CEE 226 _ Geosynthetic Properties and Design Methods

Lecture 6-3

UCLA – Winter 2017

Material properties

- Physical (index properties)
  - Thickness, density, specific gravity
- Mechanical
  - Tensile properties (yield / break stress; yield / break elongation)
  - Tear and puncture resistance
  - Hydraulic properties
  - Interface shear strength
- Endurance
  - chemical
  - biological
  - thermal
  - UV

Type of Tests

Index Tests: - used primarily for product identification, comparison, specification and quality control purposes by manufacturers and QA/QC during construction

Design / Performance Tests: - used to establish engineering properties for a geosynthetic in combination with companion materials (e.g. soils) under project specific design conditions

Geosynthetic Properties

- Design Properties
- Index Properties
  - Manufacture
  - QA / QC
  - Empirical / Regulatory Design

Physical properties

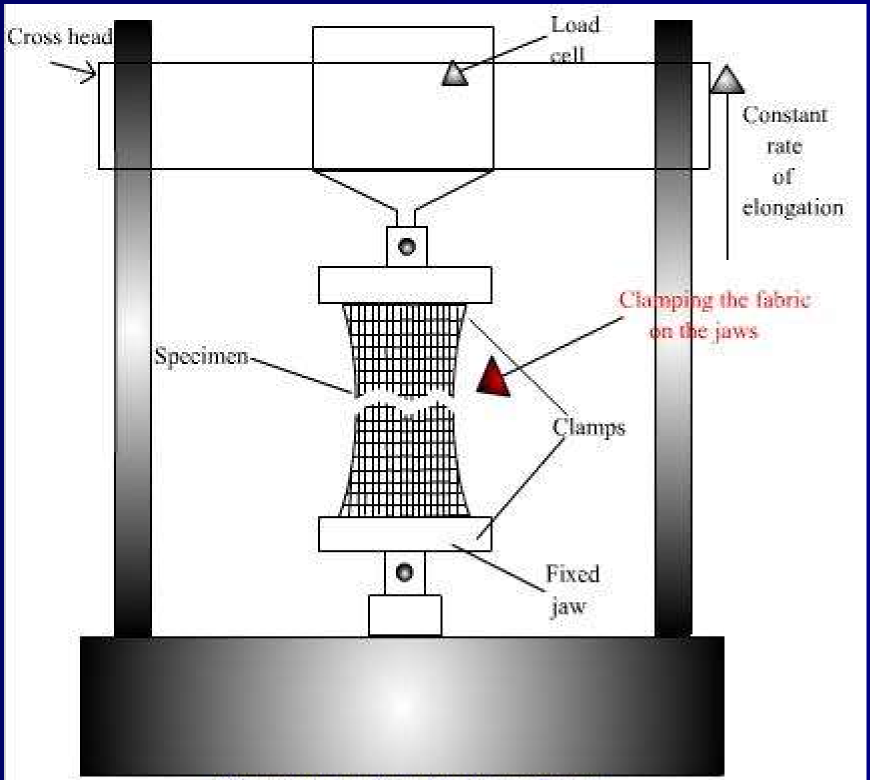
- Thickness (important for containment - GM; drainage - GC, GT, and protection / separation - GT)
  - Expressed in mils (1×10^{-3} inch) or mm
  - Typical GM = 40 to 80 mils (1 to 2 mm)
- Unit Weight / Density / mass per unit area (ex; oz/sq yd for GT)
- Resin quality (ex. Melt flow index test for GM)

Mechanical Properties

- Tensile behavior uniaxial / biaxial
  - Strength at yield and break;
  - strain or elongation at yield or break
- Tear, impact & puncture resistance
- Seam behavior (shear & peel mode)
- Interface shear strength
- Environmental stress cracking
- Hydraulic

Mechanical Properties - Tensile

- Strength at yield / break; elongation at yield / break
- Tensile behavior – 3 types of tests

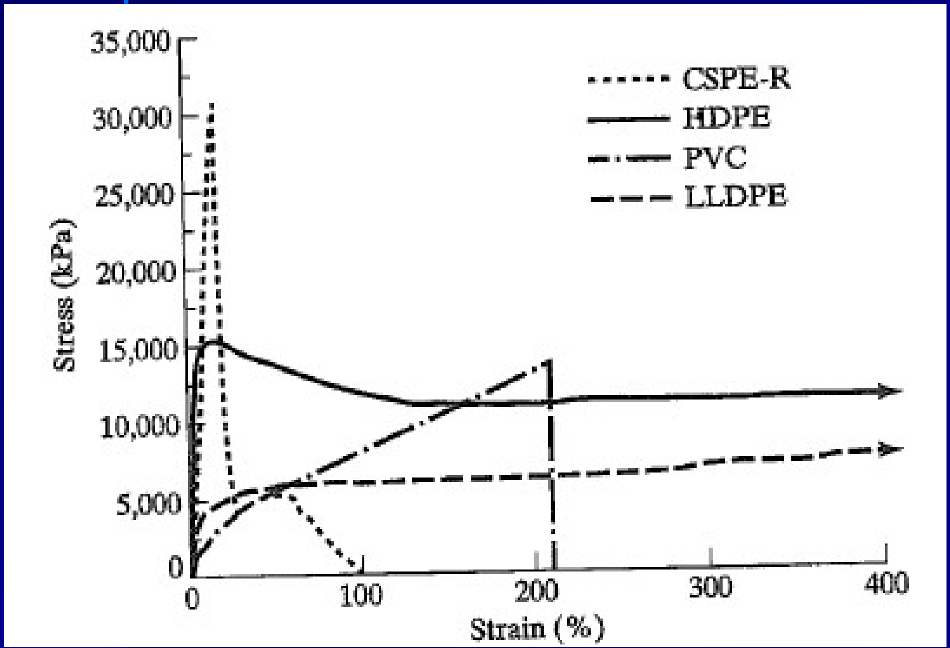


The apparatus for a fabric tensile test

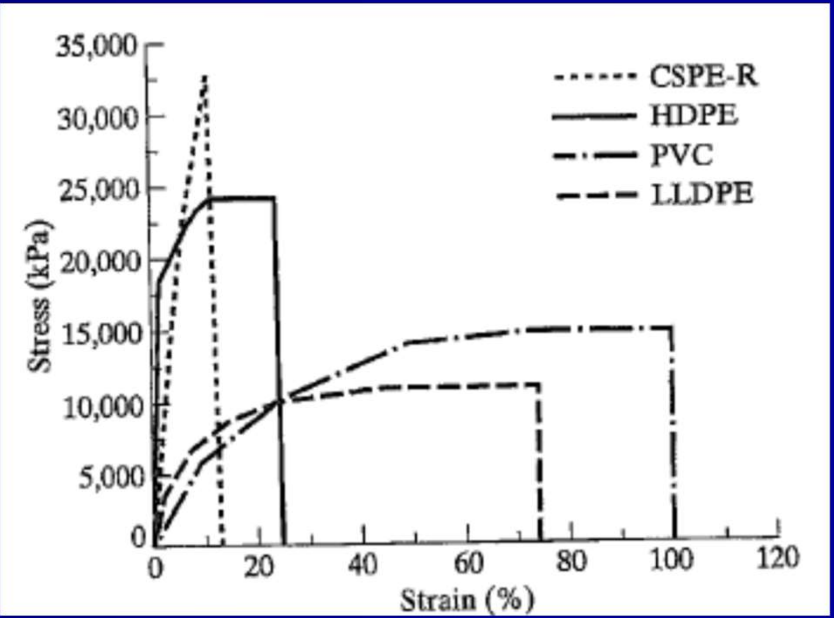
Mechanical Properties - Tensile

- narrow width samples – (index test -QA/QC)
  - 0.25 to 4 ins wide
  - Dumbbell, strip & grab shaped samples
  - 1-d behavior (with necking) not representative of field membrane action
- Uniform, wide width or strip tests – design
  - 8 in wide samples –plane strain conditions
  - long duration tests (3 hrs for 200% strain, 17 hrs for 1000% strain @ 1mm/min)
- multiaxial or axisymmetric tests - design
  - biaxial or out of plane stress deformation conditions

Tensile Stress – Strain



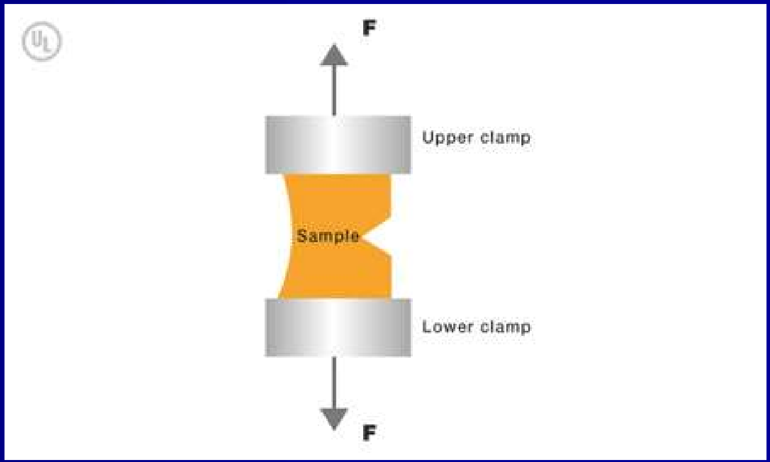
Wide Width Tensile – Plane Strain



Axisymmetric Tensile - Biaxial

Mechanical Properties – Tear & impact

- **Tear resistance** (ASTM D1004) - GM
  - index test evaluates tearing potential under high winds or handling stresses
  - Template used to form 90 deg notch, both ends of specimen gripped and tensile load applied until specimen tears



Mechanical Properties – Tear & impact

- Impact resistance - GM
  - Index test
  - Resistance to impact from falling objects
  - Free falling dart (ASTM D1709) or weight (ASTM D3029) used to measure impact resistance
  - Increased thickness or use of GT cushion improves impact resistance

Mechanical Properties – puncture resistance

- **Puncture Resistance** - GM
  - – index test
  - – ASTM D4833 and others
  - – punch resistance, relative resistance to puncture when placed on rough surfaces
  - – Increase thickness or use cushion GT to increase puncture resistance of GM

Mechanical Properties – ESC

- Environmental stress cracking (ESC) resistance
  - Index test
  - time to failure of notched sample under elevated temperature and constant tensile stress
  - ESC usually occurs at seams where scratches are caused by grinding
  - Critical in surface impoundments – exposed to atmosphere, tensile stresses due to temperature changes

Mechanical Properties _ hydraulic

- Transmissivity (in-plane drainage)
  - $T = K_p.t$ (why is T preferred to K_p ?)
- Permittivity (cross-plane filtration)
  - $P = K_n/t$
- AOS (O_{95})
- design requirements for filters:
  1. $K_n >> K_{soil}$ – to prevent head buildup
  2. proper soil retention (AOS < 2 to 3 x d_{85})
  3. long-term flow equilibrium (avoid clogging)

DRAINAGE » Geonets

Product Name	Structure [1]	Core/Net/Mesh Polymer Composition [2]	Geotextile Attached (Y/N) [3]	Width/Length m (ft)	Core/Net/Mesh [4] Thickness ASTM D5199 mm (mil)	Compressive Strength at yield ASTM D1621 kPa (psi)	Transmissivity ASTM D4716-87 [5] Gradient = 0.1 Pressure = 10kPa 209 lb/ft² m^2/s (gal/min/ft)	Transmissivity ASTM D4716-87 [5] Gradient = 1.0 Pressure = 479kPa 10,000 lb/ft² m^2/s (gal/min/ft)
GSE Lining Technology Inc. | www.gseworld.com								
GSE HyperNet Geonet	GN-HDPE	PE	N	4.6 (15) / 100 (330)	5 (200)	NP	3 x 10-3 (14)	8 x 10-4 (4)
GSE HyperNet UF Geonet	GN-HDPE	PE	N	4.6 (15) / 76 (250)	7.6 (300)	NP	9 x 10-3 (44)	2 x 10-3 (10)
GSE HyperNet TRx Geonet	GN-HDPE	PE	N	4.6 (15) / 60 (200)	7.6 (300)	NP	1.2 x 10-2 (60)	5 x 10-3 (20)
GSE PermaNet UL Geonet	GN-HDPE	PE	N	4.6 (15) / 60 (200)	7.6 (300)	1915 (278)	NP	3 x 10-3 (15)
GSE FabriNet Geocomposite	O/C	PP/PE/PP	Y, nonwoven	4.4 (14.5) / 82.3 (270)	5 (200)	NP	5 x 10-4 (2)	1 x 10-4 (0.5)

GEOTEXTILES

Problem 4

		M288 Transportation-Related Applications								Reinforcement Applications						
		Filtration/Hydraulic Properties			Physical Properties					Wide Width Tensile/Elongation ASTM D 4595 kN/m (lb/in)/%						
										Strength @ 5% Strain [5]		Ultimate Strength % (Tult) [5]				
Product Name (Structure [1]/ Polymer Type [2])	Mass Per Unit Area ASTM D 5261 g/m² (oz/yd²)	Percent Open Area CW0-22125 %	Apparent Opening Size ASTM D 4751 mm (U.S. sieve)	Permittivity ASTM D 4491 sec-1 Flow Rate (FH or CH) [3] l/min/m² (gal/min/ft²)	Puncture ASTM D 6241 kN (lb)	Trapezoid Tearing Strength ASTM D 4533 kN (lb)	Grab Tensile/Elongation ASTM D 4632 kN (lb)/%	M288 Survivability Class	M288 Applications [4]	MD	XD	MD	XD	Creep Limited Strength-MD ASTM D 5262 [6] kN/m (lb/ft)	LTDS GRI GT7-MD (in sand) [7] kN/m (lb/ft)	Other Manufacturer's Suggested Applications [8]
ACE Geosynthetics Inc. | www.geoace.com																
ACE GT70/70(PP) (W/PP)	300 (9)	NP	0.149 (100)	0.30/900 (22), CH	5.5 (1235)	0.75x0.95 (168x213)	1.6x2.0 (359x449)/NP	1	F, SP, ST	NP	NP	70 (399)	70 (399)	NP	NP	F, R, SP, ST
ACE GT70/105(PP) (W/PP)	430 (13)	NP	0.425 (40)	0.40/1200 (29), CH	5.7 (1280)	0.85x2.0 (191x449)	1.9x4.0 (427x898)/NP	1	F, SP, ST	NP	NP	70 (399)	105 (599)	NP	NP	F, R, SP, ST

Mech. Properties - Interface shear strength

Critical for slope stability

- Interface shear between GM and other earth materials (CCL, subgrade) or geosynthetics (GT, GCL, GN, GC)
- Multiple interfaces in liner system

- ASTM D5321-92
  - 12-in direct shear box
  - Soil and Geosynthetic or Geosynthetic and Geosynthetic
  - Sandwich tests

Geosynthetic seams

- Material produced in rolls up to 15 ft wide
- Field seams required
- Type of seam – depends on product / application
  - GM (containment) – welds
  - GT (filtration) – stitched or heat-bonded
  - GCL (containment) – overlapped
  - GN (drainage) – overlapped and tied
  - GG – machine direction – avoid
- Seam tests (integrity - leak detection & strength)

Endurance Properties

- Impact on long term performance of geosynthetics
  - polymeric degradation due to UV
  - chemical
  - biological
  - Thermal
  - radioactive action
  - results in brittle stress – strain behavior

Endurance Properties (contd.)

- UV Resistance

  - severe polymer degradation caused by UV from sunlight

  - polymer damage reduced by carbon black or pigments (2 to 3% in HDPE, 10 to 15% in PVC) or by covering with soil or sacrificial geotextile (periodically replaced)

Endurance Properties (Contd.)

- **Chemical resistance**

  - key property in waste containment, exposure to leachate

  - tests for chemical resistance / compatibility ASTM D5322 and EPA 9090; based on physical & mechanical properties before and after incubation in an immersion tank (room temp & elevated temp for time periods up to 120 days.

  - changes in weight, yield strength, yield elongation, tear strength & puncture resistance monitored

  - synergistic effects

Endurance Properties (Contd.)

- **Radioactive resistance:**
  - high level radioactive waste will cause polymer degradation; low-level waste can be disposed of in HDPE lined containment

- **Thermal resistance**
  - hot and cold temperatures may affect physical & mechanical properties

Endurance properties

- Oxidation resistance
  - polymer degradation due to oxidation; occurs when GM is in contact with unsaturated soils; Antioxidant additives and stabilizers are added for oxidation resistance

- Biological resistance
  - resistance to burrowing animals, fungi and bacteria; high molecular weight polymer geomembranes considered to have good resistance
  - Biological Clogging of GT

Geosynthetic Selection

- What should be specified?
- Ex: for containment function – options include
  - HDPE
  - LLDPE
  - VLDPE
  - PP
  - PVC
  - CSPE

Geomembranes
Comparison of raw materials

-	worse than average
o	average
+	better than average

Mechanical, physical properties

Properties	HDPE/MDPE	VLDPE	PP-R
Strength at yield δ_s	++ > 15 N/mm²	- ≥ 5 N/mm²	- ≥ 5 N/mm²
Elongation at yield ε_s	o < 10 %	+ ≥ 50 %	+ ≥ 50 %
Tensile strength δ_R	++ < 30 N/mm²	o > 15 N/mm²	+ > 20 N/mm²
Elongation at break ε_R	o > 700 %	+ > 800 %	o > 700 %
Multiaxial elongation	o > 15 %	++ > 50 %	+ > 30 %
Perforation resistance	o	+	o
Stress crack resistance	-	+	++
Chemical resistance	++	o	-
Cold bending	o	+	+
Dimensional stability after warm storage	o	-	++
Dimensional stability	-	-	++
Gas permeability	++	+	o
Welding ability	o	+	++

	Sig.	Material 1		Material 2		Material 3	
		Perf	Adj.	Perf	Adj.	Perf	Adj.
Parameters required	A	B	A x B	C	A x C	D	A X D
Total			F		G		H

A: 1-5; 1= little importance, 5 = very important

B,C, D : 1-10 Performance of material, 1 poor, 10 good

F, G, H: rating of each material, highest is best

Parameters	Significance		
	Primary Liner	Secondary Liner	Cover
Leachate resistance	**5**	**3**	**1**
UV resistance	**3**	**2**	**4**
Oxidation resistance	**4**	**2**	**4**
Yield strain	**4**	**3**	**5**
Puncture strength	**5**	**3**	**2**
Puncture strain	**5**	**5**	**5**
Interface friction	**4**	**3**	**5**
Stress cracking resistance	**5**	**5**	**5**

LINER	Sig.	HDPE		PVC	
		Perf	Adj.	Perf	Adj.
Parameters required	A	B	A x B	C	A x C
Leachate resistance	**5**	**10**	**50**	**5**	**25**
yield strain	**3**	**5**	**15**	**8**	**24**
Stress cracking resistance	**5**	**6**	**30**	**8**	**40**
Expansion coefficient	**3**	**5**	**15**	**6**	**18**
UV resistance	**1**	**8**	**8**	**8**	**8**
Regulatory acceptance	**3**	**10**	**30**	**3**	**9**
CQA-ability	**3**	**10**	**30**	**7**	**21**
Total			178		145

Design Methods

(a) based on experience
(b) "Generic Specification" – for common applications (e-x underdrains, separation between 2 different materials, etc)
(c) "Function" – for specialty, critical and/or permanent applications

Design-by-Function

FS = Allowable (test) property / Required (design) property

= Capacity / Demand

Where

- Capacity based on lab tests (Test Methods are from ASTM, ISO or GRI)
- Demand based on analysis (design models)
- FS > 1
- factor-of-Safety is Application Specific (level of uncertainty; consequences of failure; acceptable risk; loading conditions e.g. static vs. seismic; code requirements)
- EX: FOS = 3 (drainage applications); = 2 for tensile strength; = 1.5 for static stability; = 1.1 for seismic

Reduction Factors for geosynthetics

- Concept - modify an index / ultimate test value to a site-specific performance value

  where

$$\Pr operty_{(allow)} = \Pr operty_{\substack{(Ult/)\\test}} \left[\frac{1}{RF_1 \times RF_2 \times \cdots} \right]$$

  RF_i = those details not included in test, but geosynthetic is vulnerable to

- Currently used for reinforcement, tensile strength and flow related problems
- Not currently used on barrier problems

Allowable Vs. Ultimate (Reduction factors)

Laboratory test values must be reduced to reflect field conditions during long-term usage

- RF_i (≥ 1.0) – Installation (damage during installation)
- RF_c – Creep – Issue with all polymers
- RF_{cbd} – Chemical and Biological degradation / clogging
- Reduction Functions depend on application

Reduction Factors

2.4.2 Flow-Related Problems

For problems dealing with flow through or within a geotextile, such as filtration and drainage applications, the formulation of the allowable values takes the form of equation (2.25a). Typical values for reduction factors are given in Table 2.12. Note that these values must be tempered by the site-specific conditions, as in Section 2.4.1. If the laboratory test includes the mechanism listed, it appears in the equation as a value of 1.0.

$$q_{\text{allow}} = q_{\text{ult}}\left(\frac{1}{RF_{SCB} \times RF_{CR} \times RF_{IN} \times RF_{CC} \times RF_{BC}}\right) \tag{2.25a}$$

$$q_{\text{allow}} = q_{\text{ult}}\left(\frac{1}{\Pi RF}\right) \tag{2.25b}$$

where

- q_{allow} = allowable flow rate,
- q_{ult} = ultimate flow rate,
- RF_{SCB} = reduction factor for soil clogging and blinding (≥ 1.0),
- RF_{CR} = reduction factor for creep reduction of void space (≥ 1.0),
- RF_{IN} = reduction factor for adjacent materials intruding into geotextile's void space (≥ 1.0),
- RF_{CC} = reduction factor for chemical clogging (≥ 1.0),

Reduction Factors

TABLE 2.12 RECOMMENDED FLOW-REDUCTION FACTOR VALUES FOR USE IN EQUATION (2.25a)

	Range of Reduction Factors				
Application	Soil Clogging and Blinding(1)	Creep Reduction of Voids	Intrusion into Voids	Chemical Clogging(2)	Biological Clogging
Retaining wall filters	2.0–4.0	1.5–2.0	1.0–1.2	1.0–1.2	1.0–1.3
Underdrain filters	2.0–10	1.0–1.5	1.0–1.2	1.2–1.5	2.0–4.0(3)
Erosion control filters	2.0–10	1.0–1.5	1.0–1.2	1.0–1.2	2.0–4.0
Landfill filters	2.0–10	1.5–2.0	1.0–1.2	1.2–1.5	2.0–5.0(3)
Gravity drainage	2.0–4.0	2.0–3.0	1.0–1.2	1.2–1.5	1.2–1.5
Pressure drainage	2.0–3.0	2.0–3.0	1.0–1.2	1.1–1.3	1.1–1.3

1. If stone riprap or concrete blocks cover the surface of the geotextile, use the upper values or include an addition reduction factor.

2. Values can be higher, particularly for high alkalinity groundwater.

3. Values can be higher for turbidity and/or microorganism contents greater than 5000 mg/l.

Summary

- Properties (Physical, Mechanical, endurance)
- Geosynthetic selection
- Design Methods
- Reduction Factors

Homework & Reading assignments

- Read Articles by Bouazza (see course website)
  - Introduction to Geosynthetics
  - Introduction to Geomembranes
- Homework assignment