Liner Protection with Geotextiles (HPS)
Introduction

The design of an engineered landfill is considered as a continuous project, including development, operational activity, closure and aftercare. The UK Environment Agency state that a designer should consider during planning and design any changes that are likely to occur over the whole life of the landfill and make appropriate provisions for these.

Environment Agency guidelines define the required design parameters that must be considered in landfill engineering. The inclusion of an artificial sealing layer is required in circumstances where a substantial natural geological barrier is absent. The use of a High Density Polyethylene (HDPE) geomembrane as a barrier layer for lining basal areas is the system of choice for most engineers. HDPE geomembranes are readily available and are generally produced at a consistent and high standard, with methods for material testing and installation well established (see LFE5: Using geomembranes in landfill engineering).

When installed, a geomembrane should be protected against puncture, ultra violet degradation, thermal and localised stress and stress concentrations. These include indentations that lead to stress cracking. The most effective method of protecting a geomembrane has been proven to be a thick geotextile or Geocomposite layer.

The function of the protective liner is to protect the liner from stresses, puncture and penetration from the overlying drainage media and waste; both short term dynamic loadings and long term static loadings. A protective material must protect the geomembrane through the permanent distribution of concentrated stresses on the geomembrane.
History

The first protection layers placed over early membranes were generally locally won minerals such as sands, silts and clays. The specifications for these materials were generally derived from the geomembrane manufacturer’s installation guidelines which tended to specify grain size distribution, grain angularity and minimum thicknesses. Grain size specifications ranged from less than 2mm to less than 8mm, although it was recognised that the smaller grain sizes were prone to instability when saturated and the larger grain sizes had the potential to damage the membrane.

The shape of the grain was generally specified as ‘non sharp’ although further definition of this parameter was rare, which often led to difficulties. The thickness of the protection layer ranged from 100mm to 150mm although the greater thicknesses were derived from construction practices in other engineering fields rather than any specific scientific justification.

Geosynthetic protection layers have been in use since the late 1980s and now form the majority of liner protection methods. The driving forces behind the movement from mineral protection were lower costs due to void space savings and speed of installation, with a much lower risk of installation damage.

Once installed, a protective geotextile or geocomposite layer is placed before a stone leachate drainage blanket on the surface. It is important that the stone drainage blanket is free draining and has sufficient hydraulic conductivity to drain leachate over a large, relatively flat area. The secondary function of the drainage blanket is to provide a level of protection against the placement of the first layer of waste.

There is an inherent incompatibility between a smooth membrane and a coarse drainage stone and it has been identified that this relatively stiff membrane is susceptible to stress cracking if strained over a long period of time. The function of the geotextile/Geocomposite protection layer is to present a relatively smooth surface and uniformly distribute the applied loading on the surface of the geomembrane.

The selection of an appropriate geosynthetic protection layer is now made using the cylinder test. The cylinder test is recognised as an effective method for determining the effectiveness of a material in protecting a geomembrane against the long term effects of static point loads, it is designed to simulate as close as possible the conditions expected in the base of a landfill.
The Development of the Cylinder Test

The introduction of the cylinder test transformed the way in which engineer’s specified geosynthetic protectors from a rule of thumb approach based on anecdotal experience from Germany and the United States to a method which acts as a design tool for a specific site.

Initially invented in Germany by the Quo Vadis group of laboratories, the German tests were carried out to suit the landfill design regulations defined by the German government research and standards institute BAM. The criteria was that the designs should be based on 60m deep landfills using a single type of angular stone of 16-32mm diameter. Whilst a significant amount of research was conducted, the final recommendation was that a minimum allowable geotextile for all conditions was 2000gsm. Whilst this test method was not fully implemented in Germany, the research and testing was continued by GEOfabrics in the UK, and testing conditions were adapted to suit specific site conditions. The pass/fail criteria defined by the Quo Vadis group was retained.

The approach in the UK was to view each site as unique, viewing depths and stone selection independently. The key advantage of this approach is that the designer is able to balance cost and availability of a particular aggregate with a specific protection geosynthetic to find the optimum solution.

Initial experience in the UK had been positive in providing a method of comparing different geosynthetics for their suitability as protectors. However problems arose in 1997 as the number of testing laboratories conducting the test grew and inconsistencies in the test apparatus, test method and reporting of results became evident.

In order to address this issue, a small team was formed to develop a detailed test methodology within the intension of bringing a degree of consistency to the various aspects of the test. This team included manufacturers, test houses, academia and the environment agency. Initially published in March 1998, the Environment Agency test method is now the accepted method as a performance test to determine the optimum cover material for a geomembrane. Available for download on the gov.uk website the test method describes a full method for determining the effectiveness of a material in protecting a geomembrane against the long term mechanical effects of static point loads. The Environment Agency now require a cylinder test for every new cell.

The cylinder test is designed to simulate the cross section of the base of a landfill cell.
The Cylinder Test Method

The cylinder used during the test must be of steel construction and with a minimum internal diameter of 300mm. The construction inside the cylinder from the bottom up is:

1. Three point support: Three load cells or pressure gauges support the lower steel plate of the test apparatus. These measure the direct load received by the geomembrane.

2. Lower Steel plate: Lower steel plate with a minimum thickness of 20mm, and a diameter 4mm smaller than the cylinder.

3. Dense Rubber Pad: Rubber pad with a minimum thickness of 25mm and a defined shore hardness (50A). This is representative of the lower mineral layer.

4. Lead impression sheet: A lead sheet of 1.3mm thick (grade 3) to record deformation

5. A disk of proposed geomembrane: Typically 2mm HDPE - GM13 compliant

6. Protective Material

7. Drainage Aggregate: Minimum 50KG

8. Separator Disk: Geotextile Filter

9. Levelling Sand: 50mm thick

10. Upper Steel Plate: As lower

11. Loading Device

The samples of stone, fabric and membrane are selected as typical and checked for obvious flaws. The cylinder built up to cross section is often segmental in design so that the liner components can be placed and easily removed. Usually an additional layer of geotextile is placed around the wall of the cylinder to reduce the very high friction loads that occur.

The aggregate is mixed and 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 for the duration of the test.
The Pressure Calculation

The load applied includes the dead load of the waste mass and any overburden pressure due to the depth of the waste and restoration materials. That is, (depth of waste x waste density x acceleration due to gravity) + (depth of restoration materials x density of restoration materials x acceleration due to gravity). 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:

- 2.25 times the overburden pressure for tests at 20°C and 1000hrs
- 2.5 times the overburden pressure for tests at 20°C and 100hrs

These factors have been experimentally derived from simplified extrapolations of the deformation behaviour of HDPE.

Following completion of the defined test time, the cylinder is carefully dismantled, the lead sheet is carefully removed to an engineer’s table mounted with horizontal and vertical Vernier measuring devices. The aim is to find the maximum strain caused by the most damaging stone in contact with the protector. It is important to note that the cylinder test differentiates between two types of strain:

**Local Strain**: expressed as the difference between the deformed length \( l_d \) of a straight line between two points on either side of a deformation and the undeformed \( l_u \) length between the same two points divided by the undeformed length.

\[
Local\ Strain = \left( \frac{l_d - l_u}{l_u} \right) \times 100
\]

**Incremental Strain**: the strain for each 3mm segment of the measured axes through the resulting indentation

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Incremental\ Strain = \left( \frac{l_d - l_u}{l_u} \right) \times 100 \ per \ 3\ mm \ segment
\]

**Average local strain**: expressed as the mean local strain of the two opposing axis of a single indentation on the lead sheet.

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Average\ local\ Strain = \left( \frac{local\ strain\ axis\ A + local\ strain\ axis\ B}{2} \right)
\]

**Pass/Fail Criteria**

The percentage strain of the three largest indentations is reported, along with the total average. The Environment Agency Pass/Fail criteria is that the average local strain of any single indentation must be \( \leq 0.25\% \).
GEOfabrics guidance for nonwoven protectors

The mechanism by which geotextiles cushion point loads from individual stones is complex, with the geotextile being the top layer in a system that includes the geomembrane and mineral layer underlying the membrane. In addition, the influence of temperature and time (creep) must also be considered. Specifications for geotextiles based predominantly on unit weight are common in areas, this approach is like going into a car showroom and picking a car based solely on its engine size, as though efficiency and power are not important.

The Environment Agency provides designers with the option of including mass per unit area within a specification, this use of this option should be viewed as inappropriate as it does not provide any relevant indication of performance. References to other factors, such as fibre quality, polymer type and manufacturing method (i.e. the type and amount of fibre friction/entanglement) and performance values (CBR/Tensile Strength) are much more relevant to design. It is known that geotextiles with the same unit weight can exhibit significantly different performance properties.

Inter-Fibre Friction
Jones et al proposed that the level of protection performance of a needle-punched nonwoven geotextile is strongly related to inter-fibre friction.

This theory refers to a mechanism of loading a geotextile in two distinct stages; the initial compression of the geotextile and the combined subsequent geotextile compression and geomembrane deformation.

During the initial loading, the geotextile will compress, at which point two zones of influence are developed. Within zone 1, the fibres within the geotextile matt down during compression and there is no realignment or development of inter-fibre friction. Within zone 2, the vertical force can be resolved into components acting normal and parallel to the stone/geotextile interface.

The resulting effect is that shear forces are introduced into the geotextile which are transmitted into a combination of tensile forces along the fibres and frictional forces between the fibres. The higher the level of forces that can be distributed in this manner, the lower the level of compression that the protection geotextile will undergo for a particular load.

At the point at which the protection geotextile begins to deform, additional friction/tensile forces are generated at the textile/membrane contact points. At this point the most efficient structure of geotextile is a matrix of stiff, high surface friction fibres entangled such that a stone receiving a lateral load would transfer this load through the fibres to produce an evenly distributed load to the membrane. Both the vertical and horizontal components of this load can then be translated through the fibre matrix. Settlements and strains then occur until equilibrium, at a much reduced level.

This model can be correlated with strength and modulus, and it is a clear indication that mass does not correlate with an improvement in product performance. Specification that are based on the unit weight of a product are entirely inappropriate. When referring to geotextile protectors, the role of fibre interaction is central to performance. Further development in composites for membrane protection and drainage have provided additional evidence that structure and strength are paramount.