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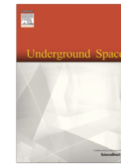

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Experimental study on geosynthetic-reinforced sand fill over marine clay with or without deep cement mixed soil columns under different loadings

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Abstract

Geosynthetics and deep cement mixed (DCM) soil columns have been widely used to improve soft soil grounds in many countries and regions. This paper presents an experimental study on a geosynthetic-reinforced sand fill over marine clay with or without DCM columns under different loadings. Two tests were conducted on the sand fill reinforced with fixed-end and free-end geosynthetics over marine clay under three-stage local loading to investigate the effects of the boundary conditions of geosynthetic reinforcement on reducing settlements. It is observed that the fixed-end geosynthetic sheet is more effective in reducing settlements than the free-end condition under identical local loading. Another test was conducted on the fixed-end geosynthetic-reinforced sand fill over the marine clay improved by DCM columns under single-stage uniform loading. The vertical stresses on the marine clay and on the DCM columns, as well as the tensile strains of the geosynthetic sheet in the overlying sand fill, were measured. The results revealed that the stress concentration ratio increases with an increase in consolidation settlements, and the maximum tensile strain of the geosynthetic sheet occurs near the edge rather than at the center of the top surface of the DCM columns.

Keywords: Settlement; Geosynthetic; Reinforcement; Deep cement mixed soil columns

1 Introduction

Geosynthetics and deep cement mixed (DCM) soil columns have been widely used to improve soft soil grounds for constructions of, for example, highway embankments, seawalls, and building foundations, and also for covering excavated and backfilled trenches. Geosynthetics, such as geotextiles and geogrids, have been widely used for many applications in geotechnical engineering. Geosynthetics are mainly used for reinforcement, filtration, separation, drainage, protection, and as fluid barriers (Shukla & Yin, 2006). The protection function of geotextiles and the erosion behavior of the geotextile revetment under bi-directional cyclic flow were examined by Ho (2007). A physical model test was conducted by Feng, Li, Yin, Chen, and Liu (2019) to investigate the separating effect of geotextile on the interface between Hong Kong marine clay and a sand fill. The effects of the geosynthetic reinforcement on controlling settlement, reducing the required height of granular fill, and enhancing the bearing capacity of soft clay subgrade were studied in both small-scale and large-scale physical model tests (Biswas, Asfaque Ansari, Dash, & Krishna, 2015; Demir, Laman, Yildiz, & Ornek, 2013; El Sawwaf, 2007; Roy & Deb, 2017). However, most of the above studies did not consider the boundary condition influences of the geosynthetic sheet. For geotextile, Espinoza and Bray (1995) indicated that the membrane

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support effect of geotextiles can be developed through not only shear stresses but normal stresses when fixing the edges of geotextiles. Liu, Kong, Li, Ding, and Gu (2008) found that the effect of a free-end geogrid on reducing differential settlements of the soft foundation of an expressway was not significant. Later, a new ground improvement technique involving fixed-geosynthetic reinforcement and pile supports was proposed by Zhang, Zheng, Chen, and Yin (2013). It was revealed that the fixed-geosynthetic reinforcement can reduce both total and differential settlements sufficiently. However, to the best of the authors' knowledge, few studies have directly investigated the influence of boundary conditions on settlement behavior.

The deep mixing technique, which was originally developed in Sweden and Japan, is used to stabilize and modify soil by adding binders, such as lime, cement, or other additives (Hausmann, 1990; Kitazume & Terashi, 2013). Portland cement has been widely utilized to treat marine clay. The mechanical and chemical properties of cement mixed clay have been investigated for decades (Chew, Kamruzzaman, & Lee, 2004; Kamruzzaman, Chew, & Lee, 2006, 2009; Yin & Lai, 1998). Yin and Fang (2006) studied the consolidation behavior of a composite foundation of soft marine clay improved by a deep cement mixed (DCM) soil column by using a small-scale model test. Afterwards, Yin and Fang (2010) investigated the behavior of DCM improved soft clay ground under a rigid footing and observed wedge-shaped block failure. In another study, the bearing capacity and failure mechanism of soft soil improved by DCM columns under both rigid and flexible footings were examined by Rashid, Black, Kueh, and Noor (2015). Although the arching effect in column- or pile-supported embankments has been studied by many scholars (Abusharar, Zheng, Chen, & Yin, 2009; Chen, Chen, Han, & Xu, 2008; Lai, Zheng, Zhang, & Cui, 2018; Russell & Pierpoint, 1997; Zhuang, Wang, & Liu, 2014), the investigation of the loading distribution between soils and reinforcements when considering the fixed-end condition of a geosynthetic sheet can still yield useful results.

In this paper, an experimental study including three physical model tests is presented. The objectives of this experimental study are as follows: (a) to investigate the effect of the boundary conditions of a geosynthetic sheet on reducing the settlements of a sand fill over marine clay, and (b) to monitor the vertical stresses on the marine clay improved by DCM columns and the tensile strain of the geosynthetic sheet in the overlying sand fill. For the first objective, two physical model tests were conducted on a sand fill reinforced by fixed-end and free-end geosynthetics over marine clay under three-stage loading. For the second objective, one physical model test was performed for the sand fill reinforced by a fixed-end geosynthetic sheet over marine clay improved by DCM columns under single-stage uniform loading.

2 Experiment

The details of the three physical model tests (Test 1, Test 2, and Test 3) involved in this experimental study are listed in Table 1. Each physical model was 1 000 mm long, 300 mm wide, and 700 mm tall. Figure 1 shows that the physical model comprises two layers of soils: a subgrade marine clay and an overlying reinforced sand layer. Test 1 and Test 2 were conducted to investigate the effect of different boundary conditions of geosynthetic reinforcement (free-end and fixed-end) on settlement under three-stage local loading. The duration of each stage of loading was three days. In Test 3, which involved DCM columns, uniform loading was applied. The vertical stresses on DCM columns and surrounding clay, as well as the tensile strains of the geosynthetic sheet, were monitored during the test. Four fiber Bragg grating (FBG) sensors were attached to the geosynthetic sheet in Test 3 by using an epoxy resin. The locations of the installed FBG sensors were 0 mm (mid-span, over the surrounding clay), 180 mm (near the edge of the DCM column), 250 mm (over the center of the DCM column), and 400 mm (over the surrounding clay) from the center of the geosynthetic sheet along the length direction of the physical model, as shown in Fig. 1.

Traditional earth pressure transducers, which work based on strain gauges, were used by Yin and Fang (2006) to monitor vertical stresses. Similarly, in Test 3, two earth pressure transducers based on the FBG sensing technique (FBG-EPCs) were utilized to monitor the total vertical stresses on the DCM column and surrounding clay, respectively. The FBG-EPC transducer and FBG sensor are shown in Fig. 2. The earth pressure transducers comprise a stainless-steel cell and an FBG sensor. The FBG sensor was attached to the inside surface of a flexible plate on top of the stainless-steel cell. When the FBG-EPC is installed in soils, the outer surface of the plate will deform under pressure. The deformation of the plate is then transferred to the FBG sensors and changes the wavelength of the sensors, which can be recorded by an interrogator. By calibrating the transducers using water pressure, the relationship between the applied pressure and the wavelength of the FBG sensors can be obtained. A strongly linear relationship is observed between the calibrated pressure and the wavelength change of the FBG -EPCs for both the measured stress over the DCM column and that over the surrounding soft clay, as shown in Fig. 3. The sensitivity of the FBG-EPCs is 0.001 5 nm/kPa.

2.1 Materials

The marine clay used in this study was originally taken from a coastal area near Lantau Island in Hong Kong and reconstituted in a laboratory. The basic properties of the marine clay are as follows: a specific gravity of 2.63, a liquid limit of 57.1%, a plastic limit of 25.2%, and a plasticity index of 31.9 %. The mechanical parameters of the marine