Lecture 22

Geosynthetic clay liners and geomembranes
Geosynthetic materials

Geotextiles – filter fabrics
Geogrids – reinforcement materials
Geonets – drainage
Geomembranes – containment
Geosynthetic clay liners – containment
Geopipe – buried plastic pipe
Geocomposites – combinations of above
Geo-Others – specialty products

Timeline for geosynthetics

Late 1950s – First use of geotextiles for erosion control

1960s – woven fabrics in use as geotextiles

1968 – First commercial product: needle-punch fabric by Rhone-Poulec Textiles in France

Late 1970s – First non-woven geotextiles used in US imported from Netherlands


MR. MCQUIRE: Ben - I just want to say one word to you - just one word -

BEN: Yes, sir.

MR. MCQUIRE: Are you listening?

BEN: Yes I am.

MR. MCQUIRE: Plastics.

BEN: Exactly how do you mean?

MR. MCQUIRE: There is a great future in plastics. Think about it. Will you think about it?

BEN: Yes, I will.

MR. MCQUIRE: Okay. Enough said. That's a deal.

“The Graduate” 1967
Historical growth in geosynthetic market

Historical growth in geosynthetic market

EPA regulations for geosynthetics

1982 – RCRA regulations require FMLs
1982 – single geomembrane
1983 – double geomembrane
1984 – primary geomembrane, secondary composite
1985 – geonet for leachate collection
1987 – primary composite, secondary composite
Composition of geomembranes

Geomembranes consist of:
- Polymers (plastics)
- Fillers
- Plasticizers
- Carbon black
- Additives
- Scrim reinforcement
Plastics in geomembranes

Thermoplastics

Example: polyvinyl chloride (PVC)
Thermoplastics soften upon heating and can be molded
Thermoplastics can be heat welded at seams in the field
Plastics in geomembranes

Crystalline thermoplastic
Also called semicrystalline
Examples: HDPE, LDPE, polypropylene
Polymeric chains are folded in a crystal lattice
Folded chains form lamellae (plate-like crystals)
Plastics in geomembranes

Crystalline thermoplastic

Non-crystalline tie-molecules connect lamellae: more tie molecules create more flexibility

Variations in molecular content change stiffness/brittleness
Plastics in geomembranes

Thermoplastic elastomers

Examples: chlorinated polyethylene (CPE), chlorosulfonated polyethylene (CSPE, Hypalon)

Elastomers

Example: butyl rubber

Thermoset plastics

Rarely used due to lack of good seaming methods
Geomembrane additives

Additives address these concerns:

**Ultraviolet degradation** – UV radiation breaks polymer chains, make membrane brittle

**Swelling** – exposure to liquids causes polymers to swell

**Oxidative degradation (aging)** – oxygen reacts with polymers, makes membrane brittle rather than flexible

Note: this takes 100’s of years, accelerated by heat
Geomembrane additives

Additives address these concerns:

**Delamination** – Separation of polymer layers

**Extractive degradation** – Extraction of particular component (such as plasticizer) from polymer

**Chemical degradation** – Reaction of leachate components or organic chemicals with liner
Composition of geomembranes

Other components:
- Fillers – small mineral particles to reduce cost and increase stiffness
- Carbon black – increases stiffness and retards UV degradation
- Plasticizers – increases flexibility
- Scrim reinforcement – embedded nylon or polyester fiber to increase strength, reduce tears and punctures
Composition of geomembranes

Other components:

- Fungicides and biocides – prevent fungal or bacterial attack
- Antioxidants – reduce oxidative degradation
Geomembrane manufacturing

Extrusion – molten polymer is extruded in a non-reinforced sheet

Spreading – coating of fabric with polymer

Calendering – heated polymer passed through series of rollers

Sometimes with two sheets or with scrims
High-density polyethylene (HDPE)

Semicrystalline thermoplastic

Typical content:
- 97% polyethylene
- 3% carbon black (for UV resistance)
- Traces (up to 1%) of stabilizers and antioxidants

Extruded Properties:
- Most chemical resistant liner material
- Low permeability
- UV resistant (especially with carbon black and antioxidants)
- 30 mil to 140 mils thick

Most widely used geomembrane
Linear low-density polyethylene (LLDPE)

Also called very flexible polyethylene (VFPE)
More flexible than HPDE – used for non-uniform surfaces such as lagoons, pond liners, landfill caps
Semicrystalline thermoplastic
Extruded
Properties:
- Withstands tension, high elongation capability
- Puncture and stress-crack resistant
- Good chemical resistance
- Low permeability
- Good UV resistance
- 40 to 100 mils thick
Coextruded HDPE and LLDPE

Example: HDPE/LLDPE/HDPE
   10-20% of thickness from HDPE – for chemical resistance
   LLDPE for flexibility
Not a laminate—molten polyethylene bonds at molecular level

Applications:
   White/black coex for exposed geomembranes (white side to sun to reduce temperature)
Coextruded HDPE and LLDPE

High/low carbon coex – high-carbon layer can carry an electrical current

Electrical charge is applied to high-carbon layer on underside – brass wand brushed on surface will spark at any holes:

Brass wand

Electrically charged layer
Flexible polypropylene (fPP)

Usually scrim-reinforced for high tensile strength (fPP-R)
36 or 45 mils thick
Used for floating covers on surface impoundments, other high stress applications
Good chemical, UV resistance

\[ \text{CH}_3 \]

\[ \text{C} \quad \text{C} \quad \text{H} \quad \text{H} \]
Polyvinyl chloride (PVC)

One of earliest geomembranes
Typical mix: 35% resin, 30% plasticizer,
25% filler, 5-10% pigment,
2-3% additives
Properties:
  Good puncture resistance
  Very good chemical resistance
  Poor UV resistance
  Excellent flexibility
  Easiest material to install, easier seam formation using solvents
  Low cost
Chlorosulphonated polyethylene (CSPE) (Hypalon)

Thermoplastic elastomer – polymers cross-linked with sulphur compounds
Always scrim reinforced (CSPE-R)
Also an early geomembrane
Used for exposed conditions like floating covers and uncovered waste liners due to UV resistance
Thermoplastic initially – polymers crosslink over time and become thermoset
Chlorosulphonated polyethylene (CSPE) (Hypalon)

Properties:
- Very good chemical resistance (except aromatic hydrocarbons)
- Excellent UV and temperature resistance
- Fair to good tear, puncture resistance
- Solvent or thermal seam
- 36 or 45 mils thick
Butyl rubber and ethylene-propylene rubber (EPDM)

Good resistance to UV, oxidation
Good temperature performance
Low strength (butyl rubber), high strength (EPDM)
Poor chemical resistance, difficult to seam
Geomembrane testing methods

Variety of physical and chemical tests to evaluate materials

ASTM methods for:

- Tensile strength (ASTM D638)
- Tear resistance (ASTM D1004)
- Puncture resistance (ASTM D4833)
- Low-temperature brittleness (ASTM D746)
- Stress crack resistance (ASTM D1693)
- Permeability
- Carbon black content and diffusion (ASTM D1603 and D2663)
- Accelerated heat aging (ASTM D573, D1349)
- Density (ASTM D1505 or D792)
- Melt flow index (ASTM D1238)
- Thickness (ASTM D5199)
- Ply adhesion (ASTM D413)
Geomembrane stress-strain


Figure 7-2. Multiaxial stress vs. strain for five geomembrane materials (Frobel, 1991).
Liner leakage

Permeation – some water will permeate geomembranes, but mechanism is not well understood – believed to occur at molecular level

Permeability of geomembranes is so low that there is question as to applicability of Darcy’s law

\[ K \approx 10^{-12} \text{ cm/s} \]

Usually negligible source of leakage
Liner leakage

Pinholes – defined as holes with diameter less than liner thickness
  Originate in manufacturing
  Usually negligible source of leakage
Liner leakage

Holes – openings with diameter greater than liner thickness

Sources:
  defective seams
  seam failures
  punctures
  construction damage

Gases and organic chemicals also can permeate liners
## Water vapor permeation

<table>
<thead>
<tr>
<th>Polymer</th>
<th>Thickness (mm)</th>
<th>Transmission (g/m²/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PVC</td>
<td>0.28</td>
<td>4.4</td>
</tr>
<tr>
<td>PVC</td>
<td>0.52</td>
<td>2.9</td>
</tr>
<tr>
<td>PVC</td>
<td>0.76</td>
<td>1.8</td>
</tr>
<tr>
<td>CSPE</td>
<td>0.89</td>
<td>0.44</td>
</tr>
<tr>
<td>HDPE</td>
<td>0.80</td>
<td>0.017</td>
</tr>
<tr>
<td>HDPE</td>
<td>2.44</td>
<td>0.006</td>
</tr>
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</table>

Solvent vapor permeation of 0.8 mm HDPE

<table>
<thead>
<tr>
<th>Solvent</th>
<th>Transmission rate (g/m²/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water vapor</td>
<td>0.017</td>
</tr>
<tr>
<td>Methyl alcohol</td>
<td>0.16</td>
</tr>
<tr>
<td>Acetone</td>
<td>0.56</td>
</tr>
<tr>
<td>Cyclohexane</td>
<td>11.7</td>
</tr>
<tr>
<td>Xylene</td>
<td>21.6</td>
</tr>
<tr>
<td>Chloroform</td>
<td>54.8</td>
</tr>
</tbody>
</table>

### Summary of most common geomembrane materials

<table>
<thead>
<tr>
<th>Property</th>
<th>HDPE</th>
<th>CSPE</th>
<th>PVC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat resistance</td>
<td>↑↑↑↑↑</td>
<td>↑↑↑↑</td>
<td>↓</td>
</tr>
<tr>
<td>Microbial resistance</td>
<td>↑↑↑</td>
<td>↑↑</td>
<td>?</td>
</tr>
<tr>
<td>Chemical resistance</td>
<td>↑↑↑↑↑</td>
<td>↑↑↑</td>
<td>↑↑↑</td>
</tr>
<tr>
<td>UV resistance</td>
<td>↑↑↑↑↑</td>
<td>↑↑↑↑</td>
<td>↓</td>
</tr>
<tr>
<td>Puncture resistance</td>
<td>↑ to ↑↑</td>
<td>↑ to ↑↑</td>
<td>↑↑</td>
</tr>
<tr>
<td>Ease of placement</td>
<td>↑</td>
<td>↑↑</td>
<td>↑↑↑</td>
</tr>
<tr>
<td>Cost</td>
<td>Moderate</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Tensile strength</td>
<td>↑↑↑↑</td>
<td>?</td>
<td>↑↑↑</td>
</tr>
<tr>
<td>Cold weather problems</td>
<td>↑↑</td>
<td></td>
<td>↓</td>
</tr>
</tbody>
</table>

Geomembrane and Geosynthentic

Seaming of geomembranes

Sheets of geomembrane must be joined at edges—i.e., seams

Methods:
- Thermal seaming
- Extrusion or fusion seaming
- Chemical seaming
- Mechanical seaming
Thermal seaming

Works with thermoplastic geomembranes only (including crystalline thermoplastic)

Techniques:
Hot wedge (or knife) –
  used for long seams
  requires 4- to 6-inch overlap
  traveling vehicle moves along seam, heating top and bottom membrane
Hot wedge seam welding

Thermal seaming

Hot-knife seaming with double track weld creates air pocket for non-destructive testing:

Hot air bonding
Dielectric bonding (not a field technique)
Extrusion or fusion welding

Used with HDPE
Welder extrudes a ribbon of melted HDPE (extrudate)
  Used for patches
  Usually pre-heat pieces to be joined so that membrane will also melt and fuse with extrudate
Extrusion welder

Extrusion welding gun

Other seaming methods

Chemical seaming
  Cement
  Solvent
  Vulcanizing adhesive

Mechanical methods
  Tape – necessary for thermoplastics
  Sewing
Solvent seaming

Adhesive seaming

Geomembrane seam alternatives

Examples of alternative field seams for geomembranes.
Special seaming considerations

“Fishmouths” – wrinkles perpendicular to seam
    Should be cut along wrinkle ridge, welded, and then patched over
Cold weather and hot weather – compromises seam quality
Rain or fog – seams should be free of moisture and clean
Seam testing

Trial welds - welding of scrap pieces of membrane followed by destructive testing of three 1-inch wide samples

Field tests:
  Seam tests
  Vacuum tests
  Destructive tests
Seam strength tests

Shear test

Peel test
Seam tests

Used on double-track welds:
Seal both ends with air injection needle welded in
Pressurize void between dual-track welds to 24 to 35 psi
Pressure should remain stable, indicating no leaks
Cut end opposite needle – void should depressurize, demonstrating no blockage of channel
Seam testing

Vacuum tests

Vacuum box with gasket, viewing window
Soapy solution applied to seam
Vacuum box placed on top, depressurized
If seam leaks, bubbles will be apparent
Vacuum box

Destructive tests

Approximately one test per 500 feet of seam
Patch of seam cut out, ten 1-inch samples created
Samples shear tested in lab – any failure of weld is a seam failure
Keep number of tests to minimum – locations of samples must be patched
Geosynthetic clay liners

Layer of clay between two geotextiles or glued to geomembrane

Manufactured with bentonite:

- Bentonite clay (sodium bentonite in US, calcium bentonite elsewhere)
- Bentonite has a thick double layers and high swelling capacity
- Water is adsorbed until crystal sheets dissociate and form a gel with thixotropic properties
- Thixotropic = becoming liquid when disturbed
- $K = 10^{-9}$ cm/sec

Produced in 4 to 5 meter panels, 20 to 60 meters long
GCL installation in Bourne landfill

Forms of GCLs

Geotextile encased – sandwich of geotextile – clay – geotextile
  Adhesive bonded: clay is mixture of clay and adhesive to hold sandwich together
    Example: Claymax 200R, Claymax 600CL
  Stitch-bonded – held together with parallel rows of stitches
    Example: Claymax 500SP
  Needle-punch – held together with fibers punched through, sometimes bonded to geotextile
    Example: Bentomat, Bentofix

Geomembrane-supported – sandwich of clay and geomembrane
  Held together by adhesive mixed into clay
    Example: Gundseal
Seaming GCLs

Bentonite swelling seals GCLs
Many types self-seal at overlaps; for some types, extra bentonite is applied to overlap
GCLs need to be covered quickly to prevent rapid hydration and uneven swelling and self-sealing
Hydraulic conductivity of GCLs

Increases with increasing compression (up to order of magnitude)

Desiccation increases $K$ – $K$ recovers upon rehydration

$K$ relatively insensitive to freeze-thaw

If permeated by organic liquid prior to hydration, bentonite does not hydrate and swell and therefore does not achieve low $K$
GCL – permeability vs. compression

\[
\log (k_w) = -8.0068 - 0.5429 \log (\sigma_w')
\]
\[R = 0.9809\]
\[3 \text{ kPa} \leq \sigma' \leq 120 \text{ kPa}\]
GCL – permeability recovery
GCL – freeze-thaw resistance

Hydraulic conductivity (cm/sec)

Number of freeze-thaw cycles

Sample-1
Sample-2
Sample-3
Advantages of GCLs

Easier and faster to construct, with lightweight equipment

Simpler QA

Comparable in cost to clay liner
  Clay is $0.50 to $5.00 per square foot
  GCL is $0.42 to $0.60 per square foot

Small thickness conserves landfill space

Better freeze-thaw, desiccation resistance

Withstand settlement better than clay liners
Disadvantages of GCLs

- Less shear strength
- Less attenuation capacity
- Faster diffusive breakthrough
- Thin GCL more subject to puncture
- Limited experience