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Puncture resistance of geotextiles against installation

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ABSTRACT: In construction of coastal revetments, choosing the right geotextile with the sufficient puncture resistance is a surmountable challenge. However, through a series of field drop test, the influences of different site conditions on the puncture resistance of geotextiles were determined. It was shown that density and type of the soil, presence of secondary stones will mobilise different failure mechanisms to cause punctures on the geotextile. Using various index tests, the puncture resistance of geotextiles against these failure mechanisms can be quantified. Finally, some design charts were derived to help engineers select appropriate geotextiles to resist damage during construction.

1 INTRODUCTION

Two field tests on the puncture resistance of geotextiles were conducted in Singapore (Chew et al. 1999 and Wong et al. 2000) and France (Caquel et al.1998) to study the puncture resistance of geotextile filters against damage caused by falling rocks during the construction of coastal revetments. The field test showed that two failure mechanisms were responsible for inducing punctures on the geotextiles under different boundary conditions (Chew & Watn 2002). A tensile-elongation failure mechanism was mobilised when the geotextile was laid over a clean sand base with secondary armour stones placed above the geotextile, typical configuration of revetments in many land reclamation projects. In contrast, a cutting failure mechanism was mobilised when the geotextile was laid over silty-sand soil with pebbles mixed within the soil matrix, typical of soils found on estuarine riverbanks.

This paper presents results of a series of laboratory experiments to show that the Tensile Energy measured using the CBR Plunger Test and Cutting Energy measured using a new index test – The Cut Index Test, can be used to quantify the puncture resistance of geotextiles against a Tensile-elongation failure mechanism and a Cutting failure mechanism respectively. These Tensile Energy and Cutting Energy were also used to correlate results obtained from field tests to show its applicability in actual construction.

A total of five polypropylene geotextiles were tested. Two of the geotextiles were woven geotextile (mass of 400 g/m^2 and 625 g/m^2). The 400 g/m^2 woven geotextile possesses almost equal strength (80 kN/m) and elongation properties (about 12%) in both machine and cross-machine directions. The 625 g/m^2 woven geotextile has a machine direction tensile strength (200 kN/m) that is 5 times the tensile strength in the cross-machine direction (40 kN/m), with an elongation of 15% in both directions. The remaining three geotextiles are needle-punched nonwoven continuous fibre geotextiles of different masses (400 g/m^2, 600 g/m^2 and 800 g/m^2). The highest and lowest tensile strength of the nonwoven geotextile is about 35 kN/m and 23 kN/m in both directions respectively. The elongation for all the three nonwoven geotextiles is about 85% in both directions. A mixture of geotextiles of different weaves and specific mass were intentionally chosen to show that the tensile energy can be used to evaluate the puncture resistance of geotextiles regardless of the manufacturing technology.

2 THE TENSILE-ELONGATION FAILURE MECHANISM AND TESTING

The puncture resistance of geotextiles against a tensile-elongation failure mechanism can be proven to be proportional to the tensile energy of the geotextiles if it could be shown that the required kinetic energy of a falling impact head to make a tensile type puncture on a geotextile is proportional to the stored tensile energy of the geotextile. Hence, the objective was to measure the tensile energy of various geotextiles and correlate it with the kinetic energy of the falling impact head in laboratory tests or the falling stones in rock dumping operations.

To measure the required kinetic energy of a falling impact head to make a puncture on the geotextile, a 5m high impact rig was erected to deliver a controlled impact energy onto the geotextile samples (Figure 1). It consists of a 5m vertical guide rail and a specially designed impact head to induce a tensile-elongation failure mechanism. When the impact head is released from a designated height, it accelerates downward under its own weight guided by the vertical guide so that it hits the centre of the geotextile test specimen. Just prior to impact, a pair of photodiodes and computer measures the speed of the impact head and calculates the kinetic energy of the impact head. The geotextile was secured using a 500mm diameter clamp ring. The latter was secured onto a steel drum filled with sand placed at a relative density of 70%. Such a setup simulates the situation of a geotextile laid over clean beach sand with secondary armour stones above it acting as anchorage points. The shape of the impact head was specially designed to mobilise tensile forces and elongation of the geotextiles predominantly in only one direction. The test was repeated with the cutting edge aligned with the machine direction and cross-machine direction. The kinetic energy required to cause the geotextile to rupture was taken as the average of the required kinetic energy to rupture the geotextiles in the machine and cross-machine directions.

The tensile energy that the geotextiles possess to resist puncture can be accurately measured using the CBR Plunger Test. The tensile energy of each test can be determined by calculating the area under the plunger force-displacement curve registered during the test. The total energy calculated till the rupture of the geotextile in the CBR Plunger Test is defined as the CBR energy.

3 DISCUSSION ON TEST RESULTS OF TENSILE-ELONGATION FAILURE TEST

Figure 2 shows the average kinetic energy required to induce a tensile-elongation type puncture on various types of geotextiles and the corresponding CBR energy of each geotextiles measured via the CBR Plunger Test. The graph shows a linear relationship between the kinetic energy needed to make a puncture and the CBR energy of the geotextile, with a high degree of correlation. It also convincingly shows that the puncture resistance of the geotextile is directly proportional to the CBR energy of the geotextile. This also suggests that the CBR energy can be used to quantify the puncture resistance of most kinds of geotextiles against a tensile-elongation mechanism, which makes it very useful for field application.

To show that the CBR energy can be used in rock dumping operations at the site, it was used to correlate results from the field data obtained in site drop test in Singapore (Chew et al. 1999, Wong et al. 2000 and Wong 2002). After much data analysis, an empirical equation that relates the relative density of sand base, drop energy of the rock, CBR energy of the geotextile and the amount of damage found on the geotextile was derived with a R^2 regression value of 0.83. This equation is shown below, while a graphical representation is shown in Figure 3.

$$\left[\frac{D_{A,95}}{RD^{1.41}}\right] = 8.55 \left(\frac{E_{drop}}{E_{CBR}}\right) - 190 \qquad (1)$$

Where $D_{A,95}$ is the 95^{th} percentile cumulative area of damage per drop. E_{drop} is the drop energy of rock and E_{CBR} is the energy at push through in the standard CBR Plunger Test. *RD* is the relative density of the sand base.

This analysis suggest that the CBR energy can be used to evaluate the puncture resistance of geotextiles in the real situation and can be a helpful tool for selecting the right geotextile to resist a tensile-elongation failure mechanism.

4 THE CUTTING FAILURE MECHANISM AND TESTING

To prove that the puncture resistance of geotextiles against a cutting failure mechanism is proportional to the energy required to cut through the cross section of the geotextiles, a similar approach to the tensile-elongation failure mechanism was adopted to study the Cutting failure mechanism.

To mobilise a cutting failure mechanism, the same impact rig was used albeit some modifications. A small concrete block was buried in the sand 5 cm underneath the geotextile surface. This setup simulates the situation whereby the geotextile is placed above a silty-sand soil with pebbles mixed within the soil matrix. During the impact with the impact head, the geotextile deforms and touches the small concrete block, allowing the knife-edge of the impact head to cut through the cross section of the geotextile. This mechanism simulates the occurrence of the geotextile coming in contact with the pebbles during impact, causing the geotextiles that is sandwiched between the impact rock and pebbles to be cut.

As there is currently no test that can determine the resistance of geotextiles against penetration by an object with an edge like a knife, a new index test was devised to measure the Cut Energy, known as the Cut Index Test (Figure 4). The apparatus essentially measures the amount of energy required for the knife-edge of a chisel head to penetrate the cross-section of the geotextile. The force and displacement on the chisel head is measured via a load cell and LVDT and data logged via a computer linked to these devices. The energy to cut through the geotextile, or the Cut Energy, is calculated as the area under the force-displacement curve of the chisel head. Again, the cutting edge can be aligned along the machine or cross machine direction of the geotextile.

5 DISCUSSION OF TEST RESULTS OF THE CUTTING FAILURE TEST

Figure 5 shows the kinetic energy needed to make a cut via the impact test apparatus versus the cutting energy of the geotextile measured via the Cut Index Test. The figure shows that the kinetic energy is proportional to the cutting energy. This observation is true for the machine direction and cross-machine direction of the geotextile. An approximate linearly proportional relationship exists between the kinetic energy and the Cut Energy. Hence, the analysis shows that the puncture resistance of the geotextile can be effectively quantified by the Cut Energy of the geotextile, which makes it very useful for field application.

To show that the Cut Energy can be used in actual rock dumping operations, the Cut Energy of the geotextile was used to correlate results from the field data obtained in site drop test in France (Caquel et al. 1998). After much data analysis, an empirical equation that relates the drop energy of the rock and Cut Energy of geotextiles and the amount of damage found on the geotextile was derived with a R^2 regression value of 0.94 (Wong 2002). This equation is shown below, while a graphical representation is shown in Figure 6.

$$L_{cum} = 0.0032 \left(\frac{E_{drop}}{E_{cut}}\right) - 6.5 \qquad (2)$$

Where L_{cum} is the cumulative length of damage per drop, E_{drop} is the drop energy of rock and E is the cut energy of the geotextile measured in the Cut Index Test.

In Figure 6, the upper bound line represents the extreme envelop of the damage versus E_{drop}/E_{cut} . Using the upper bound line for the selection of geotextiles would be too conservative. On the other hand, using the best-fit line through all the data would be too risky because that would mean that there is approximately 50% chance that the geotextile will be damaged, which is clearly undesirable for practical design purposes. This is because there is a high degree of scatter among the data and a best-fit line would not do justice to represent the general phenomenon behaviour. Hence, the most appropriate design curve would be the "Practical Limit" line, which caters for an economic design with adequate guarantee against damage.

This analysis also suggests that the Cut Energy can be used to evaluate the puncture resistance of geotextiles in actual construction situation and is thus a helpful tool for selecting the right geotextile to resist a cutting failure mechanism.

6 CONCLUSION

This paper showed that the puncture resistance of geotextiles against a tensile-elongation failure mechanism and a cutting failure mechanism is proportional to the CBR energy and Cut Energy of geotextiles respectively. Data from site drop test conducted in Singapore and France showed that the puncture resistance of geotextiles against these failure mechanisms could be reliably quantified by the CBR Energy and Cut Energy. Two empirical design charts were also developed corresponding to tensile-elongation failure and cutting failure respectively, which can be a useful tool for engineers in selecting the appropriate geotextile to resist installation damage on the geotextile during the construction of coastal revetments.

7 ACKNOWLEDGEMENT

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Figure 1 The Impact Rig

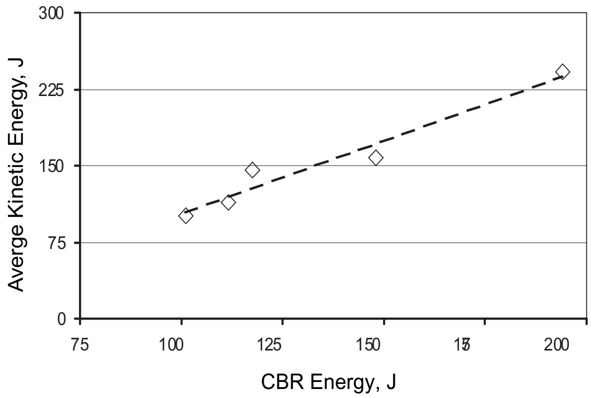

Figure 2 Averaghe kinetic energy versus measured CBR energy of all five geotextiles

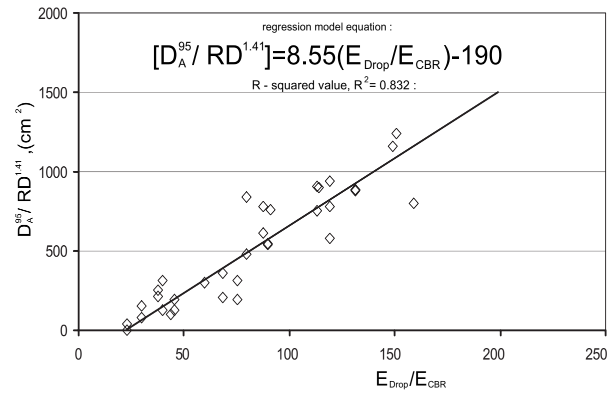

Figure 3 Design chart for tensile-elongation failure mechanism

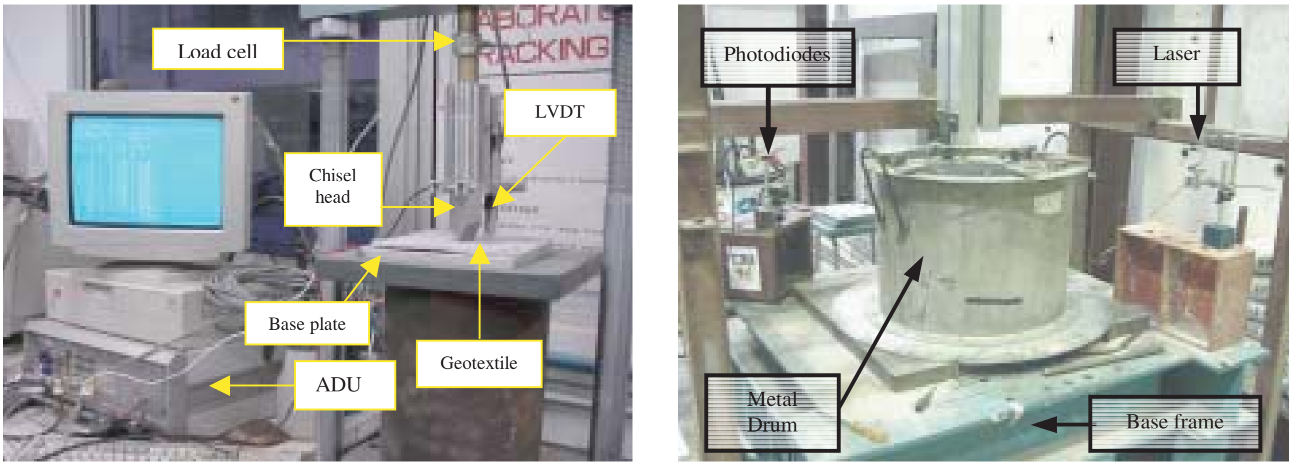

Figure 4 Apparatus of the Cut Index Test

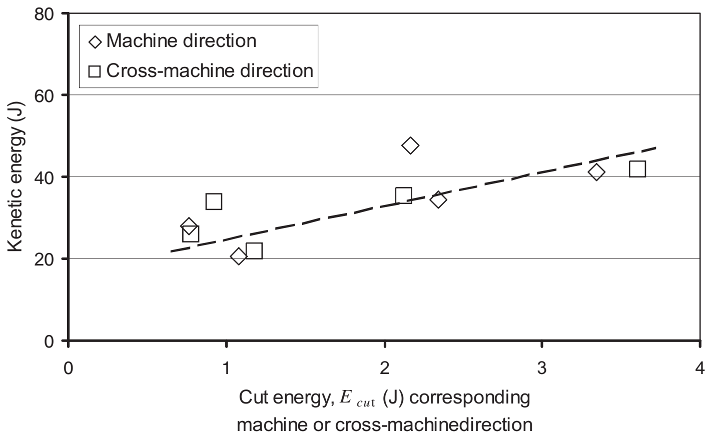

Figure 5 Kinetic energy versus Cut Energy of all five geotextiles in the corresponding machine and cross-machine direction

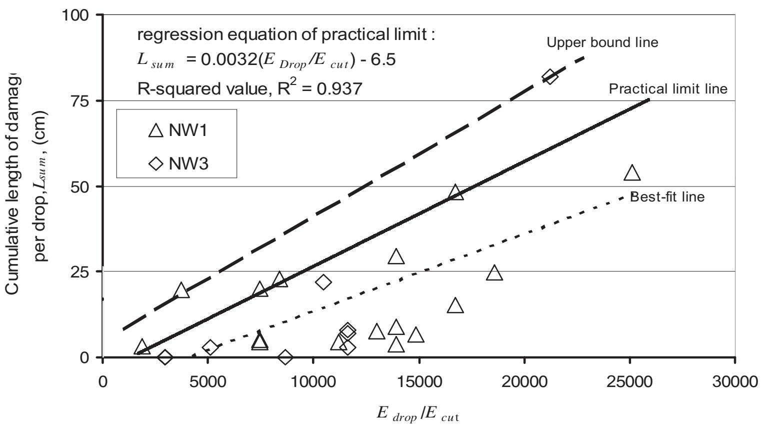

Figure 6 Empirical relationship between the amount of damage, drop energy and Cut Energy
(Data obtained and re-analysed from Caquel et al. 1998)