Lessons learned from landfills about liner performance and leakage

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Limitations

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Geosynthetics in Covers and Bottom Liners

There have been a very large number of successful applications.

Geosynthetics:

- work extremely well!!!, BUT
- they are engineered materials and need to be treated with the same respect as other engineered materials
Manufacturers provide many options:

- Different products are intended for different applications
- It is the engineers responsibility to select the right materials for their application
- You might get what you ask (and pay) for
- Good engineering can be relied on
- Luck is fickle
Topics

• Holes in geomembranes
• Leakage through geomembrane liners
• Leakage through clay liners
• Leakage through composite liners
  – Direct contact
  – Observed leakage
Plastics hold water well
Plastics hold water well - if no hole

Rapid water leakage through small hole
Holes in GM

- 2.5 – 10 holes/ha typical design value
- 3 holes/ha after installation*
- 12 holes/ha after placement of drainage layer*
- 5 holes/ha assumed in presentation
- Median equivalent radius – 5.6mm (typical)

* Nosko & Touze-Foltz (2000)
Topics

• Holes in geomembranes
• **Leakage through geomembrane liners**
• Leakage through clay liners
• Leakage through composite liners
  – Direct contact
  – Observed leakage
Leakage through single GM liner

<table>
<thead>
<tr>
<th>$h_w$ (m)</th>
<th>$r_o$ (mm)</th>
<th>$Q$ (litres per hectare per day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.3</td>
<td>0.5</td>
<td>500</td>
</tr>
<tr>
<td>0.3</td>
<td>1</td>
<td>2,000</td>
</tr>
<tr>
<td>0.3</td>
<td>5.6</td>
<td>63,000</td>
</tr>
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</table>

GM 5 holes/ha

Rowe (2012)
Topics

• Holes in geomembranes
• Leakage through geomembrane liners
• **Leakage through clay liners (CCL and GCL)**
• Leakage through composite liners
  – Direct contact
  – Observed leakage
Cation Exchange and GCLs

• When hydrating or when hydrated, sodium bentonite may experience cation exchange (replacement of sodium ions by other cations such as calcium and magnesium)

• This cation exchange may be caused by cations:
  – in the bentonite
  – in the pore water of adjacent soil
Cation Exchange and GCLs

- A number of publications* examining GCLs after 3-10 years use in landfill covers have indicated cation exchange and:
  - a decrease in swelling capacity (SI)
  - an increase in hydraulic conductivity of SOME GCLs by as much as 5 orders of magnitude (to $10^{-6}$ m/s) – others had no significant change in $k$
  - high hydraulic conductivity associated with low moisture content of GCL ($\leq 50\%$)
  - effect depends on local conditions (especially thickness of soil above GCL and presence of cations in adjacent soil) AND type of GCL

- Design wisely!

Degree of saturation of GCLs

Why is it important?
Because it influences:
   – the effect of cation exchange from surrounding soil on GCL hydraulic performance
   – the ability of the GCL to limit oxygen movement
   – GCL panel shrinkage, etc.

and so we need to understand what influences the uptake of moisture by different GCLs
What influences Degree of Saturation

- How the GCL is manufactured (they are not all the same - even if they use the same bentonite)
- Grain size distribution of the soil on which it rests
- Water content of the soil on which it rests
- Cation exchange
- Drying cycles
- Normal stress on GCL
Calculated leakage through a single primary liner

<table>
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<th>Liner</th>
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- CCL: $H_L = 0.6$ m, $k_L = 1 \times 10^{-9}$ m/s,
- GM: 5 holes/ha, $r_o = 5.6$mm

Rowe (2012)
Calculated leakage through a single primary liner

\[ h_w = 0.3 \text{ m} \]

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CCL: \( H_L = 0.6 \text{ m}, \ k_L = 1 \times 10^{-9} \text{ m/s}, \ k_L = 1 \times 10^{-8} \text{ m/s} \)

GM: 5 holes/ha, \( r_o = 5.6\text{mm} \)

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CCL: \( H_L = 0.6 \text{ m}, \ k_L = 1 \times 10^{-9} \text{ m/s}, k_L = 1 \times 10^{-8} \text{ m/s} \)

GCL: \( H_L = 0.01 \text{ m}, \ k_L = 5 \times 10^{-11} \text{ m/s} \),

GM: 5 holes/ha, \( r_o = 5.6 \text{ mm} \)

Rowe (2012)
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$h_w = 0.3$ m

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<td>$1 \times 10^{-9}$ m/s</td>
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GM: 5 holes/ha, $r_o = 5.6$ mm

Rowe (2012)
Topics

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• Leakage through clay liners
• Leakage through composite liners
  – Direct contact
  – Observed leakage
Leakage through GM in Direct Contact with Clay Liner

- GM
- GCL or CCL
- Interface between GM and clay liner (Transmissivity, $\Theta$)
GM/GCL Interface Transmissivity, $\theta$

- Harpur et al. (1993)
  
  $2 \times 10^{-10}$ m$^2$/s (at 7 kPa)

- Barroso et al. (2008, 2010)

  $1-4 \times 10^{-11}$ m$^2$/s (at 50 kPa) both smooth and textured GM

All for sodium bentonite – water as permeant
GM/GCL Interface Transmissivity, $\theta$

- Mendes et al. (2010)
  
  2-3x10^{-11} m^2/s (at 50 kPa) Na-Bentonite with $k_L = 3\times10^{-11}$ m/s (water)
  
  3x10^{-11} m^2/s (at 50 kPa) Ca-Bentonite with $k_L = 7\times10^{-10}$ m/s to 6x10^{-8} m/s (water)

- Rowe and Abdelatty (2012)
  
  2x10^{-11} m^2/s (at 100 kPa) before clay-leachate interaction (water) $k_L = 3\times10^{-11}$ m/s
  
  1x10^{-11} m^2/s (at 100 kPa) after clay-leachate interaction (leachate) $k_L = 4\times10^{-10}$ m/s

Compared to $> 2x10^{-8}$ m^2/s for GM/CCL

Rowe (2012)
Single Composite Liner Systems

- Waste Geotextile
- Geomembrane
- Geosynthetic clay liner
- Foundation layer
GM in Direct Contact with GCL

GM with no wrinkles; cloudy November morning when ambient $T = 3 \, ^\circ\text{C}$
## Calculated Leakage for Direct contact

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<td>0.3</td>
<td>0.2</td>
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GM: 5 holes ($r_o = 5.64$ mm)/ha

GCL: $H_L = 0.01$ m, $k_L = 2 \times 10^{-8}$ m/s, $\theta = 1 \times 10^{-10}$ m$^2$/s

Rowe (2012)
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GM: 5 holes ($r_o = 5.64$ mm)/ha

GCL: $H_L = 0.01$ m, $k_L = 2 \times 10^{-8}$ m/s, $\theta = 1 \times 10^{-10}$ m$^2$/s

CCL: $H_L = 0.6$ m, $k_L = 1 \times 10^{-9}$ m/s, $\theta = 2 \times 10^{-8}$ m$^2$/s

Rowe (2012)
Composite Liner Topics

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## Observed leakage

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<td>Mean (Typical)</td>
<td>Max.</td>
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<td>Active</td>
<td>90</td>
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Based on data from Bonaparte et al. (2002) and Rowe (2005)
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<td>Closure</td>
<td>0.6</td>
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Based on data from Bonaparte et al. (2002) and Rowe (2005)
Observations

• To minimize leakage you need a composite liner

• Data shows that composite liners with a GCL perform much better than a composite with a CCL

BUT

• Observed leakages 10 to 10,000 times larger than calculated using traditional equations assuming direct contact and a reasonable number of holes/ha – why?
Lessons learned from landfills about liner performance and leakage

R. Kerry Rowe

Questions?