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The use of geoprotectors in landfill: Design implications

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ABSTRACT: Geoprotectors are becoming widely used in European landfills to protect the geomembrane linings from damage. This paper discusses the design implications raised by the use of geoprotectors and reports on the results of interface shear strength testing of three types of geoprotectors.

1. INTRODUCTION

It is now common practice in most European countries for all new landfills to have full containment barrier systems, incorporating an integral leachate collection capacity. As experience continues to grow in this relatively new engineering discipline, and novel/modified materials are used in composite barrier systems, revised testing regimes and analysis techniques are required. A typical barrier system is shown in Figure 1.

As a result of recent research, which has shown that the sand protection/drainage layers placed above the geomembranes can become blocked, drainage layers formed of 16 to 32mm gravel are now often used in conjunction with geoprotectors. The role of the geoprotector is to prevent the geomembrane liner from being damaged by the gravel when loaded under the weight of the placed refuse.

Introduction of geoprotectors into landfill barrier systems results in two modes of behaviour being assessed as part of the overall design considerations: i) the ability of the layer to prevent mechanical damage to the geomembrane; and ii) the influence of the geoprotector/geomembrane interface shear strength on the stability of the lining system, both during construction and long-term.

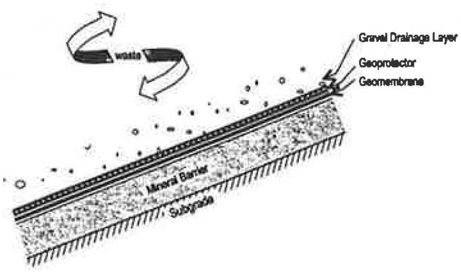

Figure 1: Typical Lining System

This paper provides a brief review of the present UK practice for the selection of geoprotectors with regard to penetration resistance and presents the preliminary results of an extensive laboratory investigation to assess the interface shear strength for typical geoprotectors, geomembranes and drainage soils. The main factors controlling material selection are discussed, in conjunction with relevant testing procedures and design considerations.

2. TYPES OF GEOPROTECTORS

The most common used in the UK are nonwoven needle punched geotextiles, generally made from polypropylene stable fibres, however, the use of high density polyethylene (HDPE) is becoming increasingly popular. There is currently a range of different quality fibres used, with recycled fibres being employed as well as quality assured virgin fibres. Traditionally the selection of these geotextiles has been based on the unit weight of the product with 1200g/m^2 being the minimum specified. However, due to the quality of the fibres used and the needling process, the unit weight of the geotextile may not be a robust measure of the protection performance of the geotextile.

Rubber mats formed from reprocessed shredded materials have been proposed, and have been used for several years in Germany. A range of different thicknesses and grades (i.e. density) are available. Also, they have not been used to any extent in the UK since they are more expensive than the 1200 g/m^2 geotextiles. However, they may become more popular if rigorous protection standards are enforced (e.g. Saathoff & Sehrbrock, 1995 suggest that 1200g/m^2 material may be inadequate).

Protection mattresses are used in Germany and in other parts of Europe and comprise of two layers of woven geotextiles linked with spacer threads and filled with concrete or sand. The concrete mattresses have the advantage that after the concrete has hardened, not only is the protection performance enhanced, but also the stability of the lining system on steep slopes can be improved.

3. DESIRED PROTECTION PROPERTIES OF GEOPROTECTORS

The desired properties of geoprotectors can be summarised as:

1. Protection of geomembrane from mechanical damage e.g. notches, cracks, perforations.
2. Restrict strains in the geomembrane to acceptable levels (typically less than 1% strain)
3. They must perform for the design life of the landfill facility (often in excess of 100 years) and under difficult conditions, i.e. aggressive chemical and biological environment, high temperatures during biodegredation, and normal stresses that can often be in excess of 500kPa

3.1 *Method of selection/performance*

Any testing procedures for the assessment of geoprotector performance, and hence selection, must enable time effects, temperature effects and the nature of the gravel drainage material used on site to be taken into consideration. At present, the most promising approach is the use of a load bearing test which was developed in Germany as discussed by Dixon & von Maubeuge (1992). Figure 2 shows the typical arrangement of the test.

The purpose of the test is to represent the long-term performance for the geoprotector at the base of a landfill, by simulating the conditions as realistically as possible. The condition of the geomembrane is indicated by the non-recoverable deformations in the lead sheet which is situated directly beneath the geomembrane.

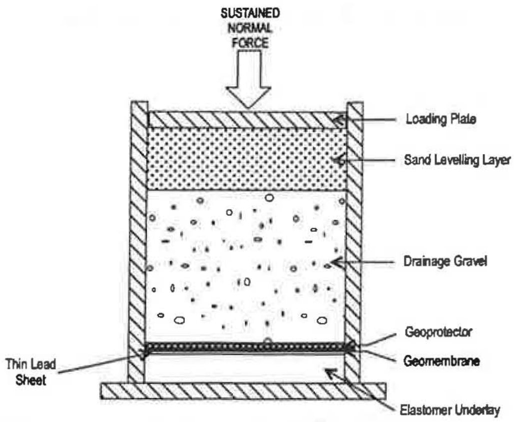

Figure 2: Load Bearing Test

This type of test is becoming increasingly popular for those assessing the relative performance of geoprotector systems, e.g. Saathoff & Sehrbrock (1995), Kirschner & Kreit (1995), Muller-Rochholz & Asser (1995) and Shercliff (1994). In the UK it is also being used by a small number of designers to assess/formulate detailed designs, and is likely to become more widely used.

Despite this test's undoubted usefulness it is however time consuming (the minimum test period being 100 hours) and hence costly. Further, the designer may not know the source of the gravel and hence its nature during the design stage. Therefore, there is a place for the use of simple index tests to assess the relative performance of protection layers, using tensile strength and puncture resistance tests, and also to assess variations in performance of a given material type. Work on assessing these tests is in progress by a number of researchers, e.g. Shercliff (1996).

A design methodology for the puncture protection of geomembranes has been suggested by Wilson-Fahmy *et al.* (1994), which comprises an empirical formulation based on the short term hydrostatic truncated cone test (Hullings & Koerner, 1991). The formulation can be used to calculate the required unit weight of protection geotextile, based on virgin polymer needle punched nonwoven geotextiles. Caution should be employed when extrapolating the formulation to recycled polymer geotextiles and other forms of geoprotectors.

3.2 *Summary*

It is clear that in the future, geoprotector design in terms of mechanical protection properties will be based on laboratory assessment using long-term performance load bearing tests. Conformance testing to ensure the suitability of material delivered to site is likely to take the form of simple index tests based on tensile strength and puncture resistance.

It is recommended that load bearing tests should be carried out to validate design assumptions, and should use the gravel drainage materials to be employed on site.

4. INTERFACE SHEAR STRENGTH

The use of geoprotectors introduces additional interfaces along which shear failure could take place, (i.e. between the geoprotector and the geomembrane and between the geoprotector and the drainage gravel). Of particular concern is the shear strength of the interface along the landfill side slopes, as this may control the overall stability of the waste/barrier system.

Although considerable international research has been done on geomembrane/soil interfaces, both against cohesive and granular materials, there is little work in the literature on geomembrane/geotextile interfaces (Stark *et al.*, 1996). Some initial results and conclusions from an extensive laboratory testing programme by the authors are presented below.

4.1 *Materials used in testing programme*

The materials tested during the laboratory programme were:

1. 2mm thick smooth HDPE geomembrane.
2. 2mm thick smooth polypropylene geomembrane.
3. Two types of 2mm thick textured geomembrane.
4. Two nonwoven needle punched polypropylene geotextiles with unit weights of 750g/m^2 and 1200g/m^2.
5. Nonwoven needle punched HDPE geotextile of unit weight 800g/m^2.
6. 4mm thick reprocessed shredded rubber mat.
7. 3 No. soil samples with a range of gradings and particle shapes to represent gravel drainage layers.

4.2 *Testing Method*

A 300mm Direct Shear Apparatus was used for the study, comprising a 305mm square top box and a 305mm x 406mm lower box. A maximum travel of 100mm could be achieved without a reduction in the area of the shear plane. This displacement enabled large strain behaviour to be investigated.

Normal loads were applied via a flexible diaphragm inflated using compressed air. A nylon block was placed in the lower container with the geomembrane placed on top and clamped to the edge of the lower container. The geotextile was placed on top of the geomembrane and clamped to the top box. This was then filled with a 100mm thickness of gravel drainage material, see Figure 3. Tests were carried out on each combination of materials at normal stresses of 25, 50 100 and 200kPa, with new geomembrane and geoprotector samples used for each test. A shearing rate of 3mm per minute was chosen as suggested in ASTM D5321. During the testing programme over 300 individual tests were carried out at The Nottingham Trent University.

4.3 *Interface Properties*

The test results indicate that the following factors influence the shear strength of the geomembrane / geotextile interface:

1. Geomembrane polymer type.
2. Geomembrane surface texturing.
3. Geoprotector type.
4. Geotextile fibre polymer.
5. Geotextile strength.
6. Gravel grading.
7. Gravel particle shape.

The peak shear strength for smooth geomembranes was mobilised at small displacements, and only a

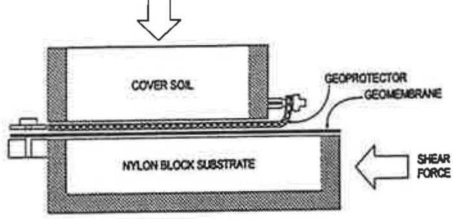

Figure 3: Direct Shear Apparatus

small reduction in shear strength was observed between peak and residual values. For textured geomembranes displacements in the region of 10 to 15mm were required to mobilise the peak interface shear strength, and significant reduction in shear strength of up to 60% were observed.

The use of a 4mm thick rubber mat geoprotector resulted in much higher shear stresses mobilised when tested against a smooth geomembrane. The peak shear stresses were very similar to the geotextile/textured geomembrane interface, but without the large strain softening behaviour with increasing displacement (Figure 4).

Typically the failure envelopes for all interfaces tested could be described by linear relationships between shear stress and applied normal stress. However, in some instances the textured geomembrane against geotextile interface failure envelope could be better described by a second order polynomial relationship. The peak failure envelopes described by straight lines for the tests results shown above are given in Figure 5.

Tests carried out using a nylon block cover above the geoprotector suggested that for smooth geomembrane the block increased the interface shear strength when compared to gravel cover soils. Conversely, for textured geomembranes, the nylon block tended to underestimate the interface shear strength. Differences in shear strength were also obtained for both smooth and textured geomembranes when sheared against geoprotectors using different soils. Therefore, the material directly above the geotextile has a controlling role in the transfer of load to the geosynthetic interface.

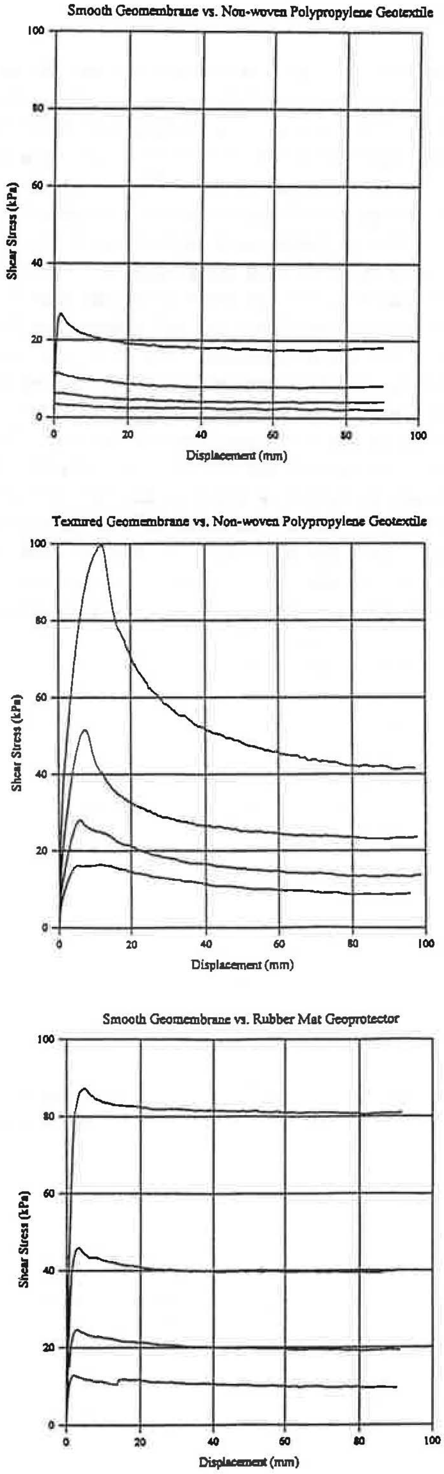

Figure 4: Shear stress vs. displacement

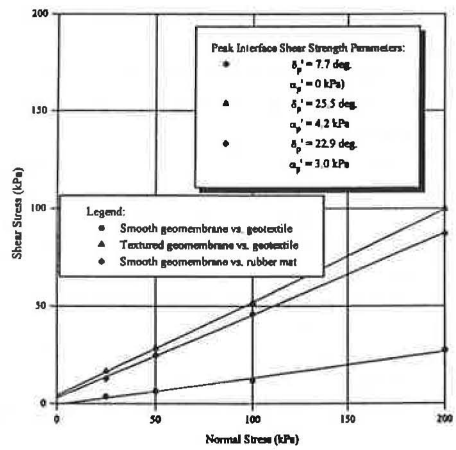

Figure 5: Shear stress vs. normal stress

In transferring the load through the geoprotector to the geomembrane the gravel can cause damage to the geoprotector. In particular, low tensile strength geotextiles such as the HDPE geotextile can undergo significant stretching and the 4mm rubber mat can start to "de-bond". Any such damage to the geoprotector usually results in scratching on the geomembrane surface during shear.

4.4 *Design Implications*

The designer should consider whether the normal stress range expected on site is compatible with the testing stress range. Appreciable apparent cohesion found from linear interpolation of some test data can be attributed to the interlock between textured geomembrane asperities and geotextile fibres. The designer should assess whether this apparent cohesion can be relied on or whether, as suggested in BS6906, it should be ignored.

It may be that for certain geosynthetic interfaces the shear strength may be better represented by a non-linear envelope. The authors have considered second order polynomial representations while Giroud *et al.* (1993) have proposed a hyperbolic relationship between mobilised shear strength and normal load.

Large displacements can be expected at the geomembrane/geoprotector induced by:

1. Dragging of the geoprotector along the geomembrane during construction.
2. Placement of the gravel drainage layer.
3. Settlement of the waste over time through degradation causing movement along the side slopes.

Byrne *et al.* (1992) in the back analysis of the Kettleman Hills failure (Seed *et al.*, 1988) concluded that large displacements and hence residual interface shear strength conditions can be mobilised along side slopes. Consequently, the design engineer must consider this in the detailed design of landfill side slopes.

4.5 *Summary*

It is suggested that performance testing should be carried out on a site specific basis since the choice of cover soils can have a significant effect on the interface shear strength. This testing should be carried out at the normal stress range anticipated on site.

The design engineer should make an assessment of whether peak or residual friction angles should be used in the analysis, and whether continuum methods would be more applicable than the limiting equilibrium methods currently employed. Further, the limit state concept of designing for ultimate and serviceability limit states should be considered.

5. CONCLUSIONS

In the selection of geoprotectors for landfill applications consideration should be given to both the mechanical protection afforded by the material, and the interface shear strength between the geomembrane and the geoprotector.

Performance testing should be carried out to assess both the above criteria, since the drainage layer material influences both the mechanical protection and the interface shear strength behaviour.

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