Geotextiles and Geomembranes 44 (2016) 278–286

Contents lists available at ScienceDirect

Geotextiles and Geomembranes

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

Assessment of friction properties at geotextile encapsulated-sand systems' interfaces used for coastal protection

Andreia Moreira*, Castorina Silva Vieira, Luciana das Neves, Maria Lurdes Lopes

Department of Civil Engineering, Faculty of Engineering, University of Porto, R. Dr. Roberto Frias, 4200-465 Porto, Portugal

ARTICLE INFO

Article history:
Received 21 June 2015
Received in revised form
8 November 2015
Accepted 24 December 2015
Available online 21 January 2016

Keywords:
Geosynthetics
Cyclic loading
Shear strength
Shear testing
Sandbags
Coastal protection

ABSTRACT

Friction properties at geotextile interfaces play an important role in the stability of geotextile encapsulated-sand systems in coastal protection. The stabilising action of the frictional force is important to oppose sliding along the contact surface and to prevent deformations, which may lead to structural failures. This paper presents a set of experiments, based on large-scale direct shear tests performed under both cyclic loading and cyclic displacement conditions, examining friction at interfaces between geotextile specimens, sand-filled geosystem elements, and between a sand layer and a sand-filled geosystem element. The results presented here indicate that the friction parameters (i.e., shear strength and friction angle) derived from geotextile specimens are below those obtained for sand-filled elements, which suggests that using the former for the stability analysis is conservative. The tests carried out with a sand layer surface showed that a modification to the shear plane slope is likely to occur – for the sand-filled geosystem element buries into the sand layer. This deformation can result in toe instability, ultimately leading to progressive damage or even collapse of the entire structure.

1. Introduction

The use of geotextile encapsulated-sand systems in coastal engineering has grown significantly since its first application in the 1970s (Hornsey et al., 2011), yet, in this context, it is still considered to be innovative. The main obstacle in their wider application is the lack of understanding about key aspects of design (see, Pilarczyk, 2000; and das Neves, 2011) – for the design of geosystems is often based on rather vague experience than on generally accepted calculation methods, as very little systematic research is available on this topic. A few exceptions are Oumeraci and Recio (2009); van Steeg and Breteler (2008); van Steeg and Vastenburg (2010); das Neves (2011); Dassanayake (2013); and das Neves et al. (2015).

The stability of sand-filled geosystems under wave loading depends, among others, on the shape of the element (and thus the deformation), for which the degree of filling, the properties of the filling material, and the properties of the element fabric are also important – as shown by Recio (2007), van Steeg and Vastenburg (2010), and Dassanayake and Oumeraci (2009), and on the structural connections in a multilayer element structure. Research by Dassanayake and Oumeraci (2012) suggests that the contribution of friction between sand-filled elements for the hydraulic stability is still not fully clarified – for it has been little investigated. It mainly depends on variables such as the geotextile material itself (both the short term and the long term properties), contact area between elements, sand fill ratio and overlapping length (Dassanayake and Oumeraci, 2012). A number of stability formulae have been derived based on the available research results into the stability of geosystems under wave loading, of which the ones proposed by Recio (2007) and by van Steeg and Vastenburg (2010), consider the contribute of the friction coefficient between elements. However, the stability relations can be more complicated than the simplifications and limits of application assumed in those formulations are, furthermore it should be beared mind that some important parameters for stability change in time due to deformation.

Until recently, most of the available data to assess the friction between sand-filled elements was obtained from direct shear testing on geotextile specimens (see, e.g., Moreira et al., 2013; and Moreira et al., 2014) rather than on sand-filled geosystems directly. Since most of the studies focused only on the friction behaviour of geotextile–geomembrane, geotextile–geonet and geomembrane–geonet interfaces (see De and Zimmie, 1998), there are relevant limitations. A number of new research have appeared in recent years focussing on the study of the friction properties at

* Corresponding author. Tel.: +351 916 307 331.
E-mail addresses: ammoreira@fe.up.pt (A. Moreira), cvieira@fe.up.pt (C.S. Vieira), lpneves@fe.up.pt (L. das Neves), lcosta@fe.up.pt (M.L. Lopes).

http://dx.doi.org/10.1016/j.geotexmem.2015.12.002

sand–geotextile interfaces (see Vieira et al., 2013) and sand/soil bags' interfaces by means of direct shear tests and vertical compression tests (see Krahn et al., 2007; Matshushima et al., 2008; Lohani et al., 2006; and Aqil et al., 2006). Krahn et al. (2007) concluded that the interface shear strength between sandbags tends to be larger than that deduced from geotextile specimens.

A different relative shear movement (with respect to the direct shear test), was investigated in Dassanayake and Oumeraci (2012), with the performance of pullout tests to study the effect of the sand fill ratio and of the friction properties on the pullout forces of geotextile sand containers constructed of woven and non-woven geotextile materials. According to their results, both types of geotextile sandbags exhibit relative friction forces more than 30% higher than the theoretical relative friction forces of the geotextile materials based on direct shear tests. Moreover, there is a clear difference in pullout resistance, which is roughly proportional to the friction coefficients. Ansari et al. (2011) conducted a numerical analysis to investigate the performance of granular materials wrapped on polyethylene bags under vertical compression and cyclic shearing. Despite some noteworthy research, further investigation is needed to establish a relationship between direct shear testing of geotextile–geotextile interfaces and the friction between sand-filled elements.

In this paper, an experimental study carried out at the Geosynthetics Laboratory (LGS) of the Faculty of Engineering of the University of Porto (FEUP) is presented. The study is part of a larger research program on the stability analysis of geotextile encapsulated-sand systems under wave loading, with focus on scour development. It is based on direct shear testing carried out under cyclic loading and cyclic displacement conditions. Interfaces between geotextile specimens and sandbags were considered. The tests performed on geotextile specimens aim at characterising the friction properties of the geotextile material itself, whilst the tests carried out on sandbags assess the friction on a more complex interface, because of the additional potential for surface deformation. Sand-geotextile interfaces, simulating the interface at the structures' foundation were also tested. The influence of frequency and amplitude of load variation and continuous cyclic shear on the friction behaviour are addressed herein.

2. Experimental study

2.1. Device and test materials

The direct shear device used in the experiments was designed and built at FEUP. It consists of a shear box, a support structure, five hydraulic actuators and respective fluid power unit, an electrical cabinet, internal and external transducers and a dedicated computer (Vieira et al., 2013). The upper shear box is 0.3 m wide, 0.6 m long and 0.15 m high and is fixed in the horizontal direction. The lower shear box dimensions are 0.34 m in width, 0.8 m in length and 0.10 m in height. It is seated on a set of rollers that allow the shear displacement. A rigid base can be inserted in the lower box to make the apparatus suitable for direct contact-area shear testing. If a rigid ring is put in place, a reduced-contact-area (0.3 m × 0.6 m) is achieved. Fig. 1 presents a general view of the equipment.

The following materials were used in the testing: a needle-punched non-woven (NW) geotextile; two woven geotextiles (W and Wp); and silicate sand (D_{50} = 273 μm; ρ_s = 2550 kg/m^3). Relevant properties of the geotextile materials are listed in Table 1. The non-woven geotextile (NW) and one of the wovens (W) have been used in the physical model testing of encapsulated-sand systems under wave loading within the current research project and past research (e.g., das Neves, 2011 and das Neves et al., 2015). The other woven geotextile (Wp) is commonly used in geosystems for coastal protection. Interfaces are as follows (refer to Fig. 2):

- NW-NW: interface between two non-woven geotextile specimens;
- W-W: interface between two woven geotextile specimens;
- Wp-Wp: interface between two woven geotextile specimens (prototype material);
- NWb-NWb: interface between sandbags (non-woven geotextile as container);
- NW-sand: interface between a non-woven geotextile specimen and a sand layer; and
- NWb-sand: interface between a sandbag (non-woven geotextile as container) and a sand layer.

In the tests with geotextile specimens a rigid base is placed inside the lower shear box and the specimens are gripped to the upper and lower boxes, outside of the shear area, by screwed rigid bars (Fig. 2). The upper shear box is then filled with a 5 cm thick sand layer. Tailor-made sandbags are placed in the upper shear (one sandbag with 0.3 m × 0.6 m dimensions) and the lower shear (two sandbags with 0.4 m × 0.34 m dimensions) boxes (Fig. 3). Chosen configuration of sandbags simulates the overlapping effect in sloped structures. In the lower shear box, the sandbags are positioned so to carefully adjust the alignment of the interface with the shear plane of the test apparatus. Each test is done with unused materials. The filling degree of the sandbags was set at 80%, as commonly used (with some exceptions like in Australia) in prototype bags (Pilarczyk, 2000; Recio, 2007 and PIANC, 2011 – cited in Dassanayake and Oumeraci, 2013). For all tests with a sand layer, the lower and upper shear boxes are, respectively, filled with wet sand (~0.1 L/kg), regularly compacted to the shear plan level, and a geotextile specimen or sandbag. In the tests with sandbags a soft membrane is placed inside the upper box to promote a uniform distribution of normal load over the area of contact between the sandbag and the loading plate.

2.2. Testing program

The testing under controlled conditions is essential to be able to extrapolate the results from the test series into an equivalent prototype situation. Main features of the prototype include the cyclic loading due to wave action, and wet and dry conditions and/or alternating dry. Friction between sand-filled elements in a coastal structure is then expected to develop under varying vertical loading conditions as the confining pressure varies with the incoming waves. The confining pressure at the interfaces of an emerged sand-filled geosystem corresponds to the weight of the overlying layers; whilst when submerged it is the submerged weight that should be considered. The orbital motion of the water particles due to the waves progress, also requests the sand-filled elements of a submerged structure repeatedly in seaward and landward directions, potentially abrading the geotextile material. This dynamic effect is reproduced in the cyclic direct shear testing by applying either cyclic variation of the normal stress or displacement-controlled shear movements in the form of sinusoidal wave forms. The amplitude of normal stress variation was defined based on the load variations induced by theoretical regular waves, of a given height and period, over a submerged geosystem. Test conditions A (Table 2) represent typical conditions along the northwest Portuguese coast (H_s = 2 m and T_p = 10 s) according to the statistical analysis in Coelho (2005). These wave loading conditions have been already used in the physical model testing of the stability of geotextile encapsulated-sand systems under wave loading conducted by das Neves (2011). The amplitude and frequency of load variation