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Shear behavior of sand-smooth geomembrane interfaces through micro-topographical analysis

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A R T I C L E I N F O

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A B S T R A C T

Quantitative measurement of induced surface changes in the geomembranes by sliding and plowing of sand particles during shear is highly beneficial for understanding the macro stress–strain response of non-dilative interface systems. This paper presents large scale direct shear and interface shear tests with a smooth geomembrane performed on sands of varying particle sizes and morphology at different normal stresses. Three sands of different particle sizes and same morphology and two sands of same size but dissimilar morphologies were used in the experiments to understand the individual effects of particle size and morphology on the interface shear behavior. The morphological properties of sands including roundness, sphericity and regularity were determined by image analysis. An advanced 3D optical profilometer was used for micro-topographical analysis of geomembrane surfaces before and after the test. Results from interface shear tests supported by surface roughness studies revealed that interface friction angle depends on the effective contacts formed on the surface of the geomembrane. Morphology of the sands was found to have major influence on the interface shear strength among all the parameters investigated. Increase in angularity of sand particles caused deeper grooves on the surface of the geomembrane, resulting in higher shear resistance at the interface. The shearing mechanism at the interface changed from sliding to sliding plus plowing beyond the critical normal stress of 53 kPa.

1. Introduction

The interface shear mechanism of geosynthetics and sand particles governs the design of systems involving continuous interaction of sand and geosynthetics. The composite liner systems in a landfill consists of soil–geomembrane interfaces involving a variety of soils. Sand–geomembrane interfaces are very common at the boundary of a drainage layer and the next layer of clay moisture barrier (Bhatia and Kasturi, 1996; Scheirs, 2009) and in landfill capping systems (Touze-Foltz et al., 2009). These interfaces become potential planes of weakness unless adequate friction is developed to resist the shear. Also the stability of mechanically stabilized soil structures depends on the shear of earth materials over relatively smooth manufactured surfaces (Dove and Frost, 1999). Understanding the fundamental physics of the interaction at the soil–geosynthetic interfaces can lead to the development of precise design methods and soil-structure interaction models. Several studies are available in literature on the shear behavior of sand–geosynthetic interfaces, however the studies specific to sand–geomembrane interfaces are limited. Most of the available studies are on dilative interfaces (Jewell et al., 1984; Lopes and Lopes, 1999; Palmeira, 2009; Liu et al., 2009; Hossain et al., 2013; Ezzein and Bathurst, 2014; Sayeed et al., 2014), where geosynthetics typically have surface asperities or apertures. Soil–geomembrane interfaces are non-dilative, because the surface of the geomembrane is smooth without asperities. The interaction mechanisms involved in dilative and non-dilative interface shear are different. The shear resistance offered in case of dilative interface is mainly due to the interlocking between the soil particles and surface asperities of the geosynthetic material (Athanasopoulos, 1993; Biabani and Indraratna, 2015). Smoothness of the geomembrane surface and its relative hardness compared to the sand particle hardness govern the dominant mechanisms at the interface, namely, rolling, sliding and plowing (O'Rourke et al., 1990; Dove and Frost, 1999). Understanding of shear behavior of non-dilative interfaces requires study of fundamental aspects that

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govern the sliding and plowing of soil particles on the surface of the geomembrane at a micro level.

Earlier studies on sand–geomembrane interfaces demonstrated that size and morphology of particles, initial void ratio and packing, normal stress and hardness of the continuum geosynthetic material are the parameters that have major influence on their shear behavior. Through a series interface direct shear tests with Ottawa 20/30 and smooth HDPE geomembrane, Dove and Frost (1999) showed that the interface friction coefficient is highly influenced by the normal stress. These tests revealed a critical normal stress, at which the contact stress per particle becomes more rather than the number of particles contacting the surface, showing a clear phase transition from predominantly sliding to predominantly plowing. These findings were well supported by the post shear roughness studies carried out on the geomembrane sample using a stylus profilometer. Fuggle (2011) also investigated the effect of normal stress and particle size using three different sands (D_{50} ranging from 0.78, 0.28 and 0.13 mm) and three different binary mixtures through interface direct shear tests. These studies concluded that particle size as well as the mixing proportions of sand samples play a significant role in influencing the interface friction angle and the critical normal stress level. Since the sands used in this study had different morphology (roundness, angularity and sphericity), the results included the effect of morphology along with the effect of particle size. Zettler et al. (2000) identified that the angularity of the sand particles is as important as normal stress, especially for the interfaces where the shearing resistance is predominantly due to plowing. Quantitative study carried out by Frost et al. (2012) on surface changes induced by the propensity of angular sands demonstrated that plowing on smooth geomembrane can be directly related to the angularity of sand particles and the normal stress. Angular sand particles are capable of indenting deeper grooves on the surface of smooth geomembrane and hence they offer higher interface shear strength compared to sub-rounded and rounded sand particles. The depth of indentation on the geomembrane further depends upon the normal stress applied.

Not many studies are available on the effect of particle morphology on sand–geomembrane interfaces. Also, in most of the studies, the effect of particle morphology is masked by the effect of particle size as these parameters are not studied independently. In the present study, effect of particle size and morphology were studied separately, by carefully scalping the sand samples. Three sands of different sizes with similar morphology were used to investigate the effect of particle size alone. The effect of morphology was studied by carrying out tests on two sands having same particle size and dissimilar morphological properties. Studies were also carried out to understand the influence of normal stress on the interface shear behavior. Micro topographical analyses were carried out on the sheared geomembrane samples to understand the fundamental mechanisms contributing to the shear resistance of the non-dilative interfaces. In the present study, non-contact 3D optical profilometer is used for surface roughness measurements, which offers several advantages over the traditional methods like stylus profilometer and optical profile microscopy, including the elimination of surface damage, increase in accuracy and increased measurement speed.

2. Materials used

2.1. Sands

Four different sands were used in this study, namely, fine sand (FS: particle size 0.425 mm–0.075 mm), medium sand (MS: particle size 2 mm–0.425 mm), coarse sand (CS: particle size 4.75 mm–2 mm), and angular coarse sand (ACS: particle size 4.75 mm–2 mm). All these sands are classified as poorly graded sands (SP) as per Unified Soil Classification System. Among them, three sands CS, MS and FS were obtained by scalping specific size fractions from a river sand. The angular coarse sand (ACS) was obtained from a local quarry. The grain size distribution of these four sands is presented in Fig. 1. Table 1 presents the properties of these sands. A photograph showing the physical appearance of these sands is given in Fig. 2. Coarse and angular coarse sands used in this study have same particle size range.

The geometry and shape of sand grains are represented by morphological characteristics. Some of the morphological properties selected for this study are roundness, sphericity and regularity of the sand grains. These properties for all four sands used in this study were quantified through image analysis. The image analysis of the particles involves conversion of Scanning Electron Microscopic (SEM) images into binary images and extraction of the pixel information to obtain the geometrical information of the particles as per the formulae given by earlier researchers, as shown in Table 2. Image analysis is carried out using MATLAB by writing a special algorithm for this purpose. To quantify the above mentioned morphological characteristics, SEM images of 50 particles were used for each sand type. The values of roundness, sphericity and regularity obtained from the image analysis for all four sands are presented in Table 2. It is observed from Table 2 that the roundness, sphericity and regularity of Coarse Sand (CS), Medium Sand (MS), and Fine Sand (FS) were almost same, indicating similar morphology of these sands. Whereas Angular Coarse Sand (ACS) has obtained different morphological properties compared to other three sands, indicating that ACS has dissimilar morphology. Visual observation of sands presented in Fig. 2 confirms the fact that the morphology of CS, MS and FS is similar and ACS looks less rounded, less spherical and less regular. The morphological classification of sands was done as per ASTM D2488-09a. According to the visual chart of ASTM D2488-09a. CS, MS and FS are classified as sub-angular sands and ACS is classified as angular sand.

2.2. Geomembrane

A smooth high density polyethylene geomembrane (GM) which is commercially available and more often used in engineering applications due to its more favorable properties like high tensile strength at low strains is used in this study. The properties of this geomembrane given by manufacturer are presented in Table 3.

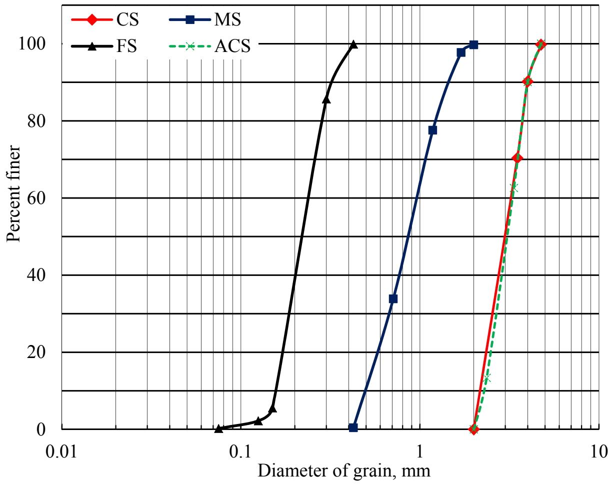

Fig. 1. Grain size distribution of sands used in this study.