inclusions in the performance of stabilized clay. The stiffness of the clay-nail composite and the obtained failure mechanism are also investigated.

2. Experimental program

2.1. Materials

The soil used in this study is brown-to-gray stiff clay sampled from the Middle Delta of Egypt, and it has a thickness in the range of 7 −12 m. Using mechanical boring, representative clay samples were collected from the same depth of 3 m for all testing program. The tested sample from each borehole was preserved in polyethylene bags to maintain its natural water content. The average properties of the tested clay used for this study were determined at bulk case and tabulated in Table 1. According to USCS classification (ASTM D422-63, 2007), the clay was classified as clay of low plasticity. The mineralogical analysis shows that the smectite is generally dominant in the sediments, with a smaller amount of kaolinite, mica and quartz. Based on the mineralogical analysis using X-ray diffraction (XRD) for the tested samples, the percentages of minerals were found to be 12.5% kaolinite, 74.84% montmorillonite and 12.66% illite.

2.2. Reinforced element/nail model

Steel smooth bars are used as vertical soil nails that are commercially available and act as a vertical inclusion, a nailed element or a model of root piles (Kul, 2003). This inclusion has a diameter of 1.6 mm and varies in length. This element is installed through a clay sample by the pressing technique using an unconfined compression apparatus with a low pressing rate. The guide ring beam is used around the perimeter of the used number of nails to prevent any lateral movement during the installation process. The nails are installed to predetermine the depth and to study the spacing in the bulk clay sample. The clay samples are prepared to be tested in an unconfined compression device by using an excluder to obtain the bulk clay samples, and all the tested samples have a diameter of 38 mm and a length of 76 mm.

2.3. Testing strategy and parameters

The testing program is done to study the influence of using vertical steel nails on the UCS of clayey soil. The unconfined compression test adopted in the current study is a quick and effective test that provides a suitable basis for the comparison between different tested parameters. First, in order to determine the optimum alignment radius (R) for installing the reinforced element, a series of unconfined compression tests is conducted at different alignment radii of $R/R_o = 0.25$, 0.5, 0.7 and 0.8. The sample radius is $R_o = 19$ mm and its height is $L_o = 76$ mm. The test results show that the optimum alignment radius for the arrangement of root elements is found at $R/R_o = 0.7$ due to a higher concentration of stress at the outer edge of the clay sample instead of the center zone characterized by low stress. Therefore, in all test series, the alignment radius is taken as constant at $R = 0.7R_o$. The number of

Table 1
The average bulk properties of the tested clay sample.

Specific gravity	Content (%)			Liquid limit (%)	Plastic limit (%)	Shrinkage limit (%)	Plasticity index (%)	Natural water content (%)	Bulk density (kg/m^3)	UCS (kPa)	USCS classification
	Sand	Silt	Clay								
2.65	0	12	88	45	22	16	23	29	1820	120	CL

Note: USCS means the unified soil classification system.

Please cite this article in press as: Azzam WR, Basha A, Utilization of soil nailing technique to increase shear strength of cohesive soil and reduce settlement, Journal of Rock Mechanics and Geotechnical Engineering (2017), https://doi.org/10.1016/j.jrmge.2017.05.009