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Measuring hydraulic properties of geotextiles after installation damage

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A B S T R A C T

Since geotextiles have been progressively incorporated into coastal protection structures, the influence of installation damage on them has been the primary concern. During installation/construction, geotextiles are repeatedly subjected to high mechanical stresses which often exceed service stress. It is therefore vital to evaluate the mechanical and hydraulic damage and determine the consequences of these damages to better develop criteria for selection of suitable products. As these damages could reduce the material's mechanical strength and hydraulic efficiency, or in the severest form of damage, puncturing, would end the separation function. The properties investigated in this paper include the permittivity and apparent opening size (AOS) of geotextiles. Generally, the greater the drop energy of armour units applied to geotextiles, the greater the potential for damage. Findings show that the residual permittivity could increase significantly, 45% during installation. The preliminary design of coastal structures will be optimised as engineers and designers can better estimate the amount of damage on geotextiles upon installation.

1. Introduction

Geotextiles have been extensively incorporated into coastal and waterway engineering and are used predominantly as filters or separators for rock revetments, armoured slope/banks along coastlines and embankments (Abromeit and Heibaum, 1996; Heerten, 1984; Palmeira and Tatto, 2015; Pilarczyk, 2000). The question around the effect of installation damage on geotextiles has been the focus point for researchers. During installation, geotextiles are repeatedly subjected to high dynamic bulk loading of armour units. This can degrade geotextile's hydraulic efficiency. Hydraulic efficiency of geotextile herein refers the ability to allow free passage of water through rock armour whilst retaining and protecting soil beneath from washing away from tidal currents and wave actions. The growing popularity of geotextile as an alternative to conventional granular filters for hydraulic structures requires research on the hydraulic properties of the material over the expected design life.

Factors that greatly influence geotextile's hydraulic efficiency include installation conditions (subgrade and construction machinery), cover materials (rock armour or aggregates), climate and geotextile characteristics. In order for geotextiles to remain durable and continue to perform the intended functions throughout the lifetime of the structure, geotextiles must first have the ability to withstand construction conditions. The durability of geotextiles would cease if the materials are severely damaged (tear/puncture/rupture) during the installation phase. Diederich (2000) points out that the greatest mechanical stress induced upon geotextiles typically occurs during the loading and construction phase rather than the service life. For coastal structures, the used of armour units are often applied to withstand cyclic wave actions (Abromeit and Heibaum, 1996). These heavy units are often dumped onto the geotextile filter layer from a certain height which induces high dynamic impact onto the material. This would result in the loss of mechanical strength, hydraulic efficiency or severest, puncturing of the material. It is therefore important that the material "survives" (does not rupture/puncture) during installation to ensure both geotextile and structure continue to perform as required.

Extensive research on the hydraulic performance of geotextiles has been conducted through long-term observational studies in

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which samples are excavated from sites after a number of installation years (5–15 years) (Christopher, 1983; Heerten, 1980; Loke et al., 1995; Mannsbart and Christopher, 1997; Wong et al., 2000). These studies have provided valuable information about the hydraulic performance after installation. Though the material survives, geotextiles still undergo high dynamic stresses (rock dumping) that would lead to physical changes (strain/elongation). These changes alter geotextiles' hydraulic properties. Christopher (1983) evaluated the performance of woven geotextile filter in a rip-rap revetment type seawall at 79th Street Causeway Project in Miami, Florida that was installed over a decade ago. The permeability of the exhumed samples was found to be 2×10^{-2} cm/s whilst new material was noted to be 4×10^{-2} cm/s. The permeability test results showed a 50% reduction in its hydraulic efficiency.

Mannsbart and Christopher (1997) evaluated the filtration performance of non-woven geotextiles at sites across Europe and Malaysia that were installed for 6–14 years. It is assumed that the percentage of permeability of geotextile would increase as the pore size increases since the material strains/elongates to conform to the laid armour units. But their investigation showed a reduction in the permeability. This appears to be correlated to the re-orientation of geotextile's micro-structure (internal fibre). The fibre re-orientation typically occurs during and after installation by loading conditions and particles, sediments or organic matter deposit that could obstruct the drainage path. Furthermore, Rollin and Lombard (1988) implied that hydraulic properties can also be influenced by salt deposition, mineral precipitation and bacterial growth. The combinations of these factors are likely to clog and decrease the permeability of material.

Loke et al. (1995) presented the results of a field investigation of non-woven geotextile filter in coastal protection works for marine clays that had been in service for more than 5 years. The geotextiles were excavated from two sites located in Malaysia. At Site A, a coastal revetment structure comprised of non-woven geotextile was constructed over marine clay and a sand layer while at Site B, the structure was underlain with a non-woven geotextile and then laid directly over marine clay. At Site A there was a substantial permeability reduction of approximately 67% for excavated-dirty and 13% for excavated-clean specimens whilst at site B, permeability of excavated-dirty specimens had a reduction of 42%. The opposite trend was observed at site B, with an increase of 60% in permeability for excavated-clean samples. This suggests the reduction in permeability is likely caused by the deposition of particles, sediments, organic matters as well as salt deposition, mineral precipitation and bacterial growth in excavated-dirty test specimens. In contrast, the increase in permeability for Site B – excavated-clean specimens was likely caused by the increase in pore size. It was found that the pore sizes for excavated-dirty were generally less than excavated-clean samples. This is in agreement with the permeability trend where excavated-dirty samples are most likely affected by environmental deposits.

Wong et al. (2000) evaluated the performance of woven, polypropylene-based geotextiles in a reclamation project located in the south-western coast of Singapore island between Jurong Town Corporation (JTC) and National University of Singapore (NUS). The geotextiles had been in service for 12 years at the time of excavation. The study aimed to evaluate the degradation of mechanical and hydraulic properties in different tropical coastal conditions. It was noted that for both locations, the permeability of both sites have increased and this observation is in contrast with the two previous case studies. A broader perspective was adopted by Wong et al. (2000) who implied that pore size is not the only determinant of its permeability. It was asserted that the continuity of pores plays a vital role in allowing water to flow through geotextiles. With the increase in pore continuity, the number of drainage paths would increase as well, thus allowing greater flow of water passing through the geotextile. This view is supported by Rawal et al. (2010) who asserted the hydraulic efficiency of geotextiles is greatly influenced by the width and depth of pores.

Undoubtedly, long term studies on hydraulic performance have aided the task of selecting the appropriate opening size to meet the filtration criteria. But, research work focuses on the long term observations; hence it would be difficult to isolate the influence of installation damage itself as there are a great number of environmental factors involved. Watn and Chew (2002) point out that there is a lack of knowledge for designers and engineers to know whether a geotextile that is designed for filtration function can survive the installation process without being damaged. Berendsen (1996) suggests that a geotextile filter designed for hydraulic structures should fulfil the filtration criteria but must have sufficient mechanical robustness to resist damage during installation particularly the dumping of amour units. The ideal approach would be to perform large scale dumping tests in real field conditions and evaluate the consequences of the damage on immediately recovered samples. However, there are limited studies (Bräu, 1996; Diederich, 2000; Paula et al., 2008) that select this study approach as such investigations requires large setup, is costly and time-consuming. A universal adoptable method would be most favourable with controlled damage simulation that closely replicates the predominant installation conditions of geotextile in the field.

Several authors (Carneiro et al., 2013; Paula et al., 2004; Rosete et al., 2013) have investigated the effect of installation damage on geotextiles using standard laboratory tests methodology for damage simulation. Carneiro et al. (2013) evaluated the short term behaviour (tensile and hydraulic) of five non-woven polypropylene geotextiles that were placed between two layers of granular material and subjected to dynamic loading using a standard installation damage simulation tool (in accordance to EN ISO 10722–1 (BSI, 1998b). Similarly, Rosete et al. (2013) evaluated the tensile and hydraulic properties of geosynthetics that were subjected to cyclic loading, following the method described in EN ISO 10722 (BSI, 2007). Rosete et al. (2013) also simulated abrasion damage on geotextiles following the procedures in EN ISO 13427 (BSI, 1998a).

At present, the only standard impact test to simulate dynamic impact of a falling armour rock on geosynthetics was developed by BAW in 1978 (current issue: RPG (1994)). The question of the suitability of the cylindrical drop hammer to represent armour units has raised concerns by others (Cheah et al., 2016). Numerous tests of rock dumping were conducted in order to propose a new methodology, the Drop Rock Test (DRT) for this application (Cheah et al., 2015, 2016; Kendall et al., 2014a; Kendall et al., 2014b), as shown to Fig. 1. This test measures the mechanical robustness of geotextiles to resist damage during installation/construction. This paper reports on the investigation of the influence of installation damage on geotextile's permittivity and apparent opening size (AOS). Test specimens were first subjected to the DRT and immediately recovered and further assessed with AS 3706.2 (2012) Permittivity Test and Bubble Point Test (ASTM D6767, 2014).

2. Test program

2.1. Materials

This paper studies four (4) grades of staple fibre non-woven geotextiles (codes GTX1, GTX2, GTX3 and GTX4) subjected to various impact energy. The hydraulic properties of the geotextile are listed in Table 1. Experimental investigations were completed following the test program listed in Table 2.