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Effect of simulated rock dumping on geotextile

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ABSTRACT

The use of geotextiles in coastal structures such as revetments and bund walls has become a common practice. The performance of these structures during their lifetime depends on the durability of geotextile used. During construction of these coastal structures, geotextiles are subjected to a drop load with high impact stress and that can damage the geotextile. In the current design practice, index tests are insufficient in predicting the performance of the geotextile. This puts the stability and performance of the coastal structures at risk. The current geotextile design guidelines are based on index tests and there is no standard procedure to account for the potential loss in the geotextile's mechanical properties during installation (construction).This study aims to develop a standard procedure to estimate the properties of geotextile after its installation and using these properties for designing the performance of these structures. This paper describes the laboratory method of simulating large scale rock dumping on non-woven geotextiles and how to quantify the retained strength of damaged geotextiles. Results show that the reduction in retained strength of geotextile could extent up to 26% during installation.

Keywords: Geotextile, Puncture Resistance, Field installation condition

1 INTRODUCTION

Studies have shown that the various functions of a geotextile allow it to substitute granular material as filters. In comparison to granular filters, the installation of geotextile is quick and labour efficient, more economical and it has consistent material quality. Hence, geotextile have gradually replaced granular filters and have been incorporated into the design of revetment structures, riverbanks, bund walls and other coastal structures(Hornsey, 2012).

The two primary functions in coastal structures are to prevent erosion and allow drainage. Hence, the durability of geotextile is vital in the lifetime of the structure, but to ensure geotextile performs as required, it must first rely on the ability to "survive" during construction. The term "survive" refers to a geotextile that did not suffer severe damages (puncture/hole) during construction. During installation process, geotextiles are subjected to high impact stress due to rock drop where it could be easily damaged (Heerten, 2008).

Carneiro et al. (2013) had proved that there would be a substantial change in geotextile's mechanical and hydraulic properties if it suffers damage during installation. Heerten (2007) further suggests any geotextile filtration design would be deemed pointless if the geotextile is punctured. Therefore, the installation of geotextiles must be dealt with great caution.

Studies revealed that mechanical properties such as tensile strength, puncture resistance and unit weight are specified to ensure the geotextile meets the requirement of an application. This approach was initially introduced by the Norwegian Road Research Laboratory(Sissons et al., 1977) and this was further adopted by the American Association of State Highway and Transport Officials (AASHTO) in 1990. Diederich (2000) pointed out that a new concept has been introduced into the European standards, both Norwegian Standard NS 3420-13 and Swiss standard SN 640 552 have incorporated the energy absorption capacity of geotextile as part of their specification system. These standards define "energy absorption as the product of tensile strength and elongation at maximum strength" (Diederich, 2000).

Efforts to obtain the mechanical properties of geotextile have been carried out via index tests. Lawson (1982) found that many mechanical tests have little relevance in quantifying the mechanical stresses on geotextiles, therefore he carried out a comprehensive study, “Geotextile Requirements for Erosion Control Structures” to determine the correlation between field performance with relevant index tests. His study claimed that results from the drop cone test represent the closest mechanical behaviour of geotextiles on field.

Recently, Paula et al. (2004) studied the damage during installation (DDI) on geotextile with the effect of the granular material and the study revealed that residual strength of the material is evidently reduced with the influence of granular material. Despite the efforts of both authors correlating field performance with index tests, index test isn’t the ideal approach to simulate field conditions as these tests do not take into account factors such as groundwater condition, characteristics of armour stone, number of drop on specimens and drop height (Chew et al., 1999).

Therefore, field trials would be ideal as it takes account of the existing site conditions. Wong et al. (2000) conducted field tests with an impact block weighing 900kg with a contact area of 0.64m^2 was released from a height ranging 0.5m to 2.5m onto subgrade overlaid by geotextile. Similarly, Hufenus et al. (2002) conducted 35 installation tests where samples were laid onto a well compacted gravel which had a covered fill material of 0.12m with a wire net placed between the materials. An additional layer was placed above the geotextile to allow compaction to occur. Both authors agreed that the damage induced during the installation process was influenced by field conditions.

Undoubtedly, field testing is the ideal approach, then again it is unempirical and often non-repeatable; yet current installation guidelines are based on such practise. Furthermore, large space and extensive time is required to complete large scale investigations and it is economically unfeasible for on-going projects which run on tight schedules.

A new testing methodology has been developed to comprehend the effect of damage during installation on mechanical behaviour of geotextiles. This paper describes the procedures of conducting the test and presents results performed on staple fibre non-woven geotextiles.

2 TEST APPARATUS

2.1 Drop Rock Test

A new testing methodology, Drop Rock Test (DRT) shown in Figure 1 is proposed by *Geofabrics Australasia* simulate installation conditions on site where ripraps are dropped above geotextiles during construction of revetments (Kendall[1] et al., 2014). The test is conducted by releasing a test block (dynamic loading) at a specified drop height onto a geotextile that is laid above a box of subgrade. The drop height can be varied from 0.5m to 2.0m and three test blocks with approximate mass of 1 tonne, 0.5 tonne and 0.1 tonne are available to choose.

This DRT does not only overcome the disadvantages of both index test and field test but incorporates the advantages of both. The DRT is not an isolated test where it only presents visibility results like field tests. Tested specimens (non-puncture) from DRT are further examined with an index test, for example, Static Puncture Test. This combination allows engineers and designers to understand the behaviour of geotextile on site and predict the long term performance of geotextile in revetment applications.

It allows controlled installation and prevents any unforseen damages during removal of geotextiles. The setup is aimed to create extreme damage by allowing the fabricated rock (test cube) to drop on a corner point (90^0) onto the subgrade overlain with a geotextile.

Figure 1 illustrates a gantry crane with a lifting capacity of 1150kg that was built together with a box frame. This semi-lab environment is the optimal approach to evaluate the puncture resistance of geotextile for coastal revetment application.

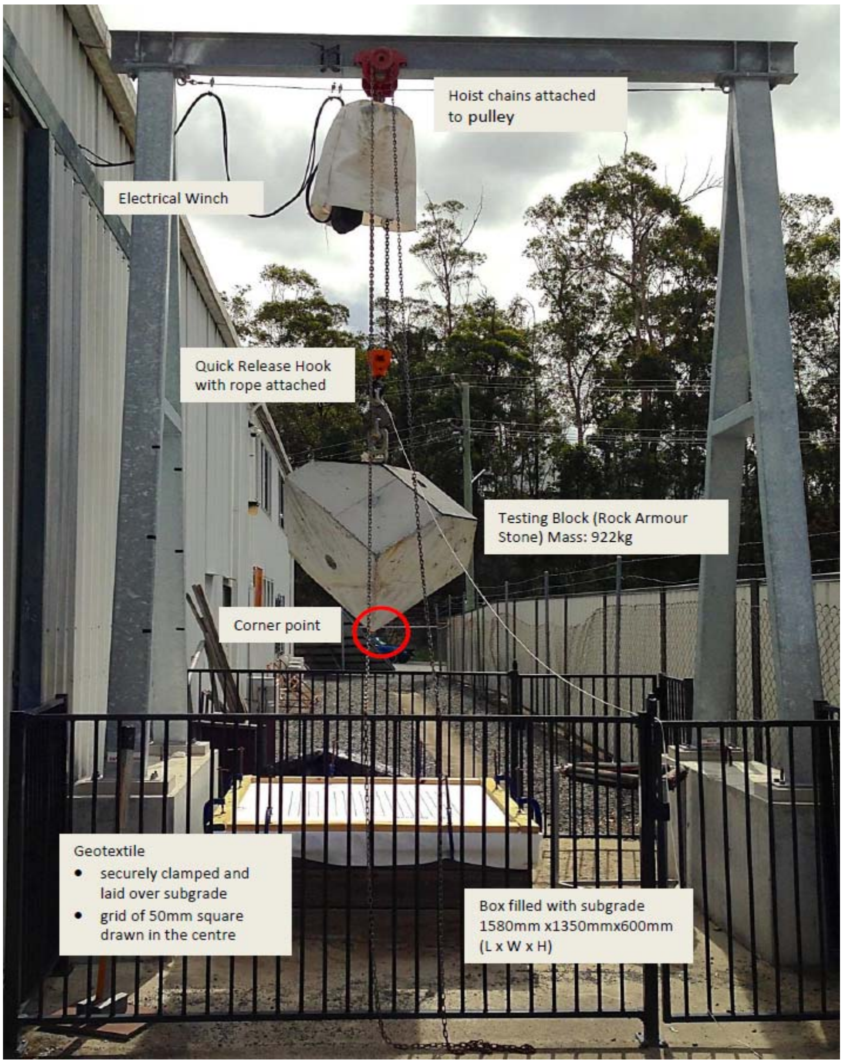

Figure 1. DRT showing a concrete block suspended over geotextile laid above the subgrade

2.1.1 Material

2.1.1.1 Geotextiles

Four staple fibre non-woven geotextiles commonly used for separation and filtration applications of differing weights and mechanical properties was selected to perform the damage evaluation of simulated field test. Mechanical and physical properties of geotextiles used in this experimental program are given in Table 1.

Table 1: Mechanical and physical properties of staple fibre non-woven geotextiles

Properties					Geotextile			
Mechanical	Test		Standard	Units	**SF1**	**SF2**	**SF3**	**SF4**
	Wide Strip Tensile Strength	MD	AS3706.2	kN/m	10	17.7	26.0	36.8
		XMD			21.4	39.0	54.6	82.7
	Trapezoidal Tear Strength	MD	AS3706.3	N	320	477	656	842
		XMD			542	917	1264	1774
	Grab Tensile Strength	MD	AS2001.2.3	N	686	1161	1753	2469
		XMD			1097	1948	2948	4539
	CBR Burst Test		AS3706.4	N	2719	4522	6526	8824
	Static Puncture Test		ISO12236:2006 (E)	N	2615	4046	7015	8236
Physical	Mass per unit area			g/m^2	380	611	846	1224

2.1.1.2 Subgrade

The particle size distribution of the subgrade used in this study is shown in Figure 2. According to the ASTM D2487- Unified Soil Classification System (USCS), the soil is classified as SP. Dry density of soil measures between 1550-1800kg/m^3 with 7-8% of water content.

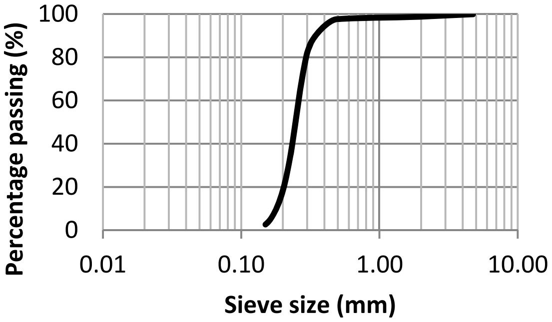

Figure 2. Particle size distribution curve

2.2 Static Puncture Test-CBR Test

CBR, which is known as California Bearing Ratio, is a test method to measure geosynthetic puncture resistance. The CBR test was carried out according to ISO 12236:2006 (E) (European Standard Online, 2006) (European Standard Online, 2006).The clamp consisted of two annular plates with an inner diameter of 150mm±0.5mm. The geotextiles sample is tightly secured between these plates by eight screws. The stainless steel plunger with diameter of 50mm and a radius of the leading edge of 2.5±0.5mm is pushed against the membrane at a rate of 50mm/minute and the load –deformation curve is obtained.

3 METHODOLOGY

3.1 Drop Rock Test

To understand the effect of drop height of rock on geotextile damage during installation, four different grades of non-woven staple fibre geotextiles (SF1, SF2, SF3, and SF4) have been studied. Table 2 summarised the numbers of tests that were carried out at the desired drop height on each grade of geotextile.

Table 2: Number of test for desired drop height

Geotextile / Drop height (m)	SF1	SF2	SF3	SF4
0.5	5	5	*	*
1.0	5	5	5	5
1.5	5	5	5	5
2.0	*	5	5	5
*Test were not carried out at that height				

To prepare the subgrade, the confined box with internal dimensions of 1580mm x 1350mm x 600mm (LxWxH) was filled with sand by manual compaction. The compaction was carried out by a hand tamping system, where a 4.2kg tamper of 200mm x 300mm x 700mm (LxWxH) was released from a height of 0.5m and was repeated 45 times to ensure repeatable compaction. After preparing the subgrade, , a 1.8m x 2.0m geotextile stencilled grid of 50mm by 50mm in the target zone, was laid directly on the subgrade and clamped securely along the frame of the box. This was to ensure no slipping occurred.

Once geotextile was laid securely, the test cube was electrically winched up to the desired drop height whilst a trolley on the crane rail was used to move the test cube laterally to the target zone. Drop height was measured from the bottom tip of test cube to the surface of geotextile with a T-gauge. The test cube was then disengaged from the quick release mechanism once it was in position.

After removing the test cube, visual observation was first made to determine the visibility of any puncture. Any punctures found on geotextiles were considered failure and discarded. For non-puncture geotextile samples, elongation values were measured against 6 squares (which initially was 300mm, as each square is 50mm by 50mm) from the point of interest (refer to Fig 3). The change in length was measured and recorded.

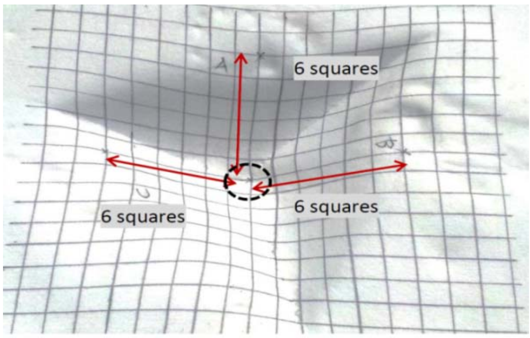

Figure 3. Elongation measured against 6 squares from point of interest

3.2 Static Puncture Test-CBR Test

For each non-punctured (1.8 x 2.0m) geotextile sample, five sub-specimens were cut out and further assessed with Static Puncture Test. Figure 4 shows that each non-puncture samples, four undamaged edge samples and one damage (impact) sample would be further examined with CBR test.

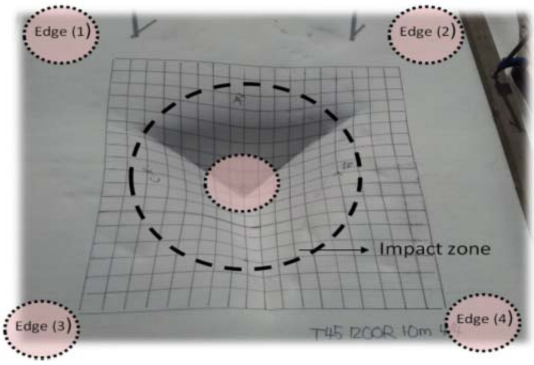

Figure 4. Locations of CBR specimens

Figure 5 depicts a typical load-elongation curve of CBR Puncture test. The curve was used to measure two parameters: puncture resistance (kN) and puncture energy (J). Puncture resistance represents the maximum load applied onto the geotextile before it punctures, and puncture energy is calculated using the area under the stress-strain curve.

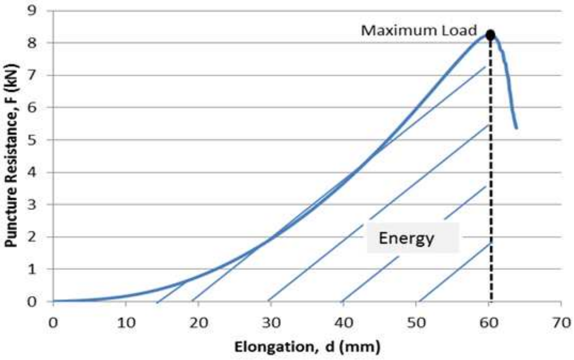

Figure 5. Typical CBR curve

4 RESULTS AND DISCUSSION

4.1 CBR Puncture Resistance of Geotextiles at 1.0m Drop Height

The puncture resistance of the undamaged edge and damage geotextile samples were compared with the results with CBR test. The data were used to compare the relationship between mass per unit area, drop height, puncture resistance and puncture energy. Each grade of geotextile was tested with DRT at the same drop height of 1.0m five times; geotextile samples that did not have visible puncture were further tested with CBR puncture test and compared with undamaged edge samples. Clearly, in the five repeated test, non-puncture conditions are random and exact assessment is not possible. However, trends can be established using the average results of these test samples was used. This approach was justified as part of the preliminary study.

Under the same test conditions, it is clearly seen in Figure 6 that all damage geotextiles with lower puncture energy showed weaker behaviour compared to those undamaged edge geotextiles with greater puncture energy. This trend is consistent for all material except SF4, where the "damage" geotextiles had similar puncture resistance of the undamaged edge samples. In this case, the residual strength after damage with the fabricated rock remains the same, which indicate that it is highly unlikely for SF4 to suffer installation damages at 1.0m drop height.

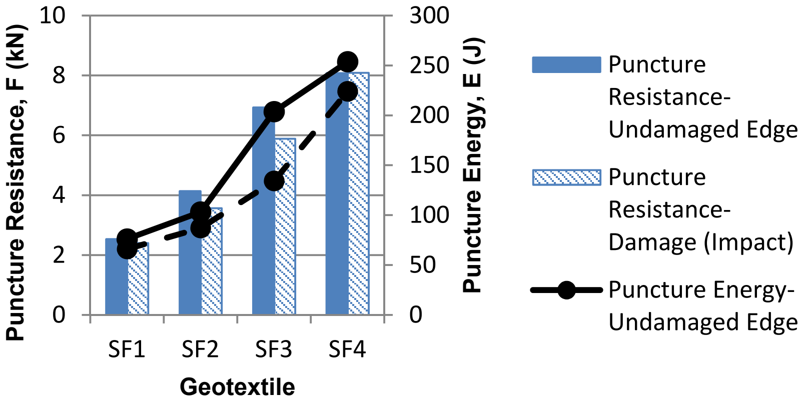

Figure 6. CBR puncture resistance of geotextiles at 1.0m drop height (comparing damage and edge)

It is also observed in Figure 6 that difference in puncture energy between damaged and undamaged geotextiles were mostly less than 15% except SF3 which had a difference of 34%. The main reason for the different results obtained have to be related with standard deviation values; as though the tests were conducted under the same conditions, there is some scatter in the results obtained. SF3, has the highest standard deviation (41.3) amongst the other geotextile elucidates the 34% variation.

The test results showed a correlation between the weight of fabrics and puncture resistance of the material. It was found that for the same drop height, 1.0m, the greater the mass of geotextile, the less damage to the geotextile and thus increased survivability.

4.2 Retained CBR strength (%) at various Drop Height

Retained CBR strength (%) illustrated in Figure 7 is expressed as the change (in percent) of the reference Static Puncture Test value in Table 1, that is shown in Eq.(1).

$$\text{Retained CBR strength (\%)} = 100\% - \frac{\text{Change in CBR strength}}{\text{Initial CBR strength (Table 1)}} \times 100\% \qquad (1)$$

The data was used to compare the relationship of varying drop heights with the same material. Each grade of geotextile was tested five times with at least two different drop heights, ranging from 0.5 to 2.0m. Evidently, out of the five repeated test, not all resulted in non-puncture condition. With a small sample size, these results needed to be interpreted with caution. For lower engineering grade geotextiles (SF1 and SF2), lower drop heights (0.5m and 1.0m) were applied as the material is expected to have lower survivability than higher engineering grade products. Similarly, SF3 and SF4 were tested at higher drop heights (1.0m, 1.5m and 2.0m). The test specimens were then removed from the DRT apparatus and subjected to a static puncture test in accordance to EN ISO 12236.

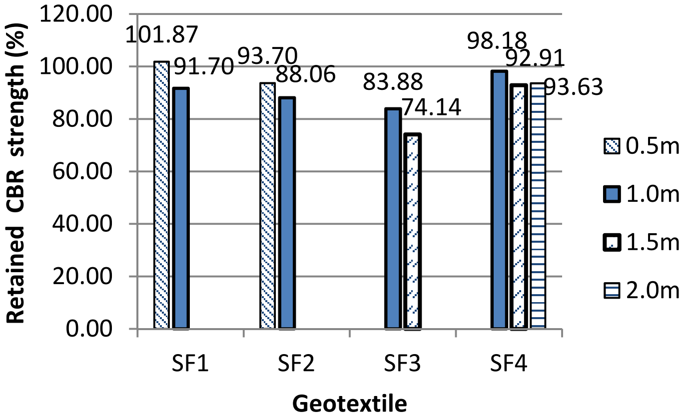

Figure 7. Retained CBR strength of geotextiles after DRT

It is apparent from Figure 7, the retained strength of geotextile after installation generally lies above 80% except of SF3. This suggests about 20% of its initial strength is lost during installation. Noting that under DRT test conditions, geotextile is only subjected to a single dynamic load, but field installations often drop a bulk load of stones (numerous loads) onto the geotextile, which increases the damage inflicted upon geotextile. Hence, suggesting the lost in its strength is likely to exceed 20%.

From Figure 7, the decrease in retained strength is evident across all geotextiles except SF1 at 0.5m drop height which had an increase of greater than 100%. This may imply material strengthening, but note the reference property from Table 1 is the average value of the tested edge specimens, and not the initial CBR value of the damage specimen. The assumption made was the initial CBR strength of both edge and damage samples are the same. However, it is possible that there is some degree of variability in the initial strength of damage specimen. Besides, the coefficient of variation for SF1 at 0.5m is 29.73% which suggests there is some obscurity in the results obtained. A larger sample size is required to determine this conjecture.

Another clear correlation is observed in Figure 7, the increase in drop height, geotextile's retained strength decreases except for SF4 at 2.0m. A further investigation is required to understand the reason behind the increase in retained strength (0.72%) at 2.0m drop height. It is difficult to explain this result, but it might be related to the density of soil. The density of soil could vary as the compaction of subgrade is performed manually by a DRT operator. It is likely the density of soil varied therefore that these variations is obtained. Further investigation is required to establish this.

It is somewhat surprising to note that SF3 which have better mechanical properties (refer to Table 1), performed weaker than the presumably the weaker SF1 and SF2. The present findings suggests indicated values in the specification and classification systems do not adequately reflect the mechanical behaviour of geotextile on site and supports the approach to use DRT to assess geotextile performance on site.

5 CONCLUSION

This study set out with the aim of assessing the puncture resistance of geotextile with a new testing method, Drop Rock Test (DRT), where the geotextile is overlaid above the subgrade and subjected to dynamic loading. The results of this study indicate that the extent of damage experience by geotextile during installation cause significant changes in its mechanical properties. In this case, the retained strength after damage during installation could decrease as much as 26%.

Past studies in relation to geotextile's damage during installation are either evaluated by mechanical tests or field tests. Evidence from this study suggests that index test values indicated in specification and classification system do not reflect geotextile's performance on site as it does not take into account field conditions such as characteristics of armour stone, number of drop on specimens, drop height and etc. Undoubtedly, the field test is the ideal approach to accurately assess geotextile's performance on site, but this method is often unempirical and non-repeatable. The ability to simulate field conditions in an empirical manner is the key strength of the DRT apparatus.

Several limitations of this study need to be acknowledged. Firstly, the sample size is small. The current study was also unable to analyse the effect of density of soil on geotextile's performance. Thirdly, there is some scatter in the results obtained. Therefore, results needed to be interpreted with caution.

Notwithstanding these limitations, the findings suggest the damage during installation could significantly change in the mechanical properties. There are several practical applications from this research. Firstly, a range of variables can be manipulated with DRT, for example, the mass of drop rock, subgrade type and the angularity of drop rock. Future trials could assess the effect of these variables on geotextile's mechanical performance. Secondly, results from DRT could be used to develop design charts for engineers. Lastly, the DRT could be used together with other tests, such as permittivity test. Therefore, it would be interesting to assess the effects of the dynamic load on the pore size and flow capability of geotextile.

REFERENCES

Aashto 1990. Standard Specifications for Geotextiles. *M288-96.* Washington DC: American Association of State Highway and Transportation Officials.

ASTM- ASTM International 2011. ASTM D2487 Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System).

Carneiro, J. R., Morais, L. M., Moreira, S. P. & Lopes, M. L. 2013. Evaluation of the Damages Occurred During the Installation of Non-Woven Geotextiles. *Materials Science Forum,* 730-732**,** 439-44.

Chew, S. H., Karunaratne, G. P., TAN, S. A. & WONG, W. K. Standardized Drop Test (SDT) to evaluate puncture resistance of geotextiles in coastal revetments. *Rencontres Geosynthetics 99*, 1999 Bordeaux, France. 303-310.

Diederich, R. 2000. Evaluation of Installation Damage of Geotextiles. A Correlation to Index Tests. DuPont de.

European Standard Online 2006. EN ISO 12236 Geosynthetics-Static Puncture Test (CBR Puncture Test).

Heerten, G. 2007. Revetment Design- Lessons learnt from failures. *10th Australia New Zealand Conference on Geomechanics.* Brisbane: Australian Geomechanics Society.

Heerten, G. 2008. Needle-punched nonwoven GTX in coastal engineering applications. *Chinese-German Joint Symposium on Hydraulic and Ocean Engineering.* Darmstadt, Germany.

Hornsey, W. P. 2012. Geotextiles in specialise marine applications: an australia prespective over 32 years. Geofabrics Australasia.

Hufenus, R., Ruegger, R. & Flum, D. Geosynthetics for Reinforcement- resistance to damage during installation. Geosynthetics- 7th International Conference on Geosynthetics, 2002 Nice, France. 1387-1390.

Kendall[1,] P., Austin, R. A., Cheah[2,] C. & Lacey[2,] M. 2014. Large Scale Controlled Testing of Geotextile Puncture Resistance. 10th International Geosynthetic Conference.

Lawson, C. R. Geotextiles Requirements for Erosion Control Structures. Symposium of Recent Developments in Ground Improvement Techniques, 1982 Bangkok, Thailand.

Paula, A. M., Pinho-Lopes, M. & Lopes, M. D. L. Damage during installation laboratory test. Influence of the type of granular material. Proceedings of 3rd of European Geosynthetics Conference, 2004 Munich. 603-606.

Sissons, C. R., Paute, J. L., Segouin, M., Van Leeuwen, J. H., Finnigan, J. A., Viergever, M. A., De Feijter, J. W., K, M., Ruddock, E. C., Ingles, O. G., Fayoux, D., Alfheim, S. L., Sorlie, A., List, H. J., Giroud, J. P., Perfetti, J., Leflaive, E. & Puig, J. Testing and classification of fabrics for application in road cosntructions. International Conference on the use of fabric in geotechnics, 1977 Paris. 33-338.

Standard Australia Online 2012. AS 3706.2 Geotextiles-Methods of Test-Determination of tensile properties- Wide strip and grab method.

Standards Australia Online 2001. AS 2001.2.3.2 Methods of test for textiles-Physical tests- Determination of maximum force using the grab method.

Standards Australia Online 2012a. AS 3706.3 Geotextiles- Methods of Test- Determination of tearing strength- Trapezoidal method.

Standards Australia Online 2012b. AS 3706.4 Geotextiles- Methods of test- Determination of burst strength- California Bearing ratio (CBR) Plunger method.

Wong, W., Chew, S., Karunaratne, G., Tan, S. & Yee, K. 2000. Evaluating the Puncture Survivability of Geotextiles in Construction of Coastal Revetments. *Advances in Transportation and Geoenvironmental Systems Using Geosynthetics.*