Capping Systems
Capping Systems

Introduction

Once a landfill cell has been filled with waste, it needs to be capped with a final cover system that prevents the infiltration of liquids and provides effective management of gasses and other volatiles.

The standard components within a standard final cover system are:

- Erosion Control Layer (Topsoil)
- Protection Layer
- Drainage Layer
- Barrier Layer
- Gas Venting Layer
- Foundation Layer

Water Control and management

The landfill directive states that appropriate measures shall be taken to:

- control water precipitations entering into the landfill body;
- prevent surface water and/or groundwater from entering into the waste
- Collect contaminated water and leachate. If an assessment is based on consideration of the location of the landfill and the waste to be accepted shows that the landfill poses no potential hazard to the environment, the competent authority may decide that this provision may not apply.
- Treat contaminated water and leachate collected from the landfill to the appropriate standard required for their discharge.

Recommendations in the EU landfill directive are set out for surface sealing as follows:

<table>
<thead>
<tr>
<th>Landfill Category</th>
<th>Non-Hazardous</th>
<th>Hazardous</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas Drainage Layer</td>
<td>Required</td>
<td>Not Required</td>
</tr>
<tr>
<td>Artificial sealing layer</td>
<td>Not Required</td>
<td>Required</td>
</tr>
<tr>
<td>Impermeable Mineral Sealing</td>
<td>Required</td>
<td>Required</td>
</tr>
<tr>
<td>Drainage Layer &gt;0.5m</td>
<td>Required</td>
<td>Required</td>
</tr>
<tr>
<td>Top Soil &gt; 1m</td>
<td>Required</td>
<td>Required</td>
</tr>
</tbody>
</table>

Above: The restoration materials used for landfill capping are often poorly defined and include large rock fragments laid over poor quality protection geotextiles.
Erosion Control Layer

A fertile topsoil placed as an erosion control layer will allow for the precipitation of vegetation which reduces the impact of rainfall and decreases wind velocity at the soil surface. It is important that the selection of appropriate vegetation is considered to prevent root damage to the cover system.

Protection Layer

The protection layer can either be a separate layer to the erosion control layer, or alternatively can be a single layer performing both functions. If a mineral sealing layer is in place the selection of the protection layer must take into account the potential for frost penetration; this is not a specific issue with a polymeric barrier.

It is suggested that it is prudent to prevent the drainage layer from freezing as if it freezes its function is reduced for part of the year. The selection of an appropriate cover layer may also need to consider the possibility of burrowing animals. If a polymeric liner is used as a barrier, it is necessary to protect it, the most effective method of protection is a thick nonwoven geotextile.

Determining the required Geotextile Protection

The level and type of protection required will depend on the topsoil used in the design.....

A geotextile has to:

1. Prevent dynamic puncture and abrasion during installation of restoration material placed by heavy plant. Restoration materials often consist of poorly defined uncontrolled materials discarded from other processes, such as quarrying or building, or other soil waste. These materials frequently include large angular rock fragments or other foreign objects, which could be damaging to the membrane. (The working strain of an LLDPE liner can be as much as 8% but this is required in service, and straining the membrane, either locally or globally during construction should be avoided).

2. Cushion any sharp object in direct contact with the liner and prevent puncture both during installation long-term loading.

3. Be flexible enough to allow differential settlement without loss of protection effectiveness.

4. Retain tensile stress to reduce loads on side slopes while having good inter-face friction with the liner material.

5. Be chemically resistant (if used under cap liner protection).

Above: Pushing a thin layer of restoration material over a protective geotextile and membrane.
**Index test correlation**

Site-damage tests (see Standard landfill site and Saltayre Landfill site) along with site simulation testing in the laboratory have shown that the stiffer and thicker a geotextile the greater its potential to prevent damage to a membrane liner.

Index tests are short-term repeatable tests used to compare different geotextiles with one another and to give a standard measure of quality during manufacture. Index tests were conceived to highlight certain characteristics in any one particular geotextile and the engineer has to decide which of these tests are most relevant to the function the geotextile has to perform.

Site trials and laboratory testing have shown that the choice of geotextile cannot be based solely on one parameter but requires a number of different parameters in order to be sure that the highest level of protection is achieved.

**Thickness:** This relates to the ability of the geotextile to cushion both a dynamic load and also a long-term load imposed by a sharp object. The geotextile distributes the load on the liner by allowing load spreading through its thickness. The importance of thickness should not be underestimated when designing for membrane protection when it is fundamental to use a fully three-dimensional product.

The puncture resistance of a geomembrane can be improved by increasing the thickness of the membrane itself, however it has been shown that increasing the thickness of the protection geotextile has a greater improvement factor. The effect of increasing the thickness of the geotextile protector is significant, with huge improvements in protection levels achieved by nominal increases in thickness.

*Above: Site trial at Standard Landfill Site*
**Dynamic perforation (cone drop):** A dynamic test where a sharp cone is dropped on to a clamped geotextile producing a measurable hole in the geotextile. This simulates the damaging effect of a stone or sharp object being dumped onto the surface of a geotextile protector.

The impact energy created in this test is 0.5kg.m (1-kg cone falling through 0.5m) represents approximately half the energy created by a 75mm rock fragment falling 2 meters during tipping and placing of restoration materials. The lower the cone drop hole diameter value for a geotextile the greater its ability to absorb dynamic loads.

**Strength:** It has been shown by various studies (Wilson et al 1996, Jones et al 1998) that an increase in strength has a significant impact on protection efficiency. However, this is only relevant if it is combined with other functions. A high strength thin material would not provide significant protection. A high load, high modulus material will significantly enhance the protection levels provided.

Fibre strength, inter-fibre friction and fabric construction are the most significant things that influence protection. There are two principal tests which measure strength and modulus, Tensile Strength and CBR.

**Static puncture test (CBR):** Has been shown via research (Jones et al 1998), using the Environment Agency “cylinder” test method, that CBR relates directly to long term-membrane protection from strain.

**Tensile strength:** This measures the in-plane, ultimate, tensile strength. Whilst this resistance contributes it does not replace the need if necessary for an additional veneer design of a long steep capping slope. It is important to note that many non-woven geotextiles have differing tensile strengths (on each axis) and dependant on orientation loads will be transferred to the weakest direction.

**Design method**

The following assumptions are made:

a) A 1mm LLDPE welded geomembrane is used as the capping liner
b) The cover material is either a stone drainage layer or a cover soil with certain maximum particle size. The design event is where a number of these particles are acting together in one area of the cap under load.

1. Select maximum particle size of restoration soils.
2. Calculate the maximum allowable height that material will fall from while tipping, placing and working restoration materials.
3. Choose appropriate geotextile using the table below which gives values derived from field and laboratory testing.
4. Calculate maximum plant loading on haul roads and during the spreading of cover materials.
5. Calculate required depth of haul roads that allow for load spreading of the heaviest machines when fully loaded to prevent any unnecessary strain.
6. Adapt method statement to allow for vehicle loading or review choice of geotextile.
Table showing the minimum protection requirements, derived from laboratory and field testing, for the protection of membranes on landfill caps.

<table>
<thead>
<tr>
<th>Maximum particle size</th>
<th>Tipping and placing material</th>
<th>1 metre</th>
<th>2 metres</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Maximum Cone drop</td>
<td>BS EN 918</td>
<td>mm</td>
</tr>
<tr>
<td></td>
<td>Minimum Thickness</td>
<td>BS EN 964-1</td>
<td>mm</td>
</tr>
<tr>
<td></td>
<td>Minimum CBR</td>
<td>BS EN ISO 12236</td>
<td>kN</td>
</tr>
<tr>
<td></td>
<td>Tensile Strength</td>
<td>BS EN ISO 10319</td>
<td>KN/m</td>
</tr>
<tr>
<td>40mm</td>
<td>Maximum Cone drop</td>
<td>BS EN 918</td>
<td>mm</td>
</tr>
<tr>
<td></td>
<td>Minimum Thickness</td>
<td>BS EN 964-1</td>
<td>mm</td>
</tr>
<tr>
<td></td>
<td>Minimum CBR</td>
<td>BS EN ISO 12236</td>
<td>kN</td>
</tr>
<tr>
<td></td>
<td>Tensile Strength</td>
<td>BS EN ISO 10319</td>
<td>KN/m</td>
</tr>
<tr>
<td>75mm</td>
<td>Maximum Cone drop</td>
<td>BS EN 918</td>
<td>mm</td>
</tr>
<tr>
<td></td>
<td>Minimum Thickness</td>
<td>BS EN 964-1</td>
<td>mm</td>
</tr>
<tr>
<td></td>
<td>Minimum CBR</td>
<td>BS EN ISO 12236</td>
<td>kN</td>
</tr>
<tr>
<td></td>
<td>Tensile Strength</td>
<td>BS EN ISO 10319</td>
<td>KN/m</td>
</tr>
<tr>
<td>&gt;75mm</td>
<td>Maximum Cone drop</td>
<td>BS EN 918</td>
<td>mm</td>
</tr>
<tr>
<td></td>
<td>Minimum Thickness</td>
<td>BS EN 964-1</td>
<td>mm</td>
</tr>
<tr>
<td></td>
<td>Minimum CBR</td>
<td>BS EN ISO 12236</td>
<td>kN</td>
</tr>
<tr>
<td></td>
<td>Tensile Strength</td>
<td>BS EN ISO 10319</td>
<td>KN/m</td>
</tr>
</tbody>
</table>

**Specification**

To ensure that the material selected is supplied to site correctly and consistently it is important to provide a realistic but well-defined specification. The following is suggested as a model specification for this application:

The geotextile to be used as protection above/below the geomembrane liner shall be a non-woven material manufactured by needle-punching virgin, staple fibres of polypropylene incorporating a minimum of 1% by weight of active carbon black. Geotextiles manufactured from fibres of more than one polymer will not be permitted.

The geotextile shall have the following properties:

<table>
<thead>
<tr>
<th>Test description</th>
<th>Approved test method</th>
<th>Units</th>
<th>Typical value</th>
<th>Allowable tolerance of typical value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cone drop perforation hole diameter</td>
<td>BS EN 918</td>
<td>mm</td>
<td>#</td>
<td>+ 20%</td>
</tr>
<tr>
<td>Thickness @2kPa</td>
<td>BS EN 964 -1:1995</td>
<td>mm</td>
<td>#</td>
<td>- 10%</td>
</tr>
<tr>
<td>Static puncture strength (CBR)</td>
<td>BS EN ISO 12236</td>
<td>kN</td>
<td>#</td>
<td>- 10%</td>
</tr>
<tr>
<td>Tensile strength</td>
<td>BS EN ISO 10319</td>
<td>KN/m</td>
<td>#</td>
<td>- 10%</td>
</tr>
</tbody>
</table>
The Drainage Layer

Water that is able to penetrate through the cover soil needs to be removed by an effective drainage layer. Koerner highlights three principal functions of a drainage layer:

1. To reduce the head of water on the barrier layer, minimising infiltration;
2. To drain water from the overlying soil, allowing it to absorb and retain additional water;
3. To reduce and control pore water pressures at the interface to the underlying barrier layer and improve slope stability.

Where there is sufficient rainfall to soak overlying soils, the inclusion of a drainage layer is important in maintaining the stability of the slope. The inclusion of a drainage layer in a final cover system can make a significant difference to the design factor of safety (doubling or halving the value depending upon whether drainage is controlled).

A drainage layer may be a cohesionless soil, almost always sand or gravel. Koerner recommends a minimum thickness of 12 inches (300mm) with a minimum slope of 4% at the bottom of the layer and a hydraulic conductivity >1.0 x 10^-2 cm/sec.

A cost effective alternative to a natural drainage solid is a factory controlled geocomposite. Koerner and Daniel 97, propose the following minimum specification:

1. Hydraulic transmissivity based on site-specified design, and greater than 3.0x10^-5 m²/sec under anticipated overburden during the design life.
2. A geotextile filter layer above drainage material to prevent intrusion and clogging of the overlying protective soil.
3. A geotextile cushion layer bedding beneath the drainage layer to increase friction and minimise slippage between the drainage core and the underlying geomembrane, and to prevent intrusion, by deformation of the geomembrane into the geonet or drainage core of the drainage layer.

It is important that water is allowed to discharge freely from the drainage layer at the base of the cover system. The drainage point at the toe of the cap must be designed in a way that prevents clogging and freezing.
Determining the required transmissivity of a Drainage Composite

The required transmissivity of a drainage geocomposite is determined by its ability to transport infiltrating flow from the cover soil.

The three conditions for stability are:
1. Ensuring adequate interface shear at all surface interactions.
2. Preventing the build-up of pore water pressures to reduce contact stresses.
3. Preventing the build-up of gas pressures beneath the liner.

Using Darcy’s Law

\[ Q = k \times i \times A \]

The inflow of water into the composite

\[ = Q_{in} = k_{soil} \times L_h \times \cos \beta \]

Where:

- \( k_{soil} \) = permeability of cover soil
- \( L_h \) = Drainage pipe spacing or length of slope measured horizontally
- \( \beta \) = slope angle

The required transmissivity of the geocomposite:

\[ Q_{reqd} = \frac{Q_{in}}{\sin \beta} \]

To determine the design factor of safety:

\[ FS = \frac{Q_{allow}}{Q_{reqd}} \]

Where:

\[ Q_{allow} = Q_{100} \left( \frac{1}{RF_{in} \times RF_{cr} \times RF_{cc} \times RF_{bc}} \right) \]

<table>
<thead>
<tr>
<th>Reduction factors</th>
<th>RF_{in}</th>
<th>RF_{cr}</th>
<th>RF_{cc}</th>
<th>RF_{bc}</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1.3</td>
<td>1.1</td>
<td>1.0</td>
<td>1.5</td>
</tr>
</tbody>
</table>

Reduction factors for determining allowable transmissivity

\( Q_{100} \) is determined by subjecting the entire geocomposite to a transmissivity test in accordance with EN 12958. An initial test was conducted using GPT3- the lowest grade within the range. It can be assumed that higher (thicker) grades will have a higher flow capacity.

The test was conducted using soft/hard platens, in a standard environment (20 ±2°C, 65 ±5% RH) with a loading of 500kPa and a hydraulic gradient of 1.0 using de-aerated water.

From this test it is recommended that a \( Q_{100} \) value of \( 17.10^{-4} \) m\(^2\).s is used.