Difficulties associated with the specification of protection geotextiles using only unit weight

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ABSTRACT: In the majority of developed countries, landfills have full containment barrier systems. These often include a geomembrane overlain by a geotextile protection layer that in turn is overlain by a granular drainage layer. The designer is required to specify a geotextile that will both prevent damage and excessive straining in the geomembrane. At present there are two different approaches to the design of geotextile protection layers. In a number of European countries (following the lead of Germany) long-term environmental stress cracking resulting from local concentrations of strain in HDPE geomembrane is considered critical, while in the USA mechanical damage to the geomembrane is the key concern. In addition to this difference of approach, the methods used for assessing geotextile protection differ. In Europe, the performance based "Quo Vadis" tests developed in Germany is increasingly being employed, and in the USA it is common to specify the protection performance of geotextile by unit weight. This paper presents the results of an investigation and performance testing of three needle punched non-woven geotextiles with the same weight. The results show a large degree of variation in protection performance related to manufacturing process of the geotextile, and hence demonstrates clearly that unit weight should not be used as the criteria for design of geotextile protection layers

1 INTRODUCTION

It has now become common practice for most developed countries to have a full containment barrier system, together with drainage systems that allow the collection and removal of leachate. Increasingly the drainage blanket comprises of coarse gravel, which is separated from the geomembrane liner with a protection geotextile. Different countries have their own methodology for the design and specification for the protective geotextile.

In Germany, the local strain within High Density Polyethylene (HDPE) geomembrane is limited to 0.25% as measured in the "Quo Vadis" static load test (Dixon & Von Maubeuge 1992). The concern is that any significant local strain will cause stress, resulting in potential environmental stress cracking. In the US however the role of the protection geotextile is seen simply as preventing the puncture of the geomembrane with no limit given for the local strain. As a result designers are faced with difficulties in designing the right protective geotextile.

In many countries the practice has been to design and specify the geotextile by their mass per unit area (unit weight). However it has been postulated, e.g. Shercliff (1996), that the protection performance is governed by the types of fibres, manufacturing process, and quality of fibres.

This paper highlights the results of an investigation to show the dangers of specifying geotextiles by their unit weight. Results are presented of both index and performance testing of three needle punched geotextiles with the same weight but different manufacturing qualities. Reasons for the variation of performance are discussed, and theory describing geotextiles postulated.

2 GEOTEXTILE PROTECTORS

Over the years many countries have adopted a gravel layer for drainage of the leachate, which has resulted in the need for a protection geotextile, to ensure the long term integrity of the leachate barrier. As a local source of stone is preferred to help reduce the carbon footprint, this has caused many different stone sizes and shapes to be used. This in conjunction with the different depths of sites has lead to site specific designs being required. The key requirement is to prevent damage to the geomembrane, and in the case of Europe to prevent stress cracking.

As the geotextile is only the top layer of the composite system, which includes a geomembrane and mineral liner it is complex to design. We also have to take into consideration the influence of temperature and time (creep). Given these controlling factors it was unrealistic to expect a simple index test, or methods of characterising the geotextile, to provide an assessment of the field performance of the protection layer. So a more rigorous approach was adopted.

3 CURRENT DESIGN METHODS

3.1 *Design based on puncture resistance*

The design of geotextile protectors is widely carried out in the USA using the method proposed by Narejo *et al.* (1996). This method is based on a factor of safety applied to the puncture resistance of the combined geotextile/geomembrane system. These authors developed an empirical formulation to determine the required unit weight of the protection geotextile for a site specific application. First the short-term failure of the geotextile/geomembrane system is determined based on Pyramid Puncture Resistance test, ASTM D 5494-93, and modification factors are then applied to correlate this data to actual field conditions. These modification factors are then applied to account for creep, chemical and biological degradation.

The maximum allowable pressure Pallow, is related to the unit weight of the protection geotextile and the stone size, and for a 1.5 mm thick HDPE geomembrane and a virgin polymer needle punched non-woven geotextile, this is given as:

$$\text{Pallow} = 450 \frac{M}{H^2}$$

where M is the mass per unit area (unit weight) of the geotextile, and H is the effective protrusion height (one half of the stone diameter). This method makes a number of assumptions that may not always be correct.

One of the main assumptions made in the development of this theoretical model is that there is frictionless contact between the protrusion and the geotextile, see Wilson-Fahmy *et al.* (1996). This assumption, together with the assumed uniform protrusion shape, idealises the model to such an extent that the mechanism for transferring the applied force through the geotextile is not considered. As described in Section 7, the authors believe that consideration of the transfer of force through the geotextile is a fundamental part of understanding the protection performance of a needle punched non-woven geotextile.

3.2 *Design based on limiting geomembrane strain*

This design method takes into consideration the long term performance of the geomembrane under local strain, due to the concerns about stress cracking. The concept of limiting the local strains on the geomembrane is based on creep tests carried out in Germany on pipes made from the same HDPE resins used in geomembranes. Based on this work the “Quo Vadis” working group (Dixon & Von Maubeuge, 1992) decided that a value of 6% total elongation of a geomembrane is the maximum allowable for it’s satisfactory life-time performance. A safety factor of 2 was applied, thus setting a permissible total elongation of 3%. Allowing for strains induced by installation and long-term settlement of the sub-strata, the group set 0.25% local strain from the accelerated testing as the limit.

The strains in geomembranes in landfill applications, underlying geotextile protectors are now routinely assessed in Germany and the UK using the cylinder test, first used in a research project in Hannover University. It was subsequently developed as a practical performance test by Geofabrics Ltd in the UK, then adopted and formalised by the UK Environment Agency (1998). It is used as a design tool for selecting the appropriate protector geotextile for specific sites.

The geotextile must provide sufficient protection if there is: no damage to the surface of the geomembrane in terms of cracks, no sharp indentations, and the local strain is less than 0.25%, this is measured by; “The difference between the deformed length of a straight line between two points on either side of a deformation, and the un-deformed length between the same two points, divided by the un-deformed length”.

CEN developed EN ISO 13719 “Determination of the long term protection efficiency of geotextiles in contact with geosynthetic barriers”, based on the cylinder test using standard loading and a standard aggregate (ball bearings). Appendix B goes on to describe the procedure for a performance test similar to the EA methodology.

4 MANFACTURE OF NEEDLE PUNCHED NON-WOVEN GEOTEXTILE PROTECTORS

4.1 *The manufacturing process*

A manufacturer of needle punched non-woven geotextiles is essentially converting a raw material of short (staple) length fibres into a wide sheet. The fibres are first opened out by a coarse combing method, then spread out on a bed and carded, or fine combed, to produce a thin sheet (or web) of fibres on a conveyor belt. This thin web is then laid in a concertina fashion using a cross lapper across the required width of the geotextile, in order to form a thick cushion of fibre (a bat). The bat is then guided towards a (tacker) loom and needled through several looms to form a sheet and is then rolled and bagged ready for dispatch.

4.2 *Designing a product by manufacturing methods*

To ensure market competitiveness the aim would be to produce a non-woven geotextile that meets the optimum performance criteria, at the minimum cost. The factors that have both performance and cost implications are:

- Fibre type – polymer, diameter, cross sectional shape, length, tenacity, crimp, additives;
- Fibre blend – mixture of different types of fibre usually different diameters, but could have more variations;
- Fibre lubrication – to reduce heating effect when needles pass through;
- Needle design – length, cross sectional shape, cross sectional area, number kick and, position of barbs;
- Needle density on board and needle pattern;
- Needling rate – often relating to three separate needle looms.

The two design criteria's outlined in Section 3 could result in two different protection geotextiles being preferred. An extreme example of a possible approach would be if a plant was setup to produce a non-woven geotextile in the quickest time possible with a target unit weight. The following factors would be considered:

- Fibre type – cheapest polymer that could be needled, random mix of diameter, length, tenacity and crimp;
- Fibre blend – use random waste fibre;
- Needle design – cheapest to achieve minimum entanglement of fibres;
- Needle density – as widely spaced as possible;
- Needle rate – as quick as possible;

The finished product would be inconsistent, with low performance characteristics, and nearly impossible to perform factory production control and CE marking on, yet it would meet the unit weight requirement. Despite this problem it is encouraged by designers using unit weight at a risk to the client.

5 DESCRIPTION OF THIS INVESTIGATION

To highlight the difference in performance using unit weight specification, three non-woven geotextile with the same weight were subjected to both an index test and performance laboratory test. The geotextiles were:

- Geotextile A – high performance geotextile with a unit weight of 1000gsm
- Geotextile B – medium performance geotextile with a unit weight of 1000gsm
- Geotextile C – low performance geotextile with a unit weight of 1000gsm

GEOfabrics Limited used the same machinery to produce all three geotextiles, yet each geotextile had a different fibre blend and different punch densities.

5.1 *Index testing*

A series of index tests were carried out on each geotextile as follows: Mass per unit area (BS EN 965); CBR puncture resistance (BS EN ISO 12236); tensile strength (BS EN ISO 10319); cone drop (BS EN 918); and thickness (BS EN 964-1:1995). These tests were carried out to categorise the three products, and should be noted they do not necessarily give an indication of performance on site. However there is good statistical evidence to suggest that the CBR puncture strength & displacement represents the closet indication of the protection performance of a needle punched non-woven geotextile. This is likely to be related to the fact that in the CBR test the force which is applied in similar way to that of drainage stone would with loading in the field, it also takes into account the bending and stiffness of the geotextile. These arguments will be explained in Section 7.

5.2 *Performance testing*

To simulate site conditions more closely the static load test or "cylinder" test was used in accordance with the guidelines published by the UK Environment Agency (1998). The cylinder test consists of a 330 mm diameter segmental cylinder which has a lower plate supported by three load cells. On this plate a dense rubber pad is placed simulating a clay base. A lead tell-tale sheet is placed on the rubber to make a permanent record of geomembrane deformation. For European sites a 2mm HDPE geomembrane is placed on top of the lead plate, followed by the protection geotextile. 300mm of the proposed drainage aggregate is then put on top of the protection geotextile. To complete the test, a geotextile separator is put between the aggregate and a sand layer. A steel plate closes the cylinder and the load is applied for 100 hours, (see figure 1).

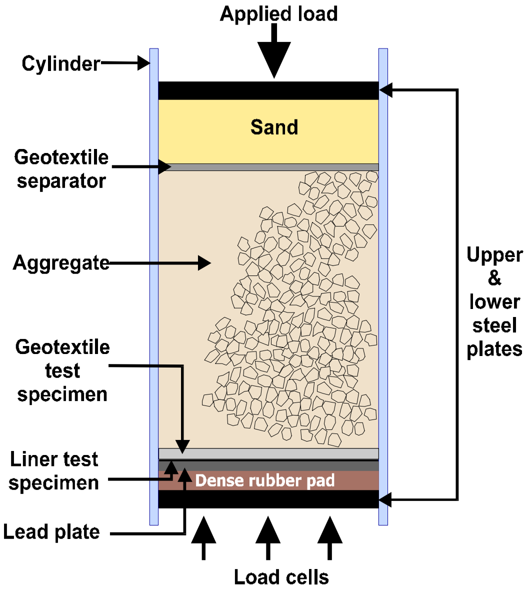

Figure 1.

The cylinder is then dismantled and the lead plate recovered. The three greatest indentations are measured and recorded.

A specific UK landfill site was chosen as being typical of many in the UK. Materials used on this site included: 2 mm HDPE geomembrane liner, the 1000gsm geotextile protector, and a sub rounded split 10 to 20 mm flint drainage gravel. Since the test was carried out at a temperature of 20°C and was for duration of 100 hours, a load simulating the depth of landfill (21 m) was multiplied by a combined factor of Safety of 2.5

6 RESULTS OF THIS INVESTIGATION

6.1 Index Testing

The results of the index testing carried out are summarised in Table 1. The numbers represent the mean of five individual tests carried out on each geotextile.

Table 1. Results of index testing

Property	units	Geotextile Type		
		A	B	C
Mass per unit area	gsm	1,000	1,000	1,000
CBR puncture strength	N	11,443	7,974	7,353
CBR displacement	mm	58	73	86
Tensile strength (MD)	kN	41	38	24
Tensile strength (XMD)	kN	110	78	66
Elongation (MD)	%	101	165	240
Elongation (XMD)	%	52	124	135
Cone Drop	mm	1.4	1.0	0.0
Thickness under 2kPa	mm	6.22	7.14	11.35
Thickness under 200kPa	mm	4.26	4.98	5.37

As can be seen from the results all the materials are different apart from the Mass value. You will also note that geotextile A is significantly higher in the CBR puncture value than the other two geotextiles. It is also interesting to note that the CBR values of Geotextile B & C are similar yet their tensile strengths and CBR displacement are significantly different.

If we keep with the assumption that CBR is the best indicator of site performance then Geotextile A should perform much better than Geotextile B & C, and the latter two should perform similarly. However if the tensile strength in machine direction is the best indicator then the difference between the three products should not be so great. However there is speculation that the CBR value and MD tensile value work together.

6.2 *Performance testing*

After carrying out the cylinder tests the lead plates were examined and the three worst indentations were measured and recorded. As detailed in the testing procedure (Environment Agency, 1998) the mean strains were calculated for each of the three largest indentations. The results are summarised in Table 2 in accordance of the EA methodology (1998).

Table 2. Summary of Performance testing results

Mean strain per dent	Geotextile Type		
	A	B	C
Dent 1	0.11%	0.54%	0.79%
Dent 2	0.10%	0.40%	0.66%
Dent 3	0.09%	0.33%	0.30%
Mean	0.10%	0.43%	0.60%

7 DISCUSSION

7.1 *Test results*

It is clear from the three results that the field performance for the geotextiles will differ. The test results show that Geotextile A has the lowest strain and is the only product to pass the 0.25% criteria (following the "Quo Vadis" guidance). Geotextile B & C would have failed and not be accepted onto the site.

If we compare the performance test results, against the index test results, we can show that the CBR puncture values, the CBR displacement values and the MD tensile values follow the same trend. The machine direction tensile strength test produces only a small difference between products A and B. The CBR displacement values are consistently different between the three products, and the cylinder test produces a significant difference. The main conclusion that can be drawn from the cylinder tests is that geotextiles with the same unit weight produced differently will perform differently on site applications.

7.2 *Inter-fibre friction theory*

It has been proposed that the protection performance of the nonwoven geotextile is strongly related to the inter-fibre friction (see figure 2).

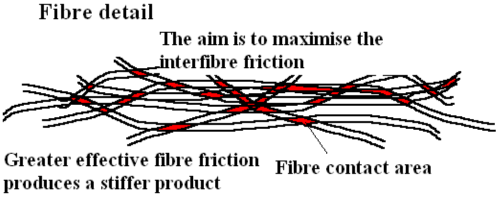

Figure 2.

The loading of geotextile/geomembrane system can be considered in two parts. The first is the compression of the geotextile, and the second is the combined subsequent geotextile compression and geomembrane deformation. These two stages are shown in figures 3 & 4. During the initial loading from the waste, the geotextile protector will compress (Figure 3). As this happens two zones of influence will develop. Firstly Zone 1 is located beneath the lowest part of the stone. In this zone, the geotextile fibres mat down during compression, and there is no re-alignment of the inter-fibre friction.

In areas surrounding the base of the stone (Zone 2), the vertical force from the waste can be resolved into components acting normal and parallel to the stone/geotextile interface. These results in shear forces being induced into the geotextile, and these will be transmitted into a combination of tensile forces along the fibres and frictional forces between fibres. The more force that can be distributed in this manner, the less compression the geotextile will undergo for a particular load.

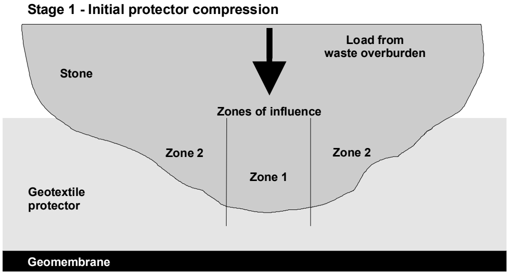

Figure 3.

Once the geomembrane beneath the geotextile begins to deform (Figure 4) additional frictional forces are generated at the geomembrane/geotextile boundary (Zone 3). The most efficient structure of geotextile fibres would be a matrix of stiff, high surface friction fibres intertwined such that a stone receiving a lateral load would transfer this load through the fibres to produce an evenly distributed load to the geomembrane.

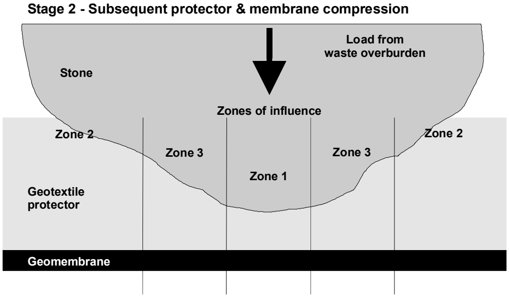

Figure 4.

The vertical and horizontal components of this load would be translated through the matrix of fibres. Settlements and strains would occur until equilibrium was reached, but their magnitude would be reduced. This model of geotextile behaviour under stone load would explain the observed correlation between performance, CBR puncture strength & displacement. The proposed model can also be used to explain why unit weight can not by itself result in adequate protection performance.

Use of poor quality fibres in conjunction with a low level of needling, will produce a geotextile that cannot generate significant tensile forces along the fibres or high friction between fibres. Hence, load will be transferred to the geomembrane, thus increasing strains. In addition, the loose assemblage of fibres means that large strains will be required to mobilise the tensile and friction fibre forces, and this will again lead to larger strains in the underlying geomembrane.

8 CONCLUSIONS

At the start of this paper we set out to explore the different practices between Europe and North America. We also set out to examine if you can specify a protection geotextile purely by its physical property of mass per unit area. Through carrying out both index test and performance test of three different products, all with the same unit weight but manufactured differently using different fibres, will result in different technical characteristics and subsequently result in performing differently in real life applications. So protection geotextiles cannot be specified by unit weight alone.

We have also shown that not one test on its own is sufficient to specify a protection geotextile, and that a number of factors need to be considered.

From the results we believe that the CBR puncture strength & displacement test give the best indication, but they also need to be used in conjunction with the wide width tensile test, mainly in machine direction. We also believe that the fibre used and the manufacturing method should also be taken into account.

The last point this paper shows is all designs where possible should be accompanied by a real life performance test to not only back up the design, proving the material is fit for purpose, but also optimizing the material for the specific site application.

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