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

Source: Koerner, Robert M., 1998. *Designing with Geosynthetics, Fourth Edition*. Prentice Hall, Upper Saddle River, New Jersey.

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

Source: Koerner, Robert M., 1998. *Designing with Geosynthetics, Fourth Edition*. Prentice Hall, Upper Saddle River, New Jersey.

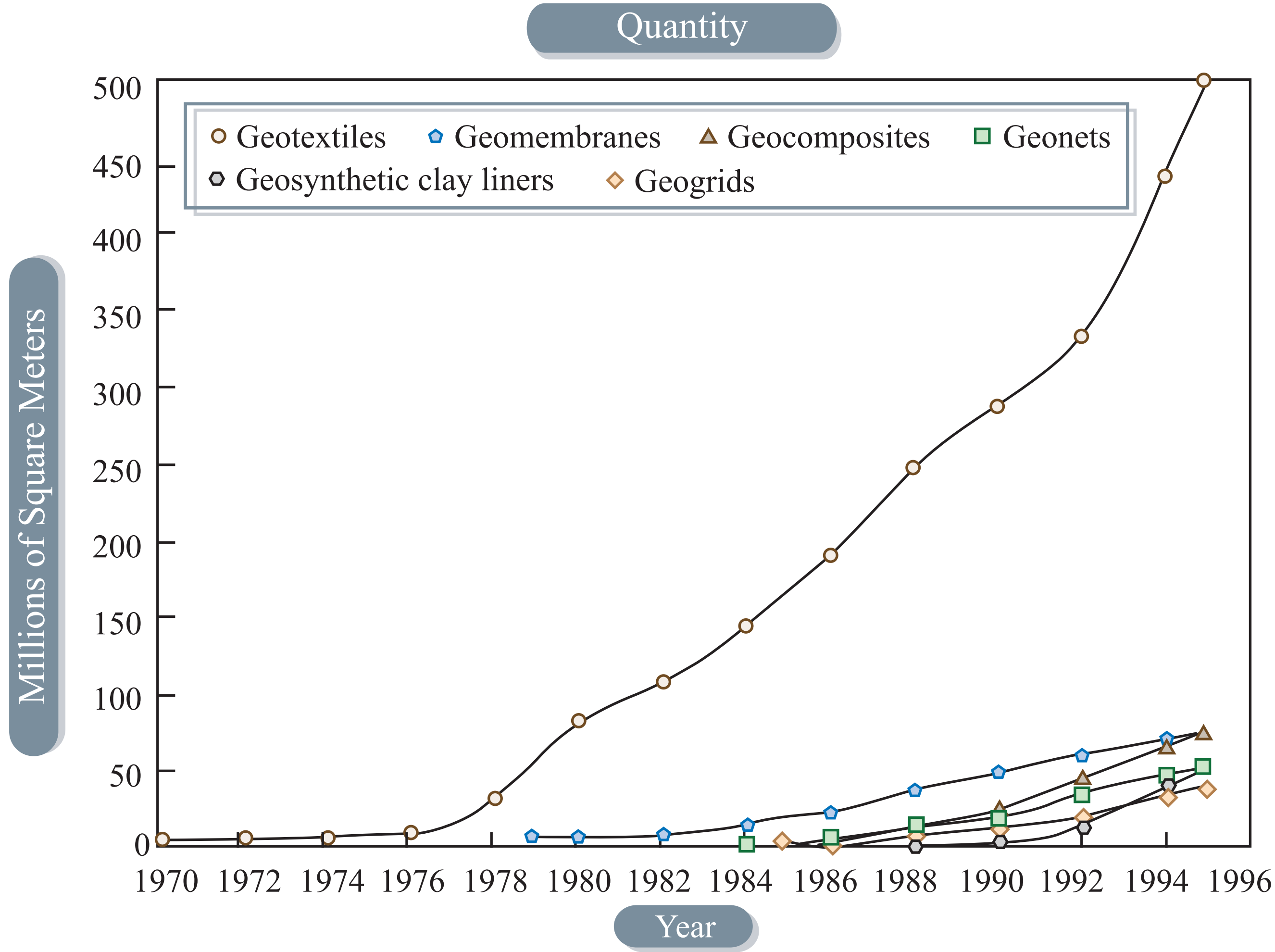
Early historical information from: Hsu-Yeh Huang and Xiao Gao, 1999. Geotextiles. http://trcs.he.utk.edu/textile/nonwovens/Geotextile.html

Geosynthetics - 1967

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.

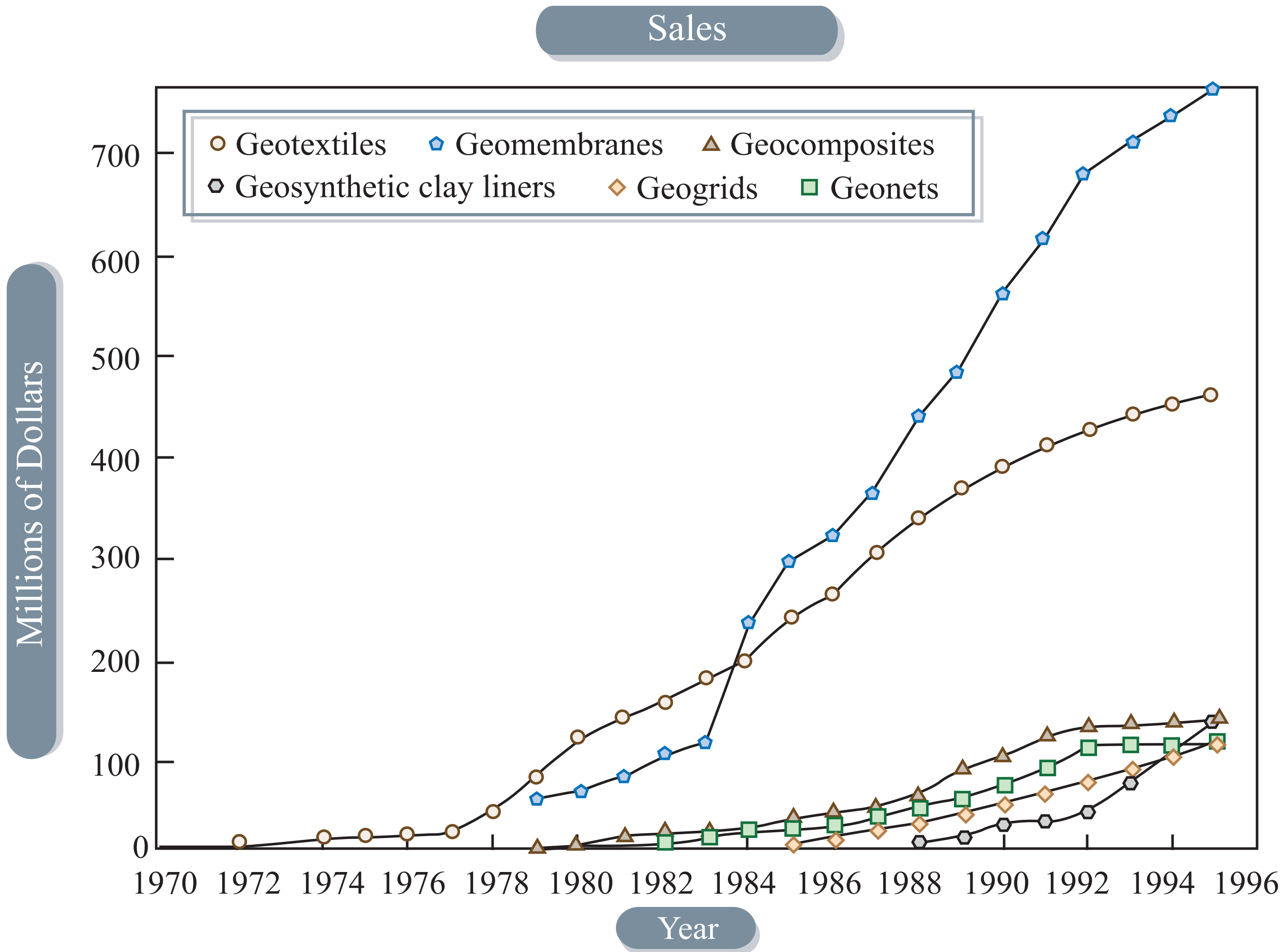
“The Graduate” 1967

Historical growth in geosynthetic market



Adapted from: Koerner, Robert M. *Designing with Geosynthetics.* 4th ed.
Upper Saddle River, New Jersey: Prentice Hall, 1998.

Historical growth in geosynthetic market



Adapted from: Koerner, Robert M. *Designing with Geosynthetics.* 4th ed.
Upper Saddle River, New Jersey: Prentice Hall, 1998.

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

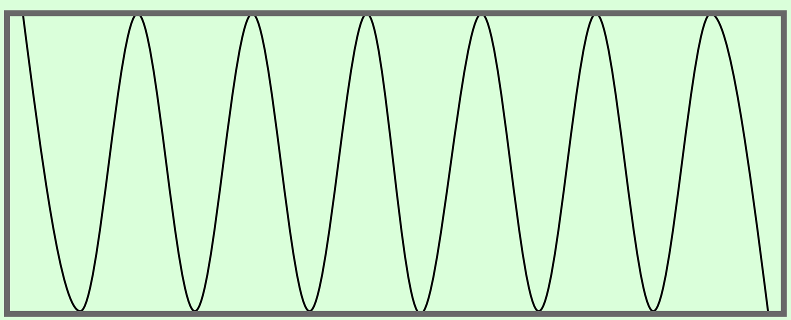
Crystalline thermoplastic

Also called semicrystalline

Examples: HDPE, LDPE, polypropylene

Polymeric chains are folded in a crystal lattice

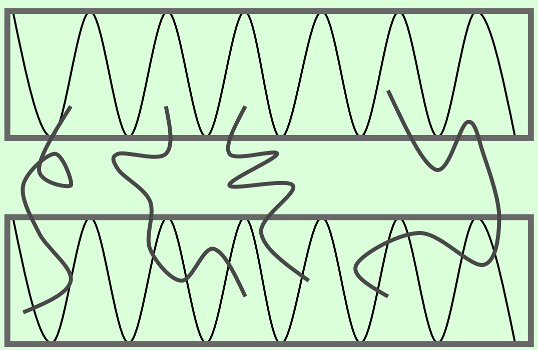
Folded chains form lamellae (plate-like crystals)



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

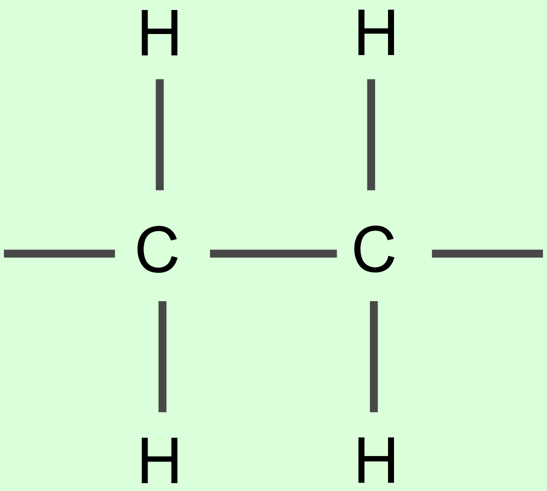
Extrusion – molten polymer is extruded in a non-reinforced sheet

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

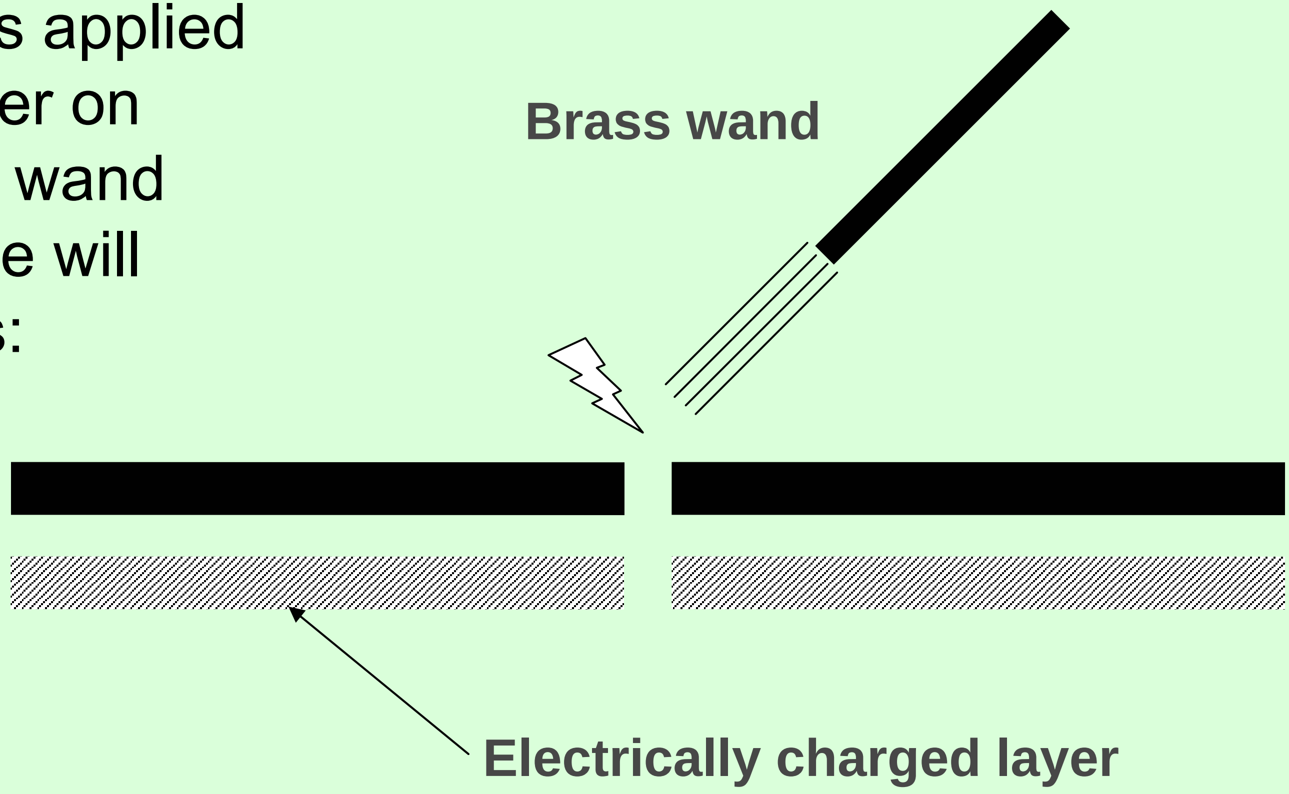
Coextruded HDPE and LLDPE

- 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:



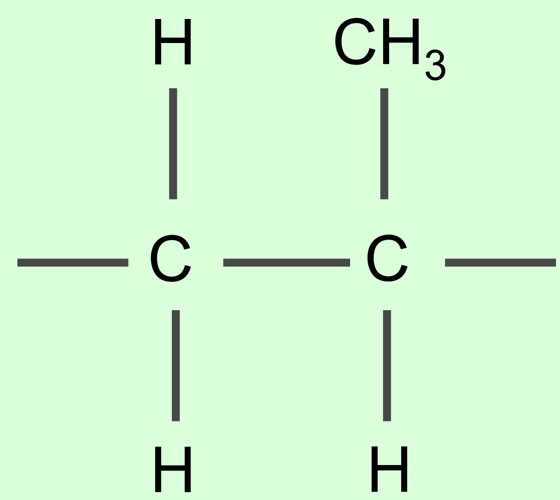
Flexible polypropylene (fPP)

Usually scrim-reinforced for high tensile strength (fPP-R)

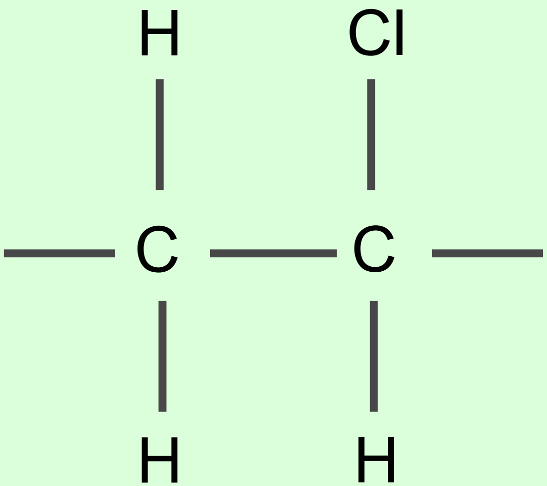
36 or 45 mils thick

Used for floating covers on surface impoundments, other high stress applications

Good chemical, UV resistance



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

Source: U.S. EPA, 1994. Seminar Publication: Design, Operation, and Closure of Municipal Solid Waste Landfills. Report Number EPA/625/R-94/008. Center for Environmental Research Information, U.S. Environmental Protection Agency, Cincinnati, Ohio. September 1994. (http://www.epa.gov/ORD/NRMRL/Pubs/1994/625R94008.pdf)

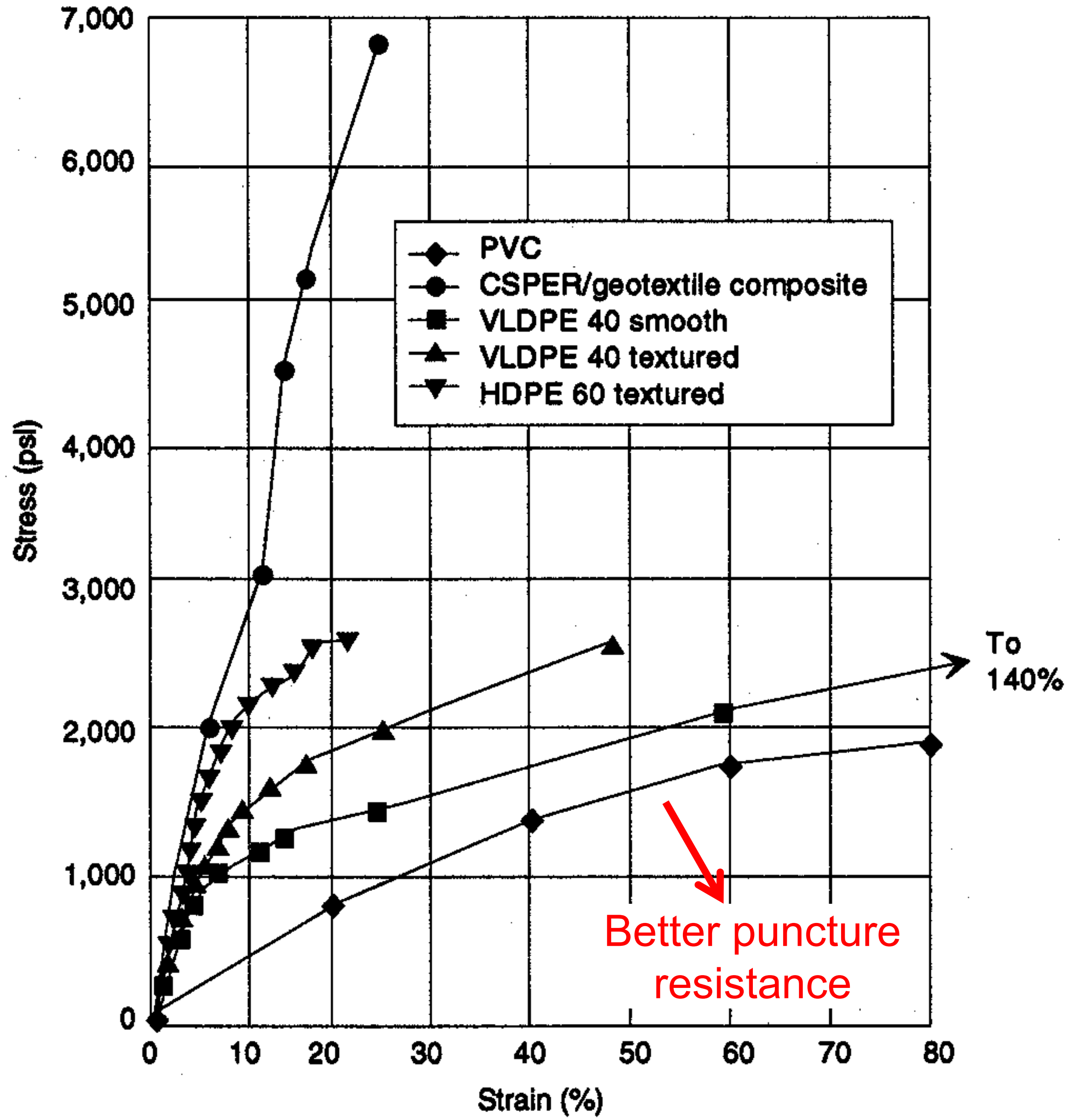


Figure 7-2. Multiaxial stress vs. strain for five geomembrane materials (Frobel, 1991).

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
- $K \approx 10^{-12}$ 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

Polymer	Thickness (mm)	Transmission ($g/m^2/day$)
PVC	0.28	4.4
PVC	0.52	2.9
PVC	0.76	1.8
CSPE	0.89	0.44
HDPE	0.80	0.017
HDPE	2.44	0.006

Source: Koerner, Robert M., 1998. *Designing with Geosynthetics, Fourth Edition*. Prentice Hall, Upper Saddle River, New Jersey.

Solvent vapor permeation of 0.8 mm HDPE

Solvent	Transmission rate ($g/m^2/day$)
Water vapor	0.017
Methyl alcohol	0.16
Acetone	0.56
Cyclohexane	11.7
Xylene	21.6
Chloroform	54.8

Source: Koerner, Robert M., 1998. *Designing with Geosynthetics, Fourth Edition*. Prentice Hall, Upper Saddle River, New Jersey. P. 423.

Summary of most common geomembrane materials

Property	HDPE	CSPE	PVC
Heat resistance	↑↑↑↑	↑↑↑↑	↓
Microbial resistance	↑↑↑	↑↑	?
Chemical resistance	↑↑↑↑	↑↑↑	↑↑↑
UV resistance	↑↑↑↑	↑↑↑↑	↓
Puncture resistance	↑ to ↑↑	↑ **to** ↑↑	↑↑
Ease of placement	↑	↑↑	↑↑↑
Cost	Moderate	High	Low
Tensile strength	↑↑↑↑	?	↑↑↑
Cold weather problems		↑↑	↓

Source: McBean, E. A., F. A. Rovers, and G. J. Farquhar, 1995. *Solid Waste Landfill Engineering and Design*. Prentice Hall PTR, Upper Saddle River, New Jersey.

Geomembrane and Geosynthetic

Source: Fernald Environmental Management Project, undated. On Site Disposal Facility (OSDF), August 2002 Photo Tour. Fernald Environmental Management Project. Fernald, OH. http://www.fernald.gov/VImages/PhotoTour/2002/Aug02/pages/6319-D3684.htm. Accessed February 26, 2003.

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) –

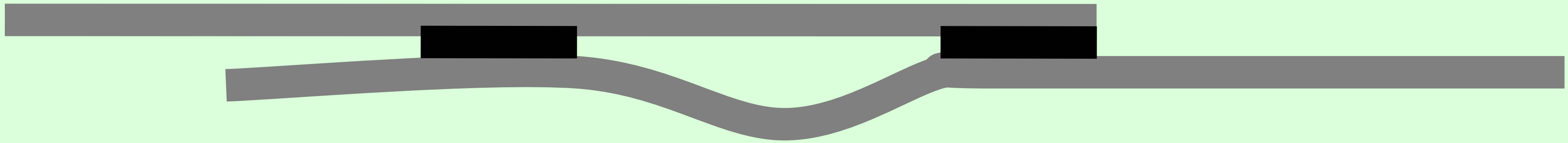
- used for long seams
- requires 4- to 6-inch overlap
- traveling vehicle moves along seam, heating top and bottom membrane

Hot wedge seam welding

See Fig. 17.6 in: Qian, X., R. M. Koerner, and D. H. Gray, 2002. *Geotechnical Aspects of Landfill Design and Construction*. Prentice Hall, Upper Saddle River, New Jersey.

Thermal seaming

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

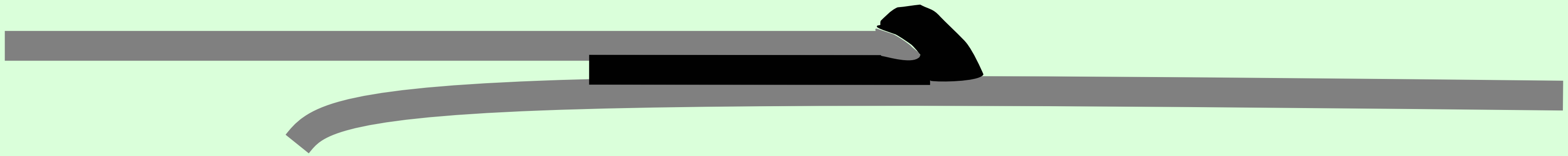


Hot air bonding

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

See Fig. 17.5 in: Qian, X., R. M. Koerner, and D. H. Gray, 2002. *Geotechnical Aspects of Landfill Design and Construction*. Prentice Hall, Upper Saddle River, New Jersey.

Extrusion welding gun

See images at: http://www.demtech.net/. Demtech Services, Inc., 2001. PRO - X, High output extrusion gun for production welding of geomembranes and rigid thermoplastics. Demtech Services, Inc., Diamond Springs, California. Accessed April 30, 2003.

Other seaming methods

- Chemical seaming
  - Cement
  - Solvent
  - Vulcanizing adhesive
- Mechanical methods
  - Tape – necessary for thermoplastics
  - Sewing

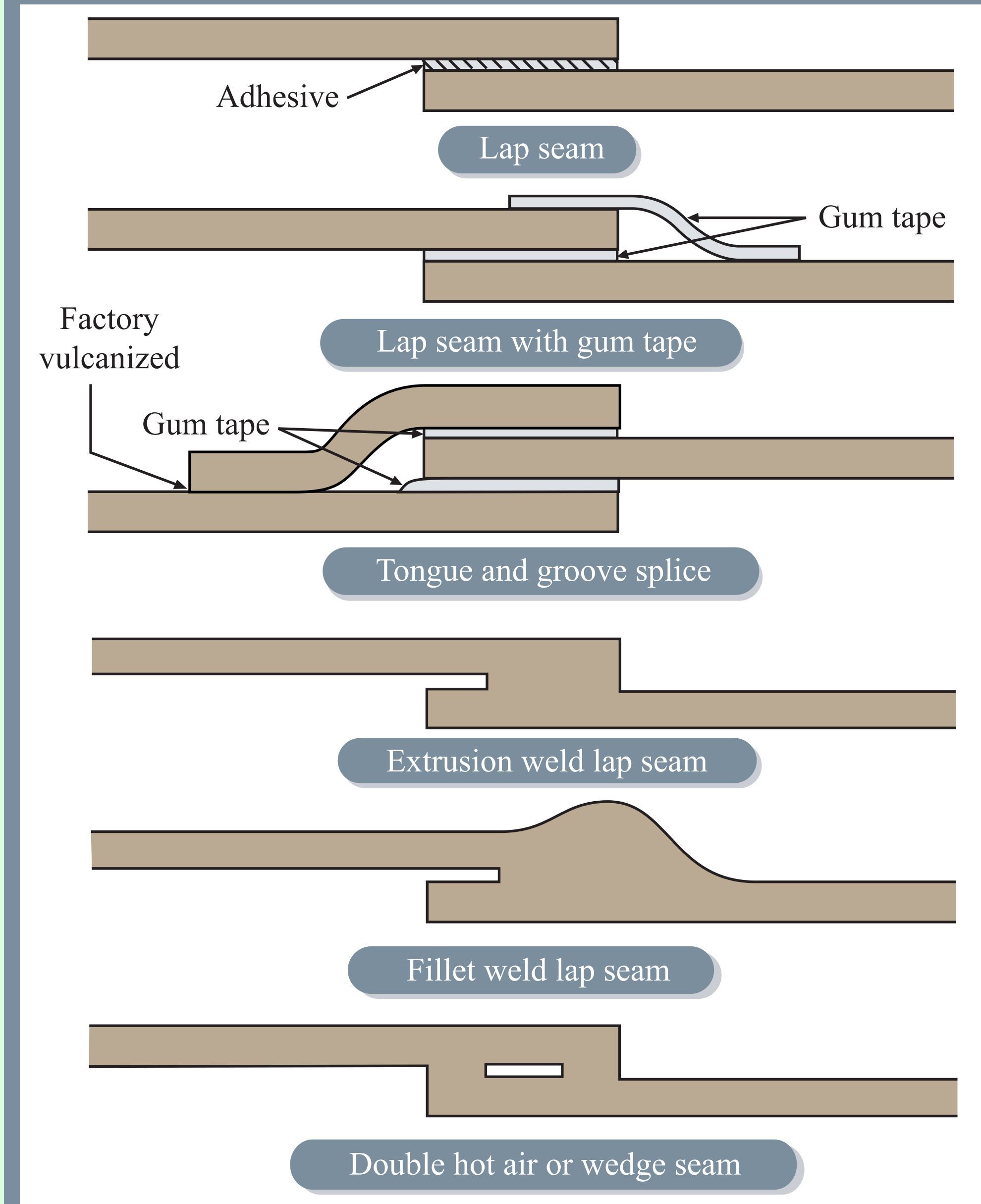
Solvent seaming

See images at: http://www.geomembrane.com/TechInfo/ChemWeld.htm. EPI, undated. Chemical Fusion Welding. Environmental Protection, Inc., Mancelona, Michigan. Accessed April 30, 2003.

Adhesive seaming

See images at: http://www.geomembrane.com/TechInfo/Adhesive.htm.
EPI, undated. Adhesive Seaming. Environmental Protection, Inc., Mancelona, Michigan. Accessed April 30, 2003.

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

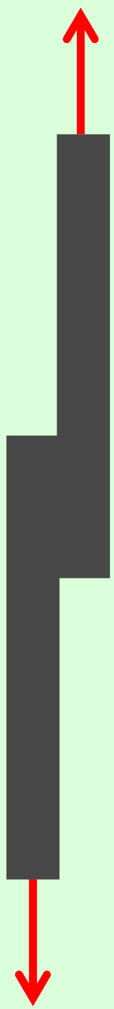
Trial welds - welding of scrap pieces of membrane followed by destructive testing of three 1-inch wide samples

Field tests:

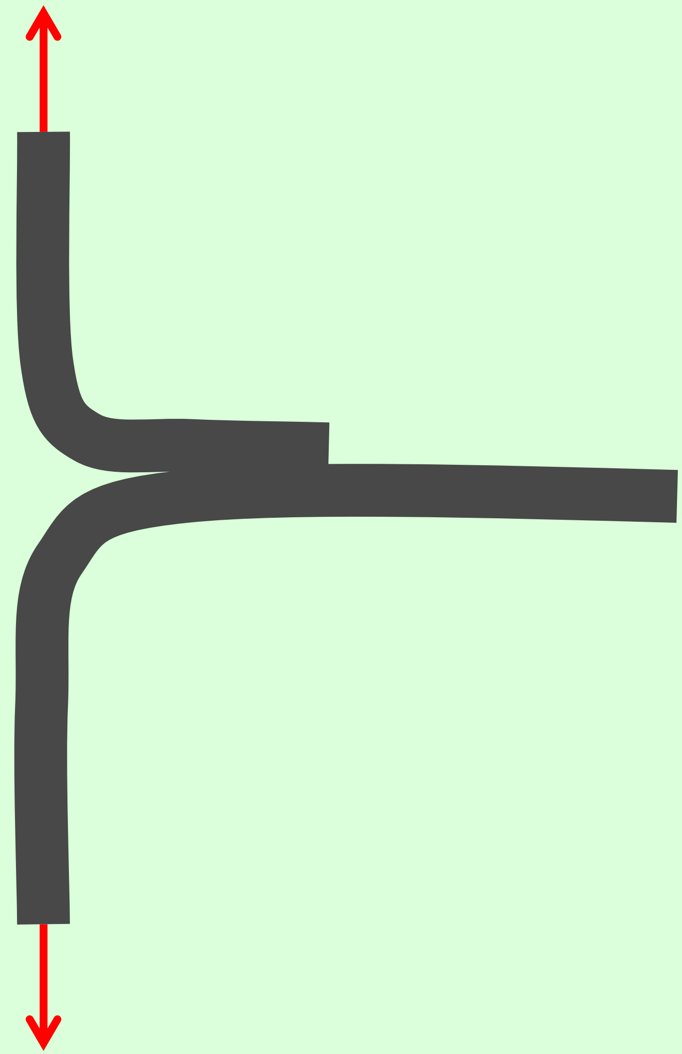
- Seam tests
- Vacuum tests
- Destructive tests

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

See image at: http://www.geomembrane.com/Testing/airtest.htm. EPI, undated. Air Channel Testing PVC Geomembrane Thermal Welds. Environmental Protection, Inc., Mancelona, Michigan. Accessed April 30, 2003.

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

See image at: http://www.ce.vt.edu/program_areas/environmental/teach/gwprimer/landfill/liner.html. Yack, J. and E.J. O'Neill, 1998. Protective Liner Uses and Landfill Application. Groundwater Pollution Primer, CE 4594: Soil and Groundwater Pollution, Civil Engineering Department, Virginia Technical Institute and State University, Blacksburg, Virginia. Accessed April 30, 2003.

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

See image at: http://www.townofbourne.com/Town%20Offices/ISWM/Phase3.htm. Department of Integrated Solid Waste Management (ISWM), Town of Bourne, May 2002. Landfill Liner Construction System: Phase 3. Department of Integrated Solid Waste Management (ISWM), Town of Bourne. Bourne, MA.

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

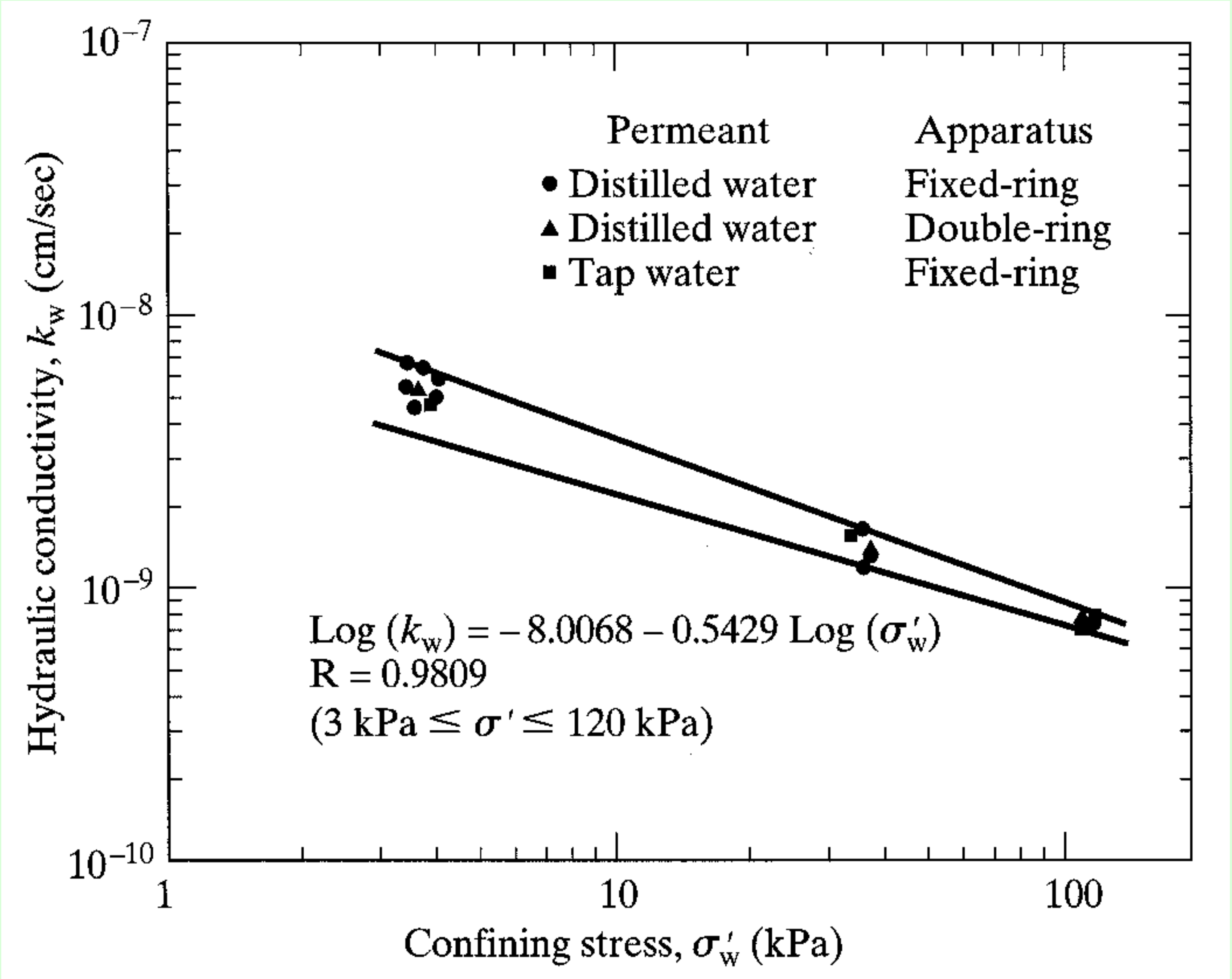
Increases with increasing compression (up to order of magnitude)

Desiccation increases K – K recovers upon rehydration

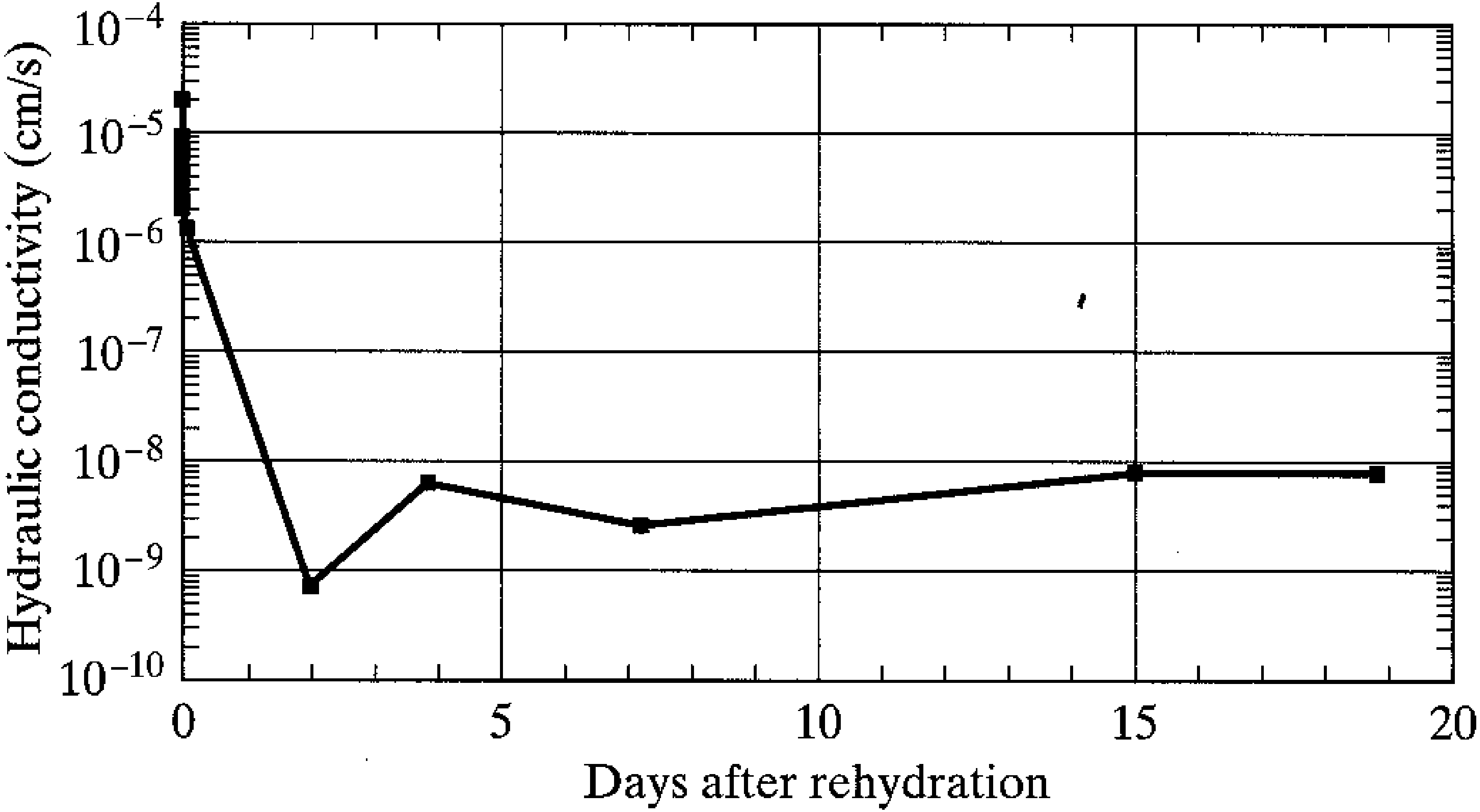
K relatively insensitive to freeze-thaw

If permeated by organic liquid prior to hydration, bentonite does not hydrate and swell and therefore does not achieve low K

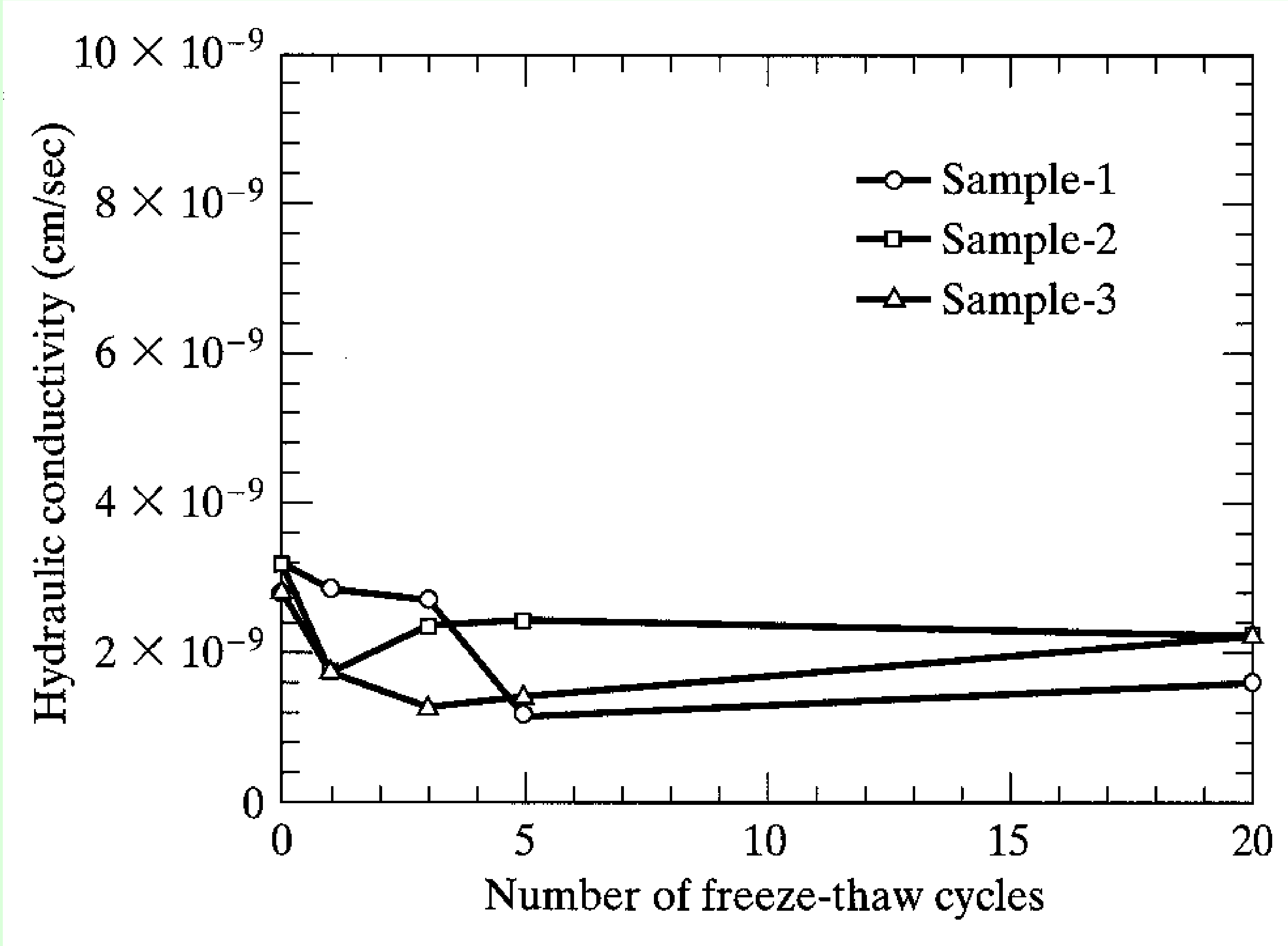
GCL – permeability vs. compression



GCL – permeability recovery



GCL – freeze-thaw resistance



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