Geotextiles and Geomembranes xxx (2017) 1–14

Contents lists available at ScienceDirect

Geotextiles and Geomembranes

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

Technical note

Microstructural investigation on mechanical behavior of soil-geosynthetic interface in direct shear test

P. Punetha [a], P. Mohanty [b], M. Samanta [b, *]

[a] Academy of Scientific and Innovative Research, CSIR-Central Building Research Institute, Roorkee, 247667, Uttarakhand, India
[b] Geotechnical Engineering Group, CSIR-Central Building Research Institute, Roorkee, 247667, Uttarakhand, India

A R T I C L E I N F O

Article history:
Received 14 August 2016
Received in revised form
17 January 2017
Accepted 10 February 2017
Available online xxx

Keywords:
Geosynthetics
Direct shear test
Interface shear strength
Image analysis
FESEM

A B S T R A C T

Interface shear strength between soil and geosynthetics mainly depends on the mechanical and physical properties of soil, geosynthetics and the normal stress acting at the interface. This paper presents results of an extensive experimental investigation carried out on sand-geosynthetic interface using modified large direct shear box. The study focusses on the shearing mechanism at the sand-geosynthetic interface and the effect of different parameters on the shearing mechanism. Smooth HDPE geomembrane, nonwoven needle punched geotextile and two types of sand having different mean particle size, have been used in the present study. Microstructural investigation of deformed specimen through Field Emission Scanning Electron Microscope (FESEM) reveals the shearing mechanism which includes interlocking and fiber stretching for sand-geotextile while sliding, indentation and plowing for sand-geomembrane interface. The shearing mechanism for sand-geomembrane interface highly depends on the normal stress and degree of saturation of sand. The critical normal stress that demarcates the sliding and plowing mechanism for sand-geomembrane interface is different for dry and wet sand. The amount of scouring (or plowing) of the geomembrane surface reduces with increase in the mean particle size of sand. FESEM images revealed that the sand particles get adhered to the geotextile fibers for tests involving wet sands. The present microstructural study aided in understanding the shearing mechanism at sand-geosynthetic interface to a large extent.

1. Introduction

Geosynthetics are polymeric materials, used for several applications including filtration, drainage, protection, separation, slope-stabilization, soil-reinforcement etc. (Giroud, 1984). All the properties of geosynthetics, except the interface shear strength (which depend upon the properties of the material in contact with the geosynthetic), can be controlled during the manufacturing process. Till now, there is no means to visualize (observe) the interaction mechanism at the interface during the shear test.

The interface study becomes more important as it has been found that the interface shear strength between soil and geotextile or geomembrane is less than the shear strength of soil alone (Gao et al., 2010; Koerner, 2012). The need to study the interface behavior got reinforced after the failure of Kettleman Hills Class 1 hazardous landfill (Mitchell et al., 1990; Koutsourais et al., 1991; Bergado et al., 2006). Large scale direct shear tests, inclined plane and ring shear tests are most commonly used to determine the interface properties. Several studies on interface friction between soil–geosynthetics have been carried out under different conditions (Martin et al., 1984; Saxena and Wong, 1984; Williams and Houlihan, 1987; Negussey et al., 1989; Garg and Saran, 1990; Athanasopoulos, 1993; Giroud et al., 1993; Orman, 1994; Alfaro et al., 1995; Blümel and Brummermann, 1996; Gilbert and Byrne, 1996; Bouazza, 1998; Tan et al., 1998; Frost et al., 1999; Ling et al., 2001; Lopes et al., 2001, 2014; Liu et al., 2009; Zhang and Zhang, 2009; Anubhav and Basudhar, 2010, 2013; Fuggle and Frost, 2010; Kwak et al., 2013; Vieira et al., 2013, 2015; Fox et al., 2014; Moraci et al., 2014; Sayeed et al., 2014; Choudhary and Krishna, 2016).

Physical properties of soil such as angularity, particle size, relative density and degree of saturation affect the interface shear strength to a large degree (Izgin and Wasti, 1998; Frost et al., 2002; Fleming et al., 2006; Khoury et al., 2010, 2011; Esmaili et al., 2014; Ferreira et al., 2015; Hatami and Esmaili, 2015; Vangla and Latha, 2015, 2016a). The testing condition also plays an important role

* Corresponding author.
E-mail addresses: punetha.piyush@yahoo.in (P. Punetha), pyushmohanty@gmail.com (P. Mohanty), manojit_samanta@rediffmail.com (M. Samanta).

http://dx.doi.org/10.1016/j.geotexmem.2017.02.001
0266-1144/

in the interface behavior (Hsieh and Hsieh, 2003). A large scattering in various test data is usually observed due to differences in the device and testing conditions (Blümel et al., 2000). Despite several attempts to investigate the effect of different testing conditions and physical properties of soil on the interface behavior, a very few of them investigated the effect of different parameters on the shearing mechanism at the interface.

It is very crucial to understand the failure mechanism at the soil-geosynthetic interface. Though, it is difficult to visualize (observe) the mechanism during the shearing, the deformed specimens after the test can be used for the micro level investigations. These micro level investigations could possibly aid in enhancing the knowledge regarding the interface behavior of soil and geosynthetic. Very few researchers have tried to study the interface behavior at the micro level (Vaid and Rinne, 1995; Dove and Frost, 1999; Zettler et al., 2000; Frost and Lee, 2001; DeJong and Westgate, 2005; Dove et al., 2006; Vangla and Latha, 2016b). O'Rourke et al. (1990) observed the polymeric sheets with different surface hardness using SEM before and after the direct shear tests to understand the shearing mechanism of sand-polymer interface. They reported the skidding and rolling of sand particles over the polymer surface as the main mechanism for polymeric sheets with high and low surface hardness respectively. Stark et al. (1996) observed significant wearing, tearing and pulling of nonwoven geotextile fibers after interface tests with textured geomembrane. Lee and Manjunath (2000) observed the alignment of fibers in the direction of shear in case of nonwoven geotextiles while physical damage was observed in woven geotextiles after direct shear tests with sand. Afzali-Nejad et al. (2017) observed wearing and tearing in woven geotextile fibers after the direct shear tests.

Thus, a large number of experimental studies have been carried out to investigate the interface behavior of soil-geosynthetics at different conditions over the years. But limited studies have been carried out to understand the deformation mechanism of geosynthetic interfaces through microstructural investigations. In the present study, about 120 large-scale interface direct shear tests have been performed using sand and two types of geosynthetics (HDPE geomembrane and nonwoven geotextile). The effects of different physical properties of sand, including relative density, degree of saturation, mean particle size (D_{50}) and testing conditions such as shearing rate have been investigated. After each test, the deformed microstructures of geomembrane and geotextile specimens were studied using Field Emission Scanning Electron Microscope (FESEM) to understand the failure mechanism at the interface. An attempt has been made to correlate the results obtained from the interface direct shear tests and the observations made in the microstructural study. The aim of the present study is to understand the shearing mechanism at the interface and the effect of different parameters on the shearing mechanism through microstructural study of deformed geosynthetic specimens using FESEM.

2. Materials used

2.1. Sand

2.1.1. Classification and properties

Two different types of river sands (Solani River sand (S1) and Yamuna River sand (S2)) were used to conduct the direct shear tests. Sands of different grain size distribution were used to study the effect of mean particle size (D_{50}) on interface behavior of geosynthetics. The properties of the sands are given in Table 1. The grain size distribution curves of the two sands are presented in Fig. 1(a). Both the sands are classified as poorly graded sands (SP) as per IS Classification System (IS 1498).

2.1.2. Morphology of sand

The particle morphological analysis was conducted to determine the angularity and circularity using image analyzer. First, the sand was sieved and the percentage of sand retained on each sieve was calculated. About 50 particles of sand retained on each sieve were taken and angularity along with circularity of each particle was determined (Vangla and Latha, 2016a). Average and standard deviation of angularity and circularity of all the particles was then calculated. The morphological properties of the sands are given in Table 2. The images were taken with the help of an image analyzer with a scale of 0.65 μm/pixel in X-direction and 0.7 μm/pixel in Y-direction. The images were then analyzed using ImageJ free software. Angularity and circularity of sand particles were calculated using the following relationship (Vangla and Latha, 2015):

$$\text{Angularity} = \left(\frac{P_c}{P_e}\right)^2 \tag{1}$$

Where P_c = convex hull perimeter of particle.

P_e = perimeter of equivalent ellipse having same area and aspect ratio of particle.

$$\text{Circularity or Sphericity} = \left(\frac{4\pi A}{P^2}\right)^{0.5} \tag{2}$$

Where A = area of profile of particle projection.

P = perimeter of particle.

It must be noted that the 2-D image analysis has been carried out in the present study and therefore circularity should be the appropriate parameter rather than sphericity. However, both are synonymous and can be used interchangeably. Fig. 1(b) and (c) show the image of the sand particles taken from image analyzer and the procedure used for morphological analysis in which the image of the particles along with the equivalent ellipse, having the same area and aspect ratio is depicted.

2.2. Geomembrane

Smooth HDPE geomembrane (GM) (1.5 mm thick) was used in the present study. Table 3 shows the properties of geomembrane used in the study.

2.3. Geotextile

Nonwoven, needle punched geotextile (GT) (1.5 mm thick) was used in the present study. Table 4 shows the properties of geotextile used in the study.

3. Interface shear test

3.1. Testing apparatus

Large size modified direct shear box is used to study the sand-geosynthetic interface behavior. Dimensions of the shear box are 300 mm × 300 mm x 200 mm. The box is divided into two halves with upper half fixed and lower half movable. Size of the direct shear box is greater than 15 times D_{85} (0.42 mm and 1.25 mm) of sands used in the study and greater than five times the opening size of geosynthetics (0.085 mm for geotextile). The depth of each half is greater than six times the maximum particle size. Thus the box dimensions meet the minimum requirements specified in ASTM D 5321. Both the upper and lower halves of the box are of same size. The large container surrounding the box restricted the maximum

Please cite this article in press as: Punetha, P., et al., Microstructural investigation on mechanical behavior of soil-geosynthetic interface in direct shear test, Geotextiles and Geomembranes (2017), http://dx.doi.org/10.1016/j.geotexmem.2017.02.001