ARTICLE IN PRESS

Geotextiles and Geomembranes xxx (2016) 1–8

Contents lists available at ScienceDirect

Geotextiles and Geomembranes

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

Technical note

Particle size effects on coarse soil-geogrid interface response in cyclic and post-cyclic direct shear tests

J. Wang [a], [b], [c], F.Y. Liu [d], [*], P. Wang [d], Y.Q. Cai [e]

[a] Architecture and Civil Engineering College, Wenzhou University, Wenzhou, 325025, Zhejiang, China
[b] Key Laboratory of Engineering and Technology for Soft Soil Foundation and Tideland Reclamation, Wenzhou University, Wenzhou, Zhejiang, 325035, China
[c] Innovation Center of Tideland Reclamation and Ecological Protection, Wenzhou University, Wenzhou, Zhejiang, 325035, China
[d] Department of Civil Engineering, Shanghai University, Shanghai, 200444, China
[e] College of Civil Engineering and Architecture, Zhejiang University, Hangzhou, Zhejiang, 310012, China

ARTICLE INFO

Article history:
Received 23 September 2015
Received in revised form
12 April 2016
Accepted 30 June 2016
Available online xxx

Keywords:
Geosynthetics
Cyclic direct shear
Reinforced soil
Geogrid
Post-cyclic behavior

ABSTRACT

The interface shear behavior of soil against geosynthetic is important in the design of geosynthetic-reinforced soil structures. This study involves the use of a series of Monotonic Direct Shear (MDS) tests, Cyclic Direct Shear (CDS) tests and Post-cyclic Direct Shear (PCDS) tests to investigate the coarse silica soil-geogrid interface monotonic and cyclic shear behavior. In particular, the influence of cyclic shear on the interface monotonic behavior is analyzed in detail. The effect of soil particle size on interface cyclic and post-cyclic shear behavior is examined and discussed. The results indicate that in cyclic direct shear, the interfaces exhibit cyclic hardening, the interface damping ratio decreased with increasing cycle number and soil relative density, and an interface with a larger particle size has a higher contraction value. In the monotonic condition, the shear stress–displacement curves exhibit post-peak strain softening behavior, and the apparent adhesion and friction angle at the interface both increased with increasing soil particle size. Cyclic shear increased the apparent adhesion at the interface and intensified the soil dilatancy.

1. Introduction

Construction of reinforced soil structures, such as reinforced soil slopes, reinforced retaining walls and reinforced embankments, has increased significantly worldwide. The behavior of reinforced soil structures is largely governed by interaction mechanisms that develop between the reinforcement inclusions and the backfill soil (Teixeira et al., 2007). This mechanism is influenced not only by the geosynthetic properties, soil properties, loading conditions and rate of deformation but also by the method of testing (Sayeed et al., 2014). Different types of laboratory tests have been developed during the past several decades to improve the understanding of the soil-geosynthetic interaction. These methods include direct shear tests (Bergado et al., 2006; Anubhav and Basudhar, 2010; Ferreira et al., 2015), pull-out tests (Abdi and Arjomand, 2011; Ezzein and Bathurst, 2014; Hatami and Esmaili, 2015; Bathurst and Ezzein, 2016), plane strain tests (Peng et al., 2000; Hou et al., 2011; Liu et al., 2014; Carbone et al., 2015), inclined plane tests (Pitanga et al., 2009; Briançon et al., 2011), and torsional ring shear tests (Tan et al., 1998; Hillman and Stark, 2001; Eid, 2011). Among the above methods, the direct shear test is one of the most important and commonly used techniques to study the behavior at the interface between the soil and the reinforcement.

Abundant works on the direct shear behavior of soil-geosynthetic interfaces under static conditions can be found in the literature (Athanasopoulos, 1996; Lee and Manjunath, 2000; Bergado et al., 2006; Abu-Farsakh et al., 2007; Liu et al., 2009a, 2009b; Khoury et al., 2011; Vangla and Gali, 2016). Nevertheless, to ensure the stability and safety of reinforced soil structures under earthquake, blast, or other man- or machine-induced vibrations, the cyclic direct shear behavior of soil-geosynthetic interfaces must be considered. Compared to the interface static shear behavior, studies focused on the interface cyclic shear behavior are very limited. O'Rourke et al. (1990) evaluated the dynamic properties of the sand–polymer interface by conducting several cyclic direct shear tests, indicating that no significant changes were found in the interface shear resistance with repeated loading at relatively low normal stress levels. Nye and Fox (2007) investigated the dynamic internal shear behavior of a hydrated needle-punched geosynthetic clay liner through monotonic and cyclic displacement-controlled

---

[*] Corresponding author. Fax: +86 21 66133265.
E-mail address: lfyzju@shu.edu.cn (F.Y. Liu).

http://dx.doi.org/10.1016/j.geotexmem.2016.06.011
0266-1144/© 2016 Elsevier Ltd. All rights reserved.

Please cite this article in press as: Wang, J., et al., Particle size effects on coarse soil-geogrid interface response in cyclic and post-cyclic direct shear tests, Geotextiles and Geomembranes (2016), http://dx.doi.org/10.1016/j.geotexmem.2016.06.011

direct shear tests. Ling et al. (2008) studied the interaction behavior of a sand-clay mixture geogrid interface under monotonic and cyclic direct shear conditions. In this case, the applied effective shear area acted on a very small area of 100 mm × 100 mm; and the strength of the soil-geogrid interface was not significantly affected by cyclic loading. However, test results may be affected by the size of the apparatus. In fact, previous studies (Palmeira and Milligan, 1989a,b) have shown that the size of the apparatus can significantly influence the tests results. As the majority of dynamic problems involve large shear displacement, large-scale direct shear tests are more representative. Fox et al. (2011) studied interface damage effects due to static pressure, cyclic loading and large-displacement static shear by a series of large-scale direct shear tests on multi-interface geomembrane liner specimens. Vieira et al. (2013) presented the results from displacement-controlled monotonic and cyclic large-scale direct shear tests to specifically characterize the shear properties of the sand–geotextile interface.

Geogrid has been successfully used for reinforcing different types of soils under various conditions. Geogrids are geosynthetic products with comparatively large apertures, which are characterized by a combination of transverse and longitudinal ribs. The size of soil particles relative to the grid apertures has a significant influence on the size of the rupture zone. Hence, it is essential to clarify the influence of soil particle size on the interface direct shear behavior, especially under cyclic conditions. In this study, a series of MDS tests, CDS tests and PCDS tests were conducted using a large-scale direct shear test device. The influences of soil particle size on monotonic and cyclic shear behavior of the interface were investigated; in particular, the influence of cyclic shear on interface monotonic behavior was analyzed.

2. Materials and experimental program

2.1. Testing apparatus

The direct shear test device used in the current study is the ShearTracIII Large-scale Direct Shear device designed and built by Geocomp following ASTM standard D 5321. The shear box consists of an upper box with the dimensions 305 mm × 305 mm in plan and 100 mm in height, and a lower box with 305 mm × 405 mm in plan and 100 mm in height. The upper box is fixed in the horizontal direction, while the lower box moves horizontally, driven by electric motors. The device can apply static shear as well as cyclic shear, which are either load-controlled or displacement-controlled. However, due to the limitation of the device, it can only perform no more than 10 cycles of cyclic shear. In this study, displacement-controlled constant contact area shear tests were performed. The shear rate was controlled by means of a high-accuracy electric apparatus, varying from 0.00003 mm/min to 15 mm/min. The horizontal and vertical displacements were recorded by a Linear Variable Differential Transformer (LVDT) with a maximum measurement of 100 mm. The horizontal and vertical displacements indicated in this paper refer to a lower shear box displacement and the rigid plate displacement, respectively. The vertical stress was applied to the soil by the rigid plate through a hydraulic actuator and a rigid frame. All of the measurements presented in this study were obtained and recorded digitally.

2.2. Test materials

The test soil is a coarse silica soil with a specific gravity (G_s) of 2.65. To investigate the cyclic and post-cyclic shear behavior of the soil-geogrid interface for different particle sizes, the coarse soil was divided into four classes by screening according to the grain size. The particle sizes (diameter) of the four classes are: S1 (0.5 mm – 1 mm), S2 (1 mm – 2 mm), S3 (2 mm – 4 mm) and S4 (4 mm – 8 mm). The particle size distribution curve of the soils is presented in Fig. 1. The soils were classified as poorly graded sand (SP) and poorly graded gravel (GP), according to the Unified Soil Classification System (USCS). The geogrid used was a bi-directional polypropylene geogrid. The properties of the geogrid are listed in Table 1.

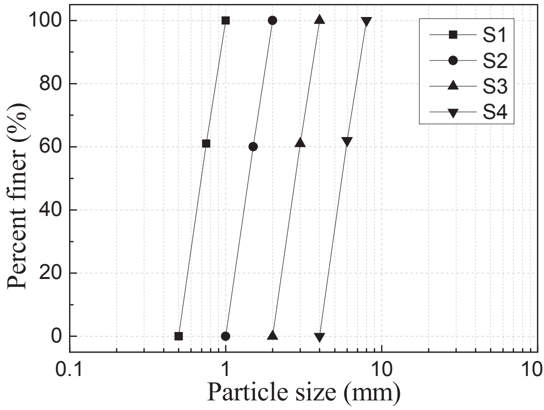

Fig. 1. Particle size distribution curves for the test soils.

2.3. Test procedures

As per ASTM D 5321, the shearing rate was designated as 1 mm/min for all the tests. The soils were air dried and then placed inside the shear box in five 20-mm-thick layers to the target unit weight. As four different soils are considered, their soil parameters, such as soil unit weight, differ from each other, which may affect the soil-geosynthetic interface behavior. To minimize this effect, the four soils were placed in the shear box with the same relative density (Dr) via tamping with a square metal plate. Geogrid specimens were secured with screws at the front and rear edges of the lower box outside the shear area. To examine the cyclic and post-cyclic direct shear behavior on the soil-geogrid interface under different conditions, a series of MDS tests, CDS tests and PCDS tests were performed.

The MDS tests were conducted at normal stresses of 30, 60 and 90 kPa, with a soil relative density of 55%. Fig. 2a shows that the tests started from the equilibrium position, following path ①, and were complete when the shear displacement reached a value of 40 mm.

In the CDS tests, as seen in Fig. 2a, the lower shear box moved from the equilibrium position following the shear paths ①—②—③—④, which were defined as one loading cycle. The waveform of the cyclic load is shown in Fig. 2b, where T represents the time for a total shear cycle. The tests were terminated when the target cycle number (N) was reached. The influences of the soil particle size (d) and the soil relative density (Dr) on the cyclic shear behavior of the interface are discussed.

The PCDS tests were conducted after the completion of CDS tests on the same soil sample. After the CDS test was finished, the normal stress applied to the sample was unloaded and reloaded to the target value of the PCDS test. The PCDS tests started from the equilibrium position, following path ①, and then completed when the shear displacement reached a value of 40 mm.

3. Cyclic direct shear results

The cyclic direct shear tests presented in this paper were performed with a normal stress of 60 kPa, a displacement semi-amplitude (Δa) of 3 mm and a shear rate of 1 mm/min. In the

Please cite this article in press as: Wang, J., et al., Particle size effects on coarse soil-geogrid interface response in cyclic and post-cyclic direct shear tests, Geotextiles and Geomembranes (2016), http://dx.doi.org/10.1016/j.geotexmem.2016.06.011