

DESIGNING WITH THE CYLINDER TEST

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ABSTRACT

Landfill closure techniques in recent years have matured and standardised. The use of a geomembrane-clay liner composite has become the most common form of engineered liner system in the UK. The standards for selection, production and installation of geomembrane liners is well defined. Recently the design criterion for geotextile protectors has improved. Engineers now have a researched and proven methodology for selecting a geotextile which will adequately protect the geomembrane from the overlying stone drainage blanket. The cylinder test or plate load test has now been adopted by the Environment Agency as the definitive proof statement for the suitability of a geotextile protector to a geomembrane in the base of a landfill. The author and colleagues carried out the necessary research and refined the test to enable the general acceptance of this useful tool.

This paper includes a description of the test procedures sighting the critical elements and shares the experience of over 200 cylinder tests carried out on different geotextile/geomembrane/stone combinations for UK sites which have now been constructed.

INTRODUCTION

High Density Polyethylene geomembranes are extensively used as basal and capping layers for landfills and contaminated land containment sites. The material is readily available and produced at a consistent and high standard and the methods of production testing and installation are well established. Once laid a protective geotextile layer is placed before a stone leachate drainage blanket is placed on the surface. The stone drainage blanket has to be free draining and have sufficient hydraulic conductivity to drain leachate over a large relatively flat area. Its secondary function is to provide a robust defence against the placement of the first layer of waste. There is an incompatibility between a smooth membrane and a coarse drainage stone and it has been shown that this relatively stiff membrane is susceptible to stress cracking if strained over a long period of time. The function of the protective geotextile is therefore to present a relatively smooth surface and uniformly distributing the load applied to the upper surface of the geomembrane. The task of the cylinder test is to simulate as closely as possible the conditions expected in the base of a landfill.

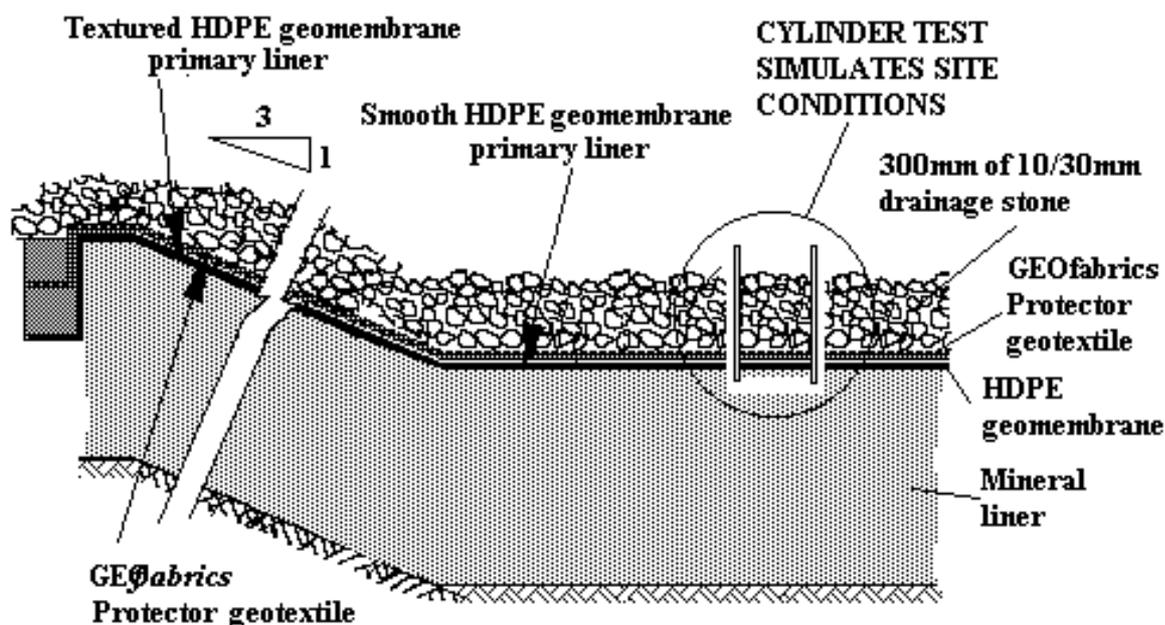


Figure 1: Simulation of the liner system at the base of a landfill

THE CYLINDER TEST

Over the last 5 years the method of specifying a geotextile protector has moved from a rule of thumb approach based on anecdotal experience from Germany and the USA to a method using a test which acts as a design tool for a particular site. The cylinder test was first invented in Germany and researched by the Quo Vadis group of laboratories. German tests naturally were carried out to suit the landfill design regulations defined by the German government research and standards institute BAM. The criteria was that designs should be based on 60m deep landfills using one type of hard angular stone 16-32mm diameter. Whilst a large amount of research was carried out the final recommendation was that the minimum allowable geotextile was a 2000g/m² could be used and only in special circumstances. It is difficult to make quality geotextiles above 2000g/m² and it is uneconomic to ask a contractor to lay two layers of geotextile. The conclusion was, at the time, that the test was too variable and the results were not commercially viable. It was at this time that the author and colleagues carried on the research and adapted the test for UK conditions. The pass/fail criteria defined by the Quo Vadis group was retained. The difference was that a more site specific design approach was acceptable in the UK where typically sites are 20-30m deep and acceptable stone types are between 5mm and 30mm in diameter. Consequently solutions were within the range of economically viable geotextiles.

The key advantage of using the cylinder test is that a designer is able to balance the cost and availability of a particular stone with a particular geotextile to find the optimum solution.

The Environment Agency Standard

"A Methodology for Cylinder Testing of Protectors for Geomembranes"

[Environment Agency, March 1998] has now been widely published and is now being used as a performance test to determine the optimum cover material for the geomembrane. This standard is available from the Regional Waste Manager, Warrington Office, Cheshire and describes in detail the apparatus, method, calculation and reporting required. There follows comments on key parts of the procedure.

The idea of the cylinder test is to simulate the cross section of the base of the landfill. The most typical cross section is shown in Figure 2.

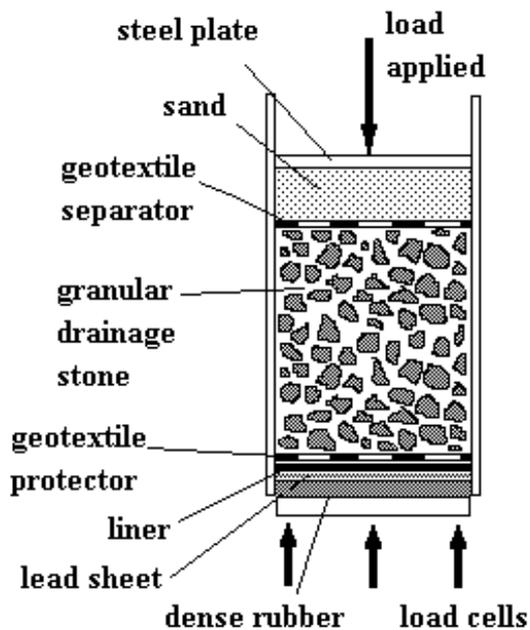


Figure 2: Typical cross section of cylinder



Figure 3: Assembled cylinder

The construction inside the cylinder from the bottom up is:

1. Three load cells support a stiff circular metal plate - these measure the direct load received by the geomembrane;
2. A thick rubber pad of a defined hardness - this is to simulate a compacted mineral liner e.g. clay
3. A thin flat metal sheet of defined stiffness (usually 1.3mm thick grade 3 lead) - this is a tell-tale sheet that deforms and maintains the deformed shape of the underside of the geomembrane
4. The proposed geomembrane (usually 2mm HDPE)

5. The proposed protection layer (usually a thick needle punched staple fibre non woven geofabric)
6. The proposed aggregate placed to a depth of 300mm - this is the usual required depth in the landfill.
7. A separator geotextile and 50mm sand layer - for load spreading
8. An upper steel plate with loading device

The procedure

The samples of stone, fabric and membrane are selected as typical and checked for obvious flaws. The cylinder built up to the cross-section as shown is often segmental in design so that the liner components can be placed and removed easily. Usually an additional layer of geotextile is placed around the wall of the cylinder to reduce the very high friction loads that occur. The placing of the stone is most critical to ensure reasonably consistent results. The aggregate is mixed to BS 812 and the stone is placed uncompacted in 3 layers to the final depth. Once the sand is in place it is tamped lightly to ensure a direct load throughout the cylinder. The load is gradually applied over one hour up to the final load and then maintained at this load for the duration of the test. The gradual increase in the applied load is to allow some bedding down of the stone and to partially simulate the increase in load that would occur on site.

The pressure calculation

The load applied includes the dead load of the waste mass and any overburden load. Factors of safety are applied in addition which have been derived experimentally to simulate the long-term plastic deformation behaviour of HDPE sheet. It is known that the HDPE continues to deform under constant load and also at higher temperatures (plastic deformation). The factors required to take account of these are:

- 1.5 times the dead load for tests carried out at 40°C and 1000hrs
- 2.25 times the dead load for tests at 20°C and 1000hrs
- 2.5 times the dead load for tests at 20°C and 100hrs

Example: A landfill with 20m waste and waste density 1000kg/m³ and a 100hr test at 20°C the test pressure would be $20 \times 1000 \times 9.81 \times 10^{-3} \times 2.5 = 490.5 \text{ kN/m}^2$ (which is effectively the load received from a 49m deep landfill)

Deformation measurement

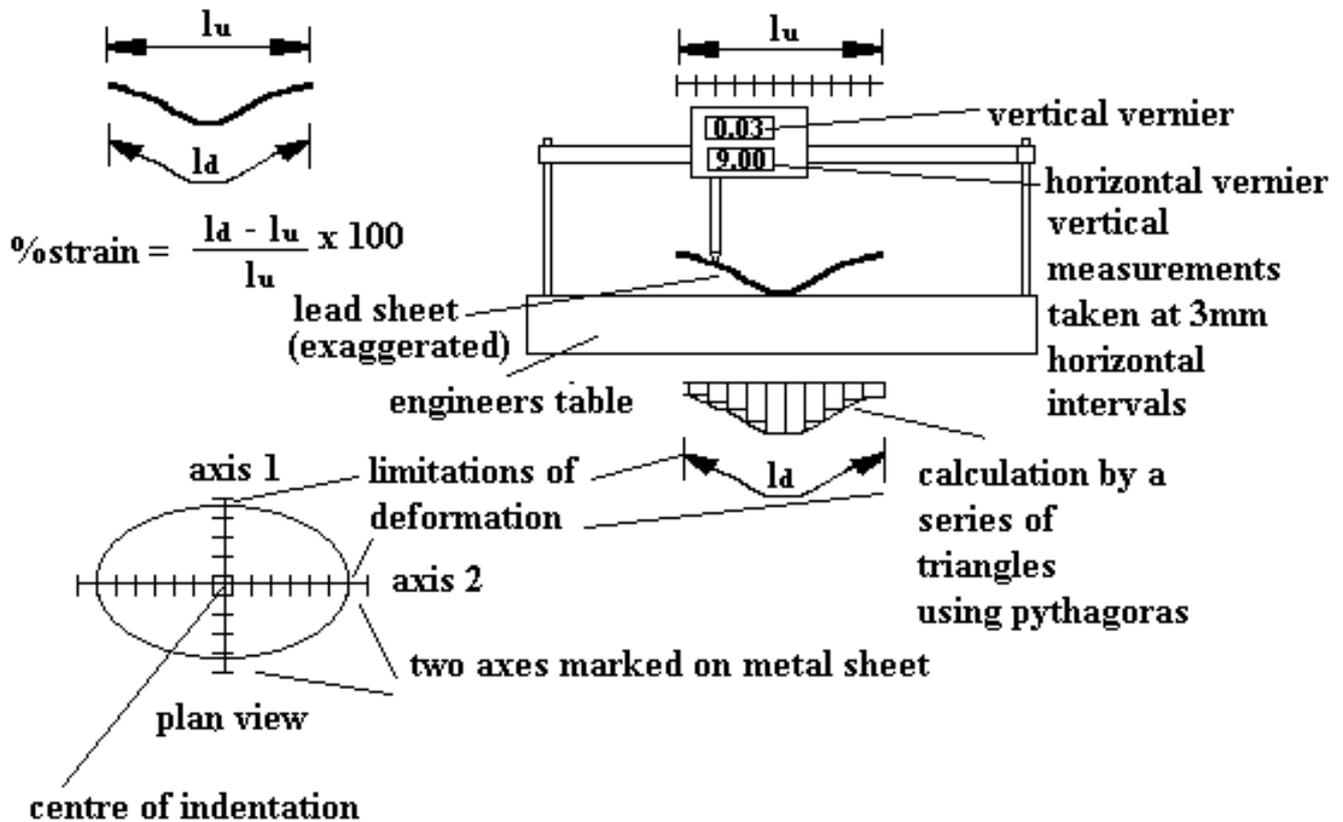


Figure 4:
Method of measurement of lead sheet

Once the cylinder has been carefully dismantled the metal sheet is removed to an engineers table mounted with horizontal and vertical vernier measuring devices. The aim is to find the maximum strain caused by the most damaging stone that was in contact with the protector. A minimum of three of the deepest indentations are selected. On each deformation two axes are drawn at right angles. Using the vernier device vertical measurements are taken at 3mm intervals across the indentation along each of the axes.

Calculation of strain

The undeformed length l_u (shortest) is calculated from the first and last measurements across the axis. The deformed length l_d (locus of curve) is calculated by using Pythagoras to calculate the slope lengths of each increment and finally adding the increments to give the total length. The strain is calculated as a percentage as shown in Fig 4:

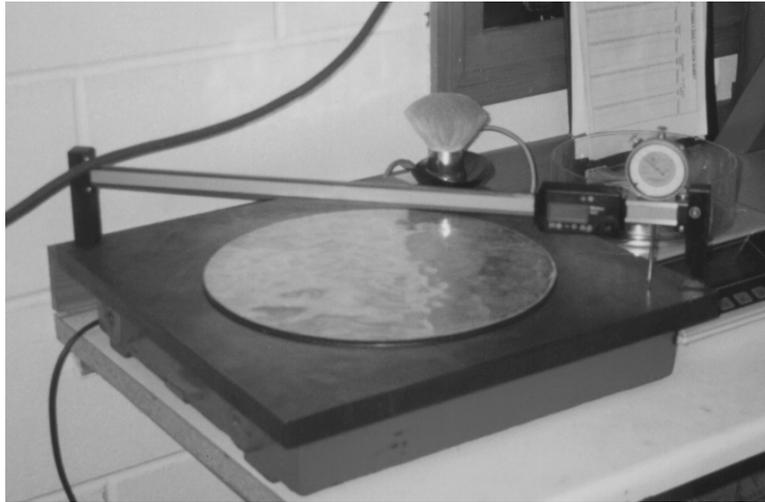


Figure 5: Deformed metal plate ready for measurement on the Engineers table

Reporting

A report is then prepared:

Naming the laboratory; referring to the test method and any agreed variations; the conditions of the laboratory; the type and appearance of materials tested before and after test; record of the load and duration of the test, the results of the strain measurements.

Results

The percentage strain of the three greatest indentations is reported along with the average. The Pass/Fail criterion is at present 0.25% allowable strain for any one indentation. The significance of choosing a minimum of three indentations is to a) reduce the possibility of missing the worst indentation, b) help with deciding if a rogue result has caused a failure through bad sampling of the stone, for instance.

Laboratory Records

Apart from maintenance of records the most important record of testing for the laboratory is the calibration of equipment used. The most critical are the metal plate and the rubber pad.

There is a specific annex to the report that defines the metal sheet to be used and a test that ensures that the plate deflects in a consistent manner under identical loads. The original material used by the Quo Vadis group was a thin organ pipe material that was not readily available in the UK. A test was devised to compare the indentation depth with a standardised method. This then allows laboratories the option of using other types of metal if they so choose. A spherical metal ball is clamped into a standard compression testing rig. A mini rubber pad is set up with the test metal on its surface. The ball is lowered onto the surface and at a set rate until a load of 250N is reached. The depth of the indentation should be greater than 2.5mm for acceptance.

Comparison tests between the original organ pipe material and the British Standard 1.3mm lead sheet grade 3 proved successful. The lead sheet is now commonly used.

The rubber pad is tested for hardness at regular intervals, as this tends to soften over time due to the high and irregular loads.

RESEARCH RESULTS

The author and colleagues have now carried out over 200 cylinder tests (equivalent to over 2 years of continuous testing) and as with any site specific simulation tests there is variation. However there are certain patterns which are emerging which can help with the selection of a stone/geotextile combination. Fundamental research [SHERCLIFF, 1996] has shown that it is puncture resistance of this type of geotextile (as defined by BS EN ISO 12236 – CBR Puncture Resistance) which defines its ability to protect a membrane. The following table is derived from these results and is intended as an INITIAL guide for ESTIMATING PURPOSES ONLY for designers to use.

TYPICAL STONE GRADINGS

Depth of Fill	10mm	20mm	20mm	20mm	30mm	30mm	40mm	Maximum stone size
	5-10mm	10-20mm	5-20mm	20mm	10-30mm	20-30mm	20-40mm	Stone grading
10m	5000N	6000N	6000N	7000N	7000N	9000N	11000N	
15m	6000N	7000N	7000N	11000N	9000N	11000N	14000N	
20m	7000N	9000N	9000N	14000N	11000N	14000N	17000N	
25m	8000N	11000N	10000N	15000N	14000N	17000N	x	
30m	9000N	14000N	11000N	16000N	15000N	x	x	
35m	11000N	15000N	14000N	16000N	17000N	x	x	
40m	11000N	17000N	15000N	17000N	x	x	x	

TABLE 1: Initial estimates of CBR puncture values of the geotextiles which will just pass the cylinder test for a given type of stone and depth of landfill

Notes on the Table 1:

- the density of landfill waste assumed is 1000kg/m³
- the stone shapes are generally angular
- the results are to the nearest 1000N CBR puncture value and reaches a maximum of 17000N which is the strongest available needle punched non woven geotextile. It is possible to lay two layers of geotextile but this is often considered uneconomic in comparison to changing the stone size
- all tests are using the load factor - 2.5 times the dead load for tests at 20^oC and 100hrs

The patterns that have emerged in order of significance are:

- the maximum stone size in a grading tends to dominate i.e. the larger the maximum stone the more damage;
- a graded stone is less damaging than a single sized stone;
- an angular or crushed stone is more damaging than a rounded stone;
- A harder stone is more damaging than a soft stone – when reporting the post test conditions it may be significant that under the test load the stone may crush to such an extent that a large percentage of fines are produced. If there is a mix of hard and soft stone this can be more damaging than all hard, as individual stones sometimes protrude through the softer.

It is always recommended that a cylinder test be carried out for a specific site as stone types especially vary so much.

ALTERNATIVE LINER SYSTEMS

The test has been adapted to simulate a number of liner systems which include a 2mm HDPE liner, such as:

Geosynthetic Clay Liner (GCL)/HDPE liner composites (Figure 6)

Where clay quality is questionable GCL liners are being used as a supplementary composite to allow for possible puncture in the HDPE membrane. The GCL is placed onto the rubber pad fitting snugly into the cylinder and overlain by the lead plate, HDPE liner, geotextile protector and stone. The stone provides a confining pressure for the GCL to be hydrated. The cylinder is then completed as normal and the load applied. The resulting deformation on the plate will simulate the contribution the Bentonite paste in the GCL makes to the deformation characteristics.

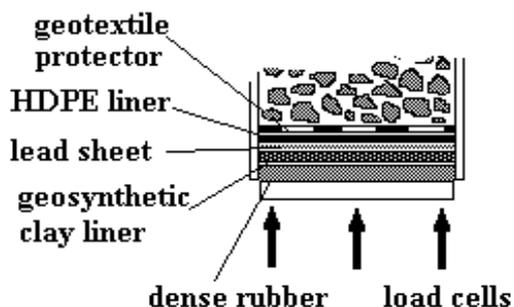


Figure 6: HDPE liner/GCL composite

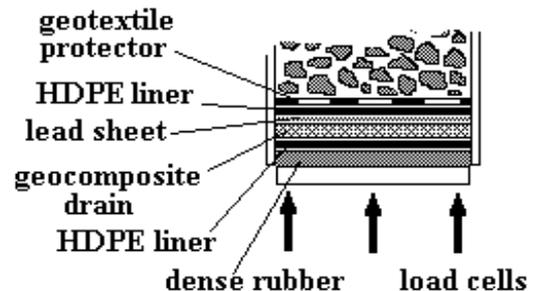


Figure 7: HDPE liner/geocomposite drain/HDPE liner

Geocomposite/ multi liner (Figure 7)

Some sites are using double layers of HDPE liners sandwiching a geocomposite leak detection layer. Often these composites are compressible and again change the characteristics of the under layer.

Vertical lining systems Example – vertical wire mesh facing.

A particular site required a test to show the ability of a geotextile to protect an HDPE geomembrane which was supported by a mesh facing to a quarry wall. The cross section was simulated in the cylinder test. A section of the mesh was introduced between the segments of the cylinder to allow it to fly past the steel walls of the cylinder therefore allowing it to distort freely under load. The lead plate showed the effect of the mesh on the liner. Several tests were undertaken with varying geotextile strengths and apertures of mesh to find the most cost-effective solution.



Figure 8: Mesh vertical walling system

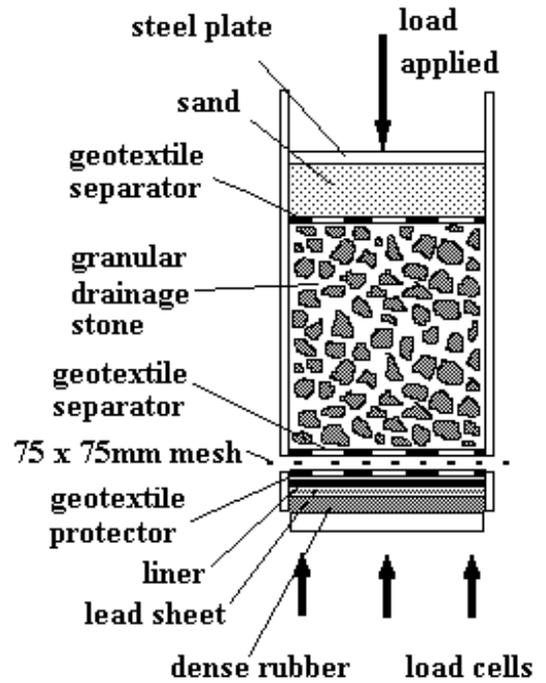


Figure 9: Adapted cylinder test with mesh

Immersion tests

The cylinder can also be adapted to allow for high temperature immersion. The factors applied in the standard are generally conservative and it is often the case that a lower cost solution can be found if the actual temperature likely in the base of the landfill (say 40°C) is used rather than ambient (20°C). This is simply achieved by lowering the whole cylinder into a large container filled with water containing a heater and thermostat

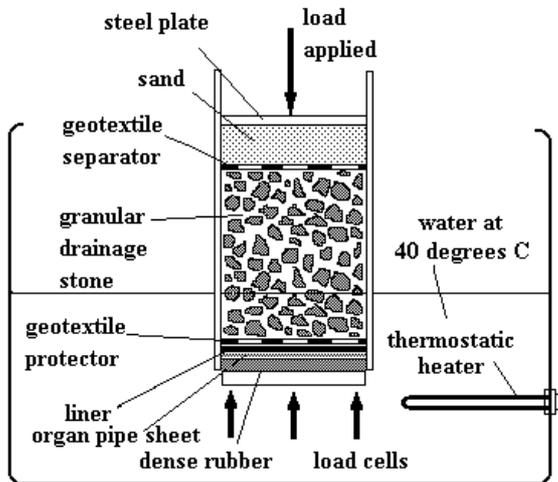


Figure 10: Immersed conditions

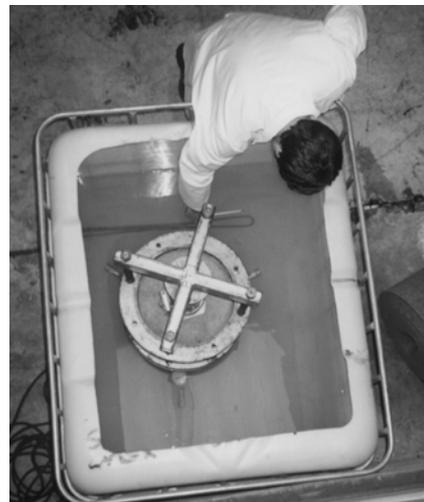


Figure 11: Checking the temperature

CONCLUSIONS

Following the research carried out by GEOfabrics Ltd and the additional research work being carried out in Germany [Brummermann, 1997] and the USA [Koerner et al, 1996] the cylinder test still remains the best design tool available to the engineer for selection of geotextile protection geotextiles in landfills. Whilst far from being perfect a sensible engineering interpretation of the results yields reasonably consistent results giving the designer and approval authorities confidence for the future. The Environment Agency has now endorsed the use of this tool for a large number of the landfill facilities in the UK.

Comments for discussion

- a) 0.25% Pass/Fail criteria – this value is extremely low in comparison to the scale of the operations on a landfill site; with the variability of the stone, liner and geotextile. There is a statistical anomaly in measuring strain to 0.01%.
- b) Modern HDPE liner polymers - the value of 0.25% is derived from experiments carried out on HDPE pipes used in landfills for 20 years and takes into account long term stress crack rupture. Polymer technology is improving all the time and new strains of HDPE polymer have been produced to reduce stress cracking. It is also significant that the extrusion of an HDPE liner has a different effect on the molecular make up of the polymer to that when producing an HDPE pipe.
- c) The method of measurement of the indentation needs further research as there is still too much leeway for interpretation especially at these very low strain values. The strain is expressed as a strain over the whole of the indentation and it is possible that the localised indentation could be more damaging than the whole. Other calculation methods should be considered using polynomial best fit curves (available on most modern spreadsheets) which will be able to model the whole of the indentation. This concept has been initially researched and proposed by Seeger (1996).
- d) Greater understanding of the way in which a geotextile protector actually fulfils its function. A number of excellent papers have been produced on this subject but which have all concluded that the heavier a geotextile is the greater the protection efficiency. The research carried out for this paper challenges that position and maintains that the puncture resistance and thickness of geotextile are the key criteria which define its ability to withstand the damaging effect of a sharp stone. It is obvious to say that the more there is of a material the bigger its effect. The key engineering definition should be the properties of that product in terms of its structure. Mercury has weight but has little structure when it comes to protecting membranes. There are very wide differences between geotextiles of the same weight and polymer in terms of structure. This can be as much as a factor of 4.

Despite these areas of concern designers, contractors and manufacturers like the test because it easily identifies with site conditions, allows the best economic materials use and selects geotextiles on directly related properties.

EUROPEAN CYLINDER TEST STANDARD

Currently within CEN an index cylinder test is in development where each of the materials used is standardised, the geomembrane is omitted and only the geotextile is varied. The resulting property is called ‘protection efficiency’. It is intended that in future a geotextile required to give long term protection to a geomembrane will be specified by its protection efficiency. The draft of this test method is expected to go for technical appraisal early in 1999.

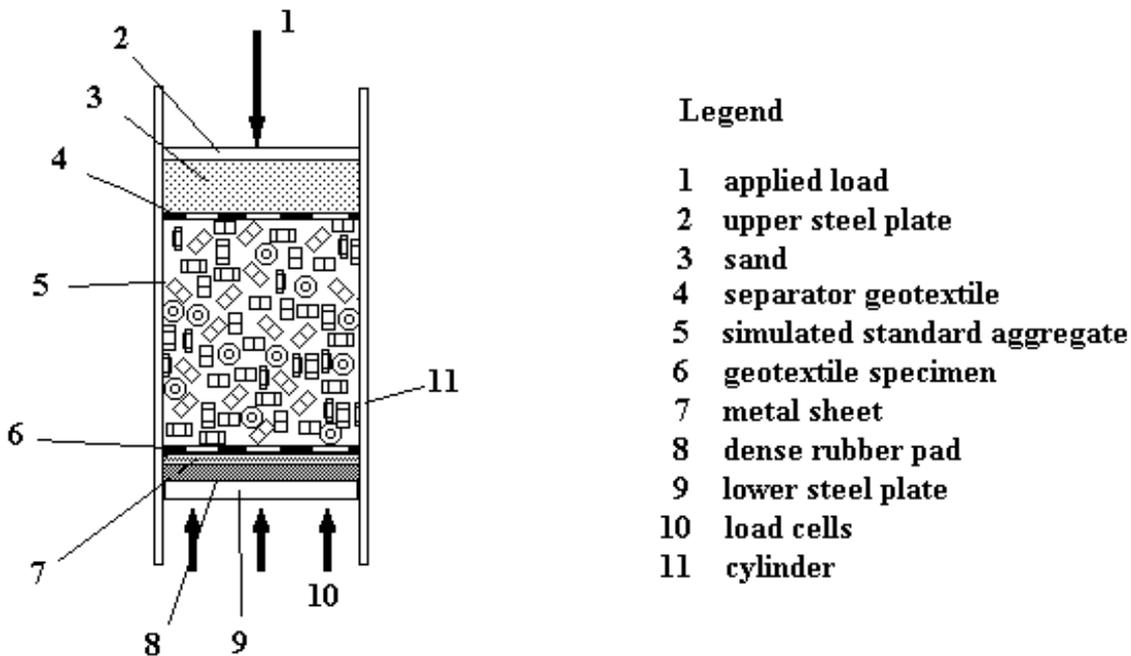


Figure 12: Proposed European (CEN) index test for geotextile protection efficiency

There is also in development an impact protection index test where the efficiency with which a geotextile will protect a geomembrane against a falling weight with a given shape and momentum is measured. This test is in its very early development stage.

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