Geosynthetics in Waste Containments:overview

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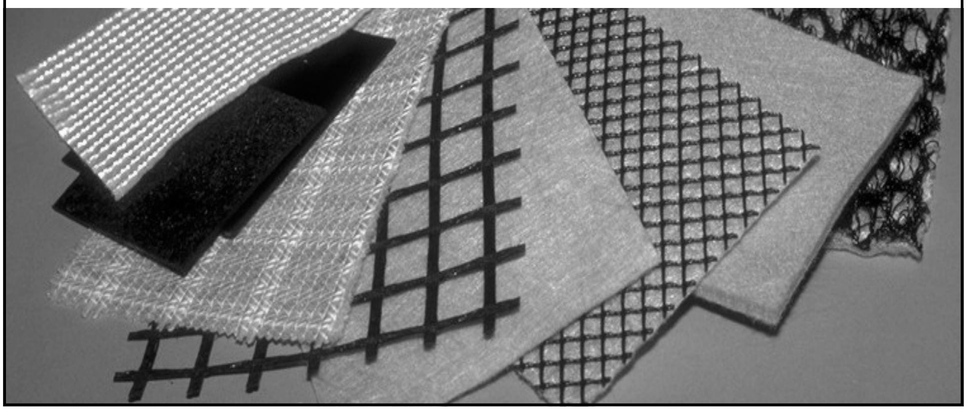
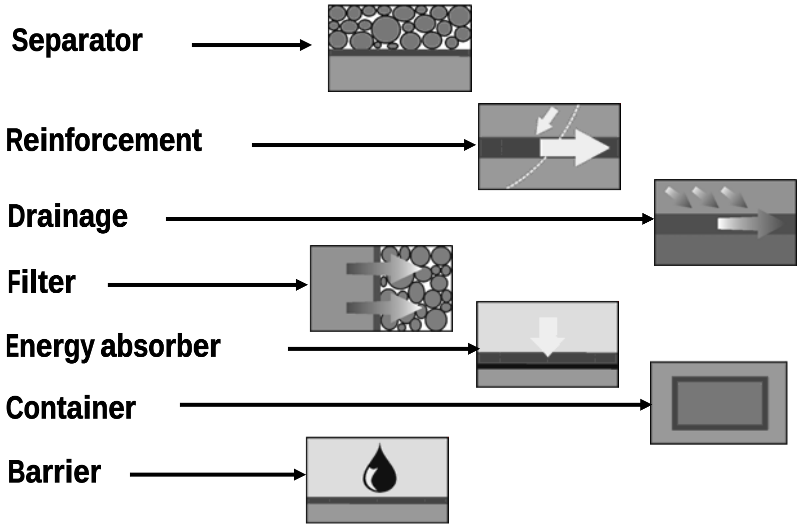
What are geosynthetics ?

Synthetic polymer materials that are specifically manufactured to be used in geotechnical and geo-environmental applications.

Geosynthetics = thin, flexible, sheet-like materials enhancing the engineering performance of soils



Roles of Geosynthetics



Categories of Geosynthetics

Today:

- Geotextiles (GTX)
- Geogrids (GG)
- Geonets (GN)
- Geomembranes (GM)
- Geocomposites (GC)
- Geocells (GL)
- Geosynthetic clay liners (GCL)
- Geofoam (GF)
- Other

Geosynthetics Functions

	Separation	Reinf.	Filtration	Drainage	Barrier	Protection
GM					•	
GCL					•	•
GN				•		
NWGT	•		•	•		•
W GT	•	•	•			
GG		•				
GC	•	•	•	•	•	•

• Primary Function

• Secondary Function

Why use geosynthetics in waste containment construction?

- They can perform a function that other materials cannot
- They can perform a function better or cheaper than an alternative material (e.g. a mineral layer)
- They are an alternative when mineral materials are not available or are costly due to shortages

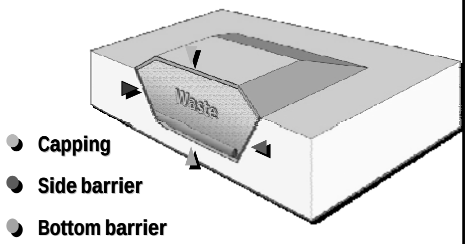
To make a design possible and/or cheaper

Geosynthetics are used to stop the release of contamination into the environment

The main engineering components of a waste containment facility are designed to:

Provide a barrier to gas and contaminated water (leachate) for the life of the facility; and

Help control the pressures of liquid and gas acting on the barrier through the use of drainage systems and caps



Barrier systems include geosynthetics functioning as barrier (GM, GCL), reinforcement (Geogrids, Fibres) and protection (GT)

Pressure control systems require geosynthetics functioning as drain (GN, Geocomposites, GT), filter (GT), separator (GT) and barrier (e.g. as part of the cap)

Material Properties Controlling Performance

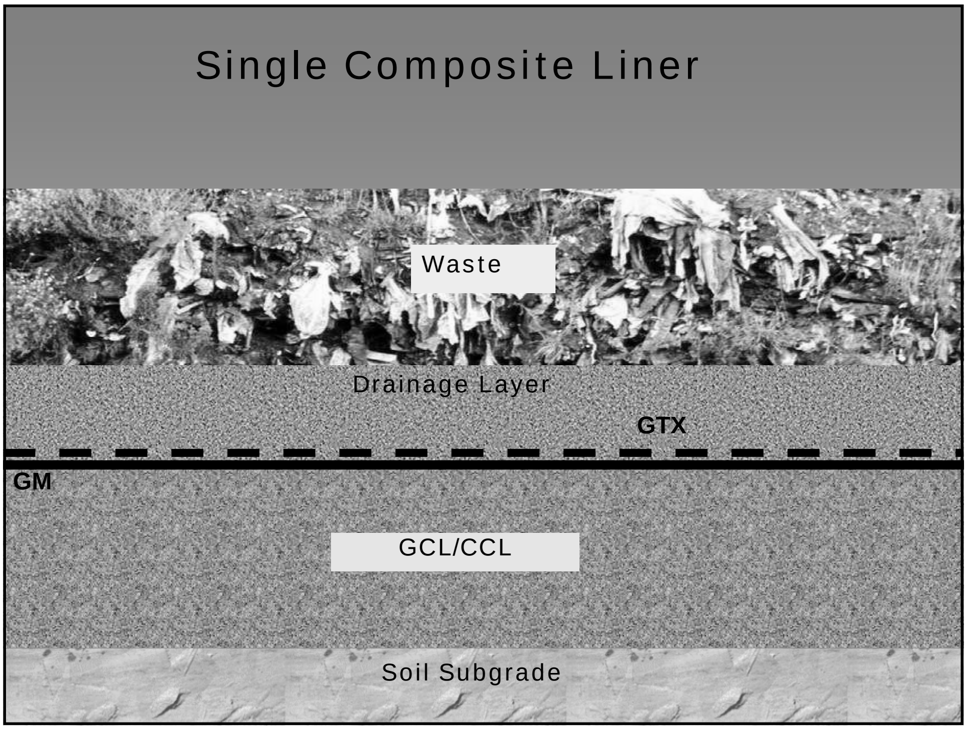
- Knowledge is required of a wide range of geosynthetic properties both for quality control and design.
  - Index tests: are used to measure physical and mechanical properties of materials (e.g. weight, thickness, tensile strength, resistance to puncture etc).
  - Values obtained are used to assess the variability (i.e. between batches) and to compare materials from different sources.
  - However, care should be taken if using index test values directly in design.

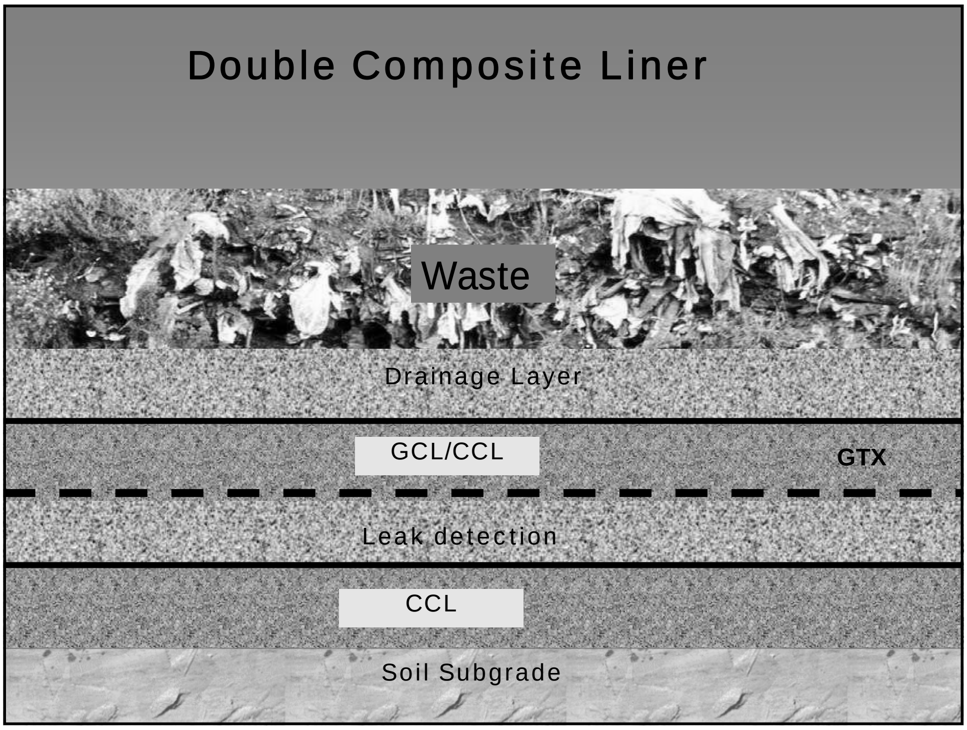
- **Performance tests: are conducted to obtain engineering properties that can be used in design (e.g. interface friction, protection efficiency).**
- **These tests are conducted using site specific materials and relevant boundary conditions.**
- **They often involve assessing the interaction between two or more geosynthetics and between geosynthetics and soils.**

Geosynthetic Barriers

There are two main types of geosynthetic barrier (both have a hydraulic barrier function) :

- Geomembranes
- Geosynthetic Clay Liners (GCL)
- They are rarely used as stand-alone barriers except in capping systems. Usually they are employed as part of a composite lining system in conjunction with a low permeability mineral layer (e.g. compacted clay)


Single Composite Liner
Waste
Drainage Layer
GTX
GM
GCL/CCL
Soil Subgrade

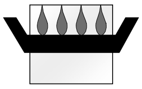

Double Composite Liner
Waste
Drainage Layer
GCL/CCL
GTX
Leak detection
CCL
Soil Subgrade

Geomembrane

• A planar, relatively impermeable, polymeric (synthetic) membrane with a minimum thickness of 1.0 mm.

- Acts as a barrier to fluids
  - Both liquids and gases
- Rolls are field seamed

- *Applications:*
  - Barrier in base of landfills
  - Barrier on sides of landfills
  - Barrier in caps of landfills



Waterproofing

Geomembrane Requirements and Characteristics

- **Physical** (e.g. thickness and density)
- **Mechanical** (e.g. tensile strength, tear resistance, impact resistance, puncture resistance, stress cracking, friction)
- **Endurance** (e.g. resistance against ultraviolet light, biological, chemical and thermal degradation)

- HDPE is the most common resin because of its good chemical resistance
- Typical thicknesses are 1 to 3 mm (lower values used for caps and upper values for basal systems)
- Surfaces are smooth, textured or profiled depending on the surface friction requirements
- LDPE, VLDPE are used in caps due to increased flexibility, hence they can respond better to differential settlement of waste

Design Philosophy for Geomembranes

- Minimise stresses and hence strains in the geomembrane
- Check that the resin used is not sensitive to *stress cracking* which can occur in materials such as HDPE. Stress cracking is brittle cracking under tensile stress less than its short-term mechanical strength
- Both aim to ensure the long-term integrity of the geomembrane and hence minimise any leakage

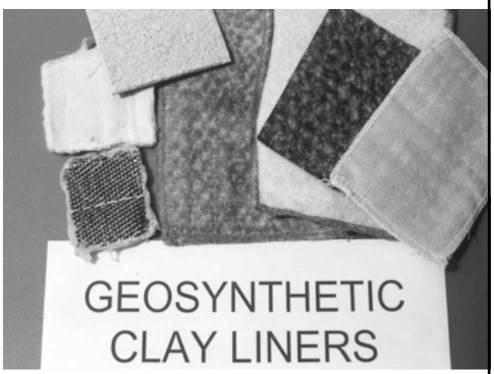
Geosynthetic Clay Liners (GCLs)

•Formed of a layer of bentonite powder sandwiched between two geotextiles, or bonded to a geosynthetic (e.g. geomembrane)

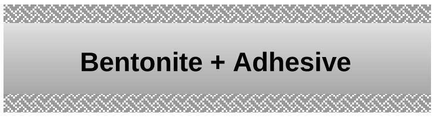
•Shear forces are transferred via needle punching or stitching the two geotextiles together

•On contact with liquid the bentonite hydrates producing a layer with low permeability

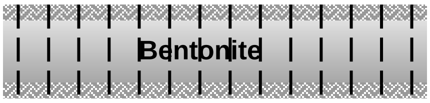
•GCLs are used extensively in capping systems



Types of Geosynthetic Clay Liners (GCLs)



(a) Adhesive bound bentonite to upper and lower GTX



(b) Stitch bonded bentonite between upper and lower GTX

Bentonite

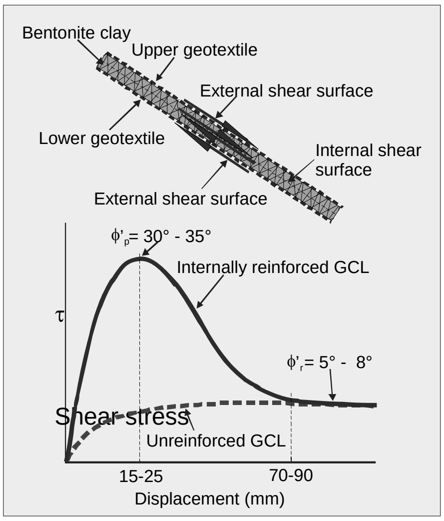
(c) Needle punched bentonite through upper and lower GTX

(d) Adhesive bound bentonite to a geomembrane

GCL's – hydraulic conductivity properties

- ***Hydration process:***
  - Water must be available at a controlled rate to enable the hydration process to take place
    - GCL's can obtain enough hydration water from the pore water of adjacent soils
  - Also, there must be some confinement of the GCL to minimise swelling and hydraulic conductivity
  - The initial presence of non-polar organic liquids (e.g. diesel, gasoline) can prevent hydration from occurring
- ***In-service performance:***
  - Once properly hydrated GCL's are resistant to a wide range of chemicals
    - Including non-polar organic liquids
  - Ion exchange can increase *k* one to two orders of magnitude
    - Presence of Ca, Mg, heavy metals, sulphates
  - Drying/wetting cycles makes *k* fluctuate – used with caution
  - GCL's should not be used where:
    - there is no access to hydration water
    - pH < 3 and pH > 11

GCL's – shear properties



- When using GCL's on slopes shear properties are important
  - External shear surfaces
  - Internal shear surface
- A critical failure surface should not pass along or within the GCL
- Unreinforced GCL's have low internal shear resistance ϕ'_r = 5°-8°
- Reinforced GCL's have short term peak internal shear resistance ϕ'_p = 30°-35° provided displacements are maintained less than 25 mm
  - Issue of long term shear stresses

Separation - Filtration - Drainage - Protection - Reinforcement

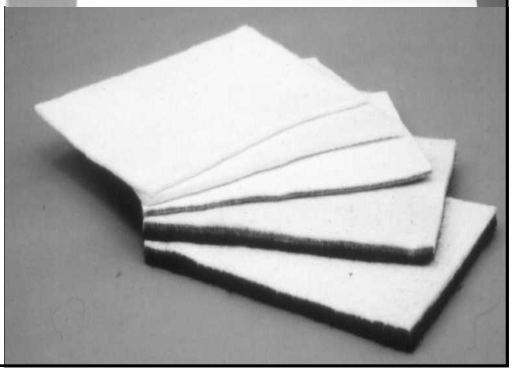
Nonwoven

Geogrids - Wovens

Geotextiles

The sheets are flexible and permeable and generally have the appearance of a fabric

- **Applications:**
  - **Filters for groundwater, leachate, gases**
  - **Protection for geomembranes**
  - **Daily cover protection**



Woven Geotextiles

▪**Two parallel arrays of elements interlaced othogonally by traditional weaving methods-**

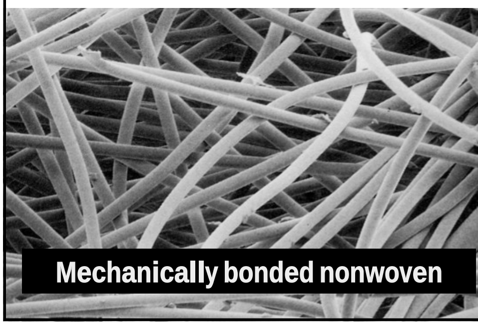
▪**Good tensile strength/low extension**

Non Woven Geotextiles

- Randomly oriented filaments or fibres
- Low tensile strength/high extension

Length of elements:
- Continuous filaments (endless)
- Cut filaments (staple fibre - length 50 to 300 mm)

Bonding:
- Mechanical (needle-punching)
- Thermal (heat-bonding, melting)


Mechanically bonded nonwoven


Thermally bonded nonwoven

Geotextiles

- **Principal functions in lining systems**
  - Protection
    - To prevent or reduce damage to geomembrane or other material
  - Separation
    - To prevent intermixing of two dissimilar soils or materials
  - Filtration
    - To permit passage of fluid while preventing passage of soils particles
    - Combined functions
- **Secondary functions**
  - Drainage, reinforcement

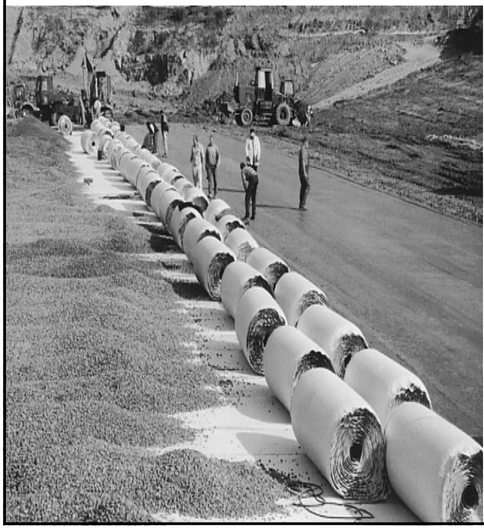
Geotextiles for geomembrane protection

- Geotextiles are used to protect the geomembrane from both mechanical damage and straining under applied loads
- Non-woven geotextiles are commonly used (e.g. needle punched non-woven geotextiles)
- Efficiency of protection is dependent upon: fibre type (e.g. length), fibre quality and manufacturing method (e.g. type and amount of needling)
- The unit weight of a geotextile should not be used to specify a protection layer

Gravel Placed on a Geotextile Protection Layer

Sand Filled Geotextile
Mattress Protection Layer

Concrete Filled Geotextile
Mattress Protection Layer



Mechanical Damage

- Mechanical damage can occur through placement of overlying layers during construction
- There is significant evidence of damage to geomembranes during placement of gravel drainage layers and waste. These often involve direct damage by the construction plant.

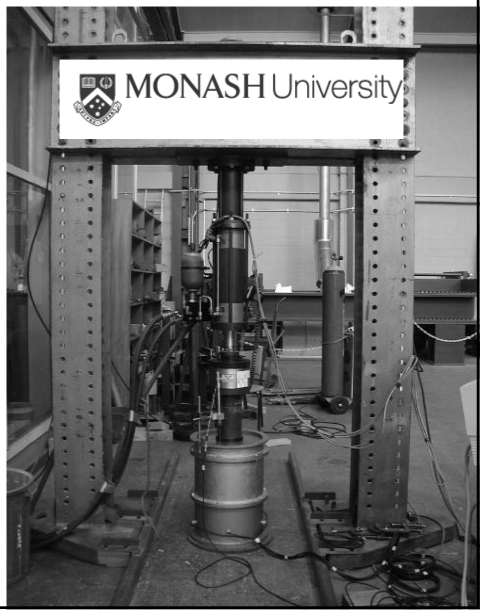
Protection Tests: Mechanical Damage

- Tests to assess the ability of materials to protect against mechanical damage (short-term loading) include the following index tests:
  - Resistance to static puncture
  - Pyramid puncture
  - Dynamic puncture test
  - Impact resistance

Protection Tests: Long-term Loading

- Protection efficiency for geomembranes under long-term loading, and hence straining that could result in stress cracking, can be assessed using a compression test. Performance type tests can be conducted using site specific geosynthetic and mineral materials.
- The full test entails subjecting the geomembrane, protection layer, gravel layer system to the design load for 1000 hours at a temperature of 40°C
- A layer of rubber is used to simulate a compacted clay layer beneath the geomembrane

Compression Test Set Up



Compression Test: Interpretation of Measurements

- German recommendations are that the lifetime strain of the geomembrane should not exceed approximately 1%
- A maximum strain value <0.25% should be obtained in a test conducted at 40°C for 1000 hours
- Factors are applied to the applied load if a test is carried out at a reduced temperature (e.g. 21°C) and for a shortened time period (e.g. 100 hours)
- Field evidence (i.e. obtained by exhuming samples of geomembrane liner from landfill sites) has demonstrated that stress cracking can occur

Without adequate protection, geomembranes will deteriorate with time. This will result in failure of the containment system

Drainage Layers

- Drainage layers are located above, and sometimes below, the barrier layers used in basal and capping systems
- Above the basal liner their role is to drain leachate and landfill gas to the extraction points, thus ensuring pressure heads are kept to a minimum
- Below the basal liner they can be used as leak collection/detection layers (if a secondary liner is placed below) or to control ground water pressures from acting on the barrier

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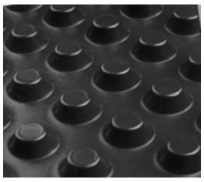
- Above capping barriers they are used to control water pressures resulting from precipitation
- Below capping barriers they are used to collect landfill gas and to provide a flow path to the extraction points

In all cases the control of pore pressure improves stability of the lining system and minimises any leakage

Geosynthetic Drainage Products


1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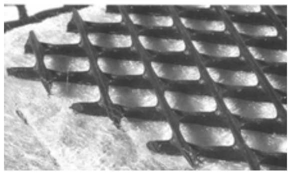
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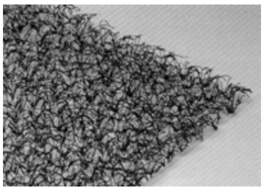
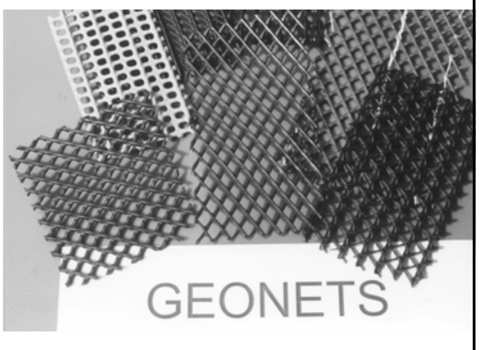

4


5

1-thermally bonded foam; 2-formed plastic sheet; 3- geonet; 4-regularly laid mesh; 5-three-dimensional entangled mesh

Geonets

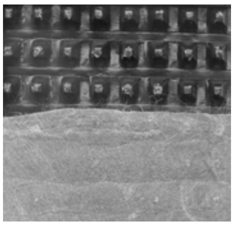
- **Geonets consist of multi-layered polymer strands bonded together**
  - **Bi-planar geonets have two polymer strands bonded together (two sets of ribs overlapping)**
    - **Flow roughly the same in all directions**
  - **Tri-planar geonets have three polymer strands bonded together (main ribs in centre with subsidiary sets top and bottom).**
    - **Flow mostly in direction of main ribs**

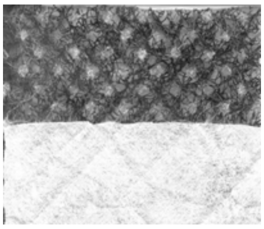


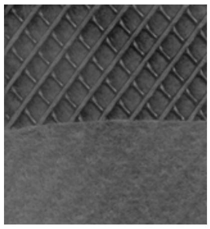
- **The polymer strands can be solid HDPE or foamed HDPE**

Geocomposite Drains

- Geocomposite drains are formed of geotextile layers (often non-woven) bonded either side of a discharge capacity core (5 to 25 mm thick)
- In plane discharge capacities are in the range 0.0002 to 0.01 m^3/ m width/sec
- A 20 mm thick geocomposite drain can have the same flow capacity as a 300 mm thick granular layer
- Geotextile layers act as a separator and filter


Cuspated Core


3-D Mesh Core

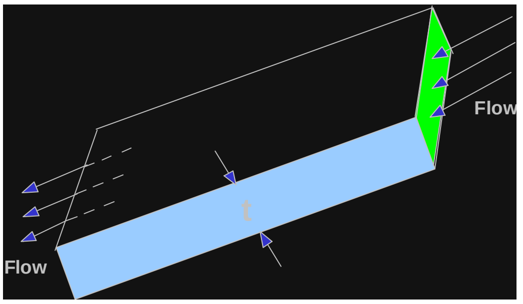

Net Core

- Flow rate per unit width >> compared to sand or gravel drainage layer
  - Q_u = ultimate flow (from test data) > Q_a = allowable flow
  - Intrusion of geotextile into geonet restricts flow (~20-35%)- reduction factor (RF_{IN}) of 1.5-2.0 from ultimate.
  - Reduction factor (RF_{CR}) for creep compression of geonet (1.4-2.0)
  - Allow reduction for biological and chemical clogging (reduction factors (RF_{BC} and RF_{CC}) of 1.5-2.0 for each)
  - $Q_a = Q_u / (RF_{IN} \times RF_{CR} \times RF_{CC} \times RF_{BC})$

Key Properties for Geosynthetics in Drainage

- Transmissivity, θ, in-plane permeability, k
- Index Tests vs Performance Tests

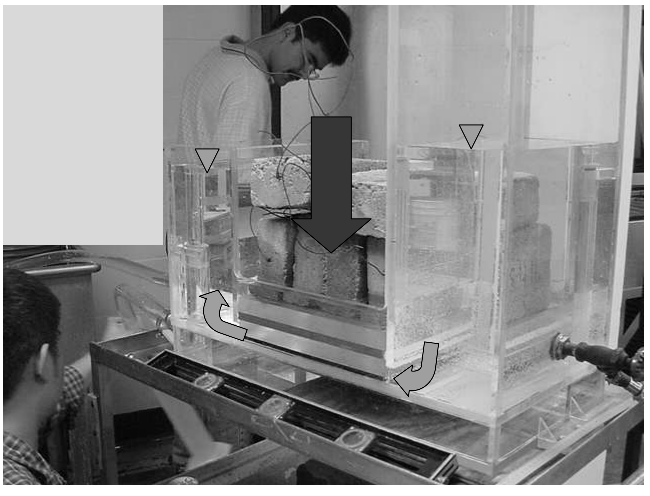
Drainage Function
"In-Plane" Flow



Function of the drain:

1. Discharge all seepage.
2. Reduce or redirect seepage forces.
3. Prevent large hydrostatic pressures.

Transmissivity, θ_{ult} or Flow Rate, q_{ult}



Design For Drainage

- Functions:
  - Adequate flow capacity under design loads to convey maximum anticipated seepage during design life.
  - Long-term performance considerations.
- Filtration
  - Prevent migration of fine particles that could eventually result in piping failure or clogging of the drainage layer.

Design Criteria and Tests

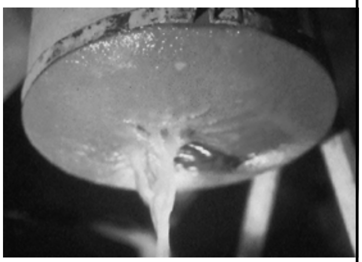
- In plane drainage capacity is dependent on:
  - adequate filtration without clogging; and
  - adequate in flow/out flow under design loads (creep can be a significant factor)
- Relevant tests include:
  - Composite internal strength
  - Tests to assess durability of materials (weathering)
  - Hydraulic properties
    - Normal to plane
    - In plane

Geocomposite Drainage Layers: Advantages

- Traditionally, granular layers have been used in landfills
- Geocomposite drains can offer some advantages:
  - Increased landfill void
  - Ease of placement
  - Quality control (i.e. uniformity)
  - Reduced use of primary aggregates

Filter Layers

- A key role of the geotextiles used in geocomposite drains is as a filter
- They must:
  - retain particles of soil and waste;
  - allow free flow of liquid and gas;
    - Up stream of the filter avoid external clogging; and
    - Through the filter avoid internal clogging of the core



- While there are many advantages to using geotextiles (e.g. low thickness, tensile strength, uniform and easy to install) there use also introduces some additional factors that must be considered (e.g. they are compressible, have variable transmissivity under confining stress, are altered by ultraviolet and can be subject to punching and tearing)

➢Permeability (EN ISO 11058)

➢Characteristic Opening Size (EN ISO 12956)-for assessing soil retention

➢Design methods
➢ Task force 25 (1983)
➢ Carroll (1983) ($O_{95} < d_{85}$)
➢ Giroud (1982)

➢Non woven most suitable

Reinforcement Layers

- The tensile properties of geosynthetic materials (e.g. geogrids and geotextiles) are used to resist stresses and control deformations (strains)

- Reinforcement is used in landfills to:
  - Improve the stability of lining systems on slopes (e.g. veneer stability);
  - Reduce stresses in geomembranes; and
  - Allow steeper sub-grade slopes to be constructed, hence increasing void space for waste

Advantages of using geosynthetic reinforcement include: simple construction methods, manual handling and light weight plant, cheaper fill material and rapid construction

Geogrids

Geogrids are geosynthetic materials that have an open grid-like appearance. The principal application for geogrids is reinforcement.

Geogrids

❑ Main use- reinforcement

✓ Used to reinforce stability of cover or drainage material on slopes or caps (veneer stability).
✓ To reduce differential settlement over soft soil or variable subgrade
✓ Used in reinforced soils walls (for steep wall lining)

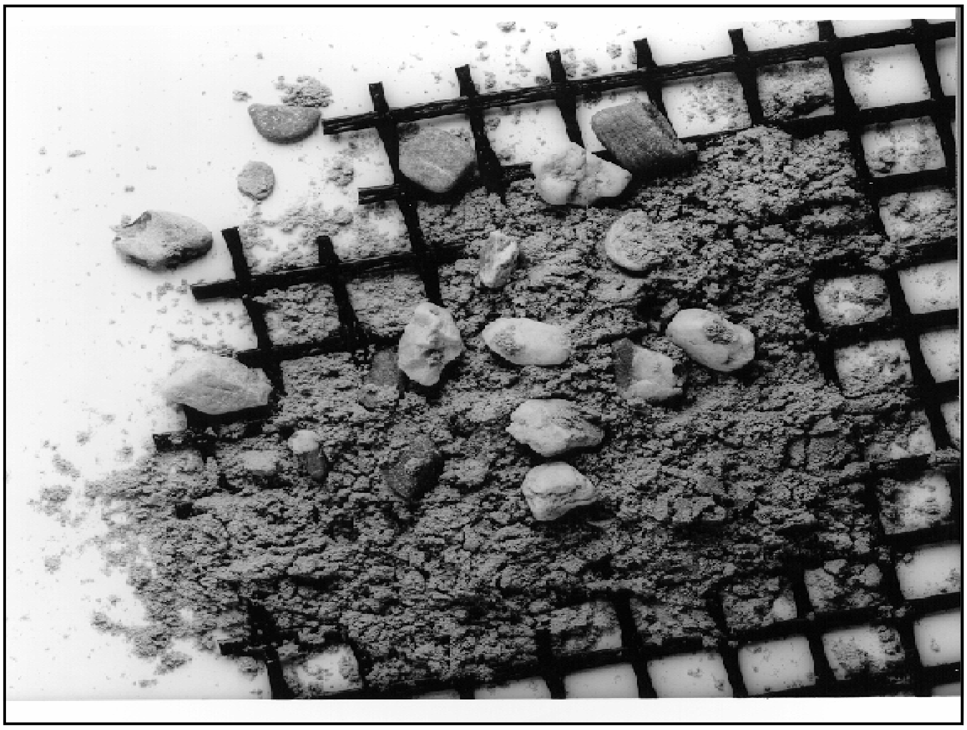
❑ Formed from HDPE or PP and polyester

Geogrids

- **Uniaxial**:
  - ✓ Designed to endure stress in one direction. The ribs tend to be thick and the apertures are long narrow slits. Stronger than biaxial, but can only be applied in situations where stresses occur in a single direction

- **Biaxial types**:
  - Biaxial geogrids can take stresses in two directions. The apertures are more evenly dimensioned. They are useful in situations where stresses are applied in two directions, but don't have as much tensile strength in either direction as a uniaxial geogrid

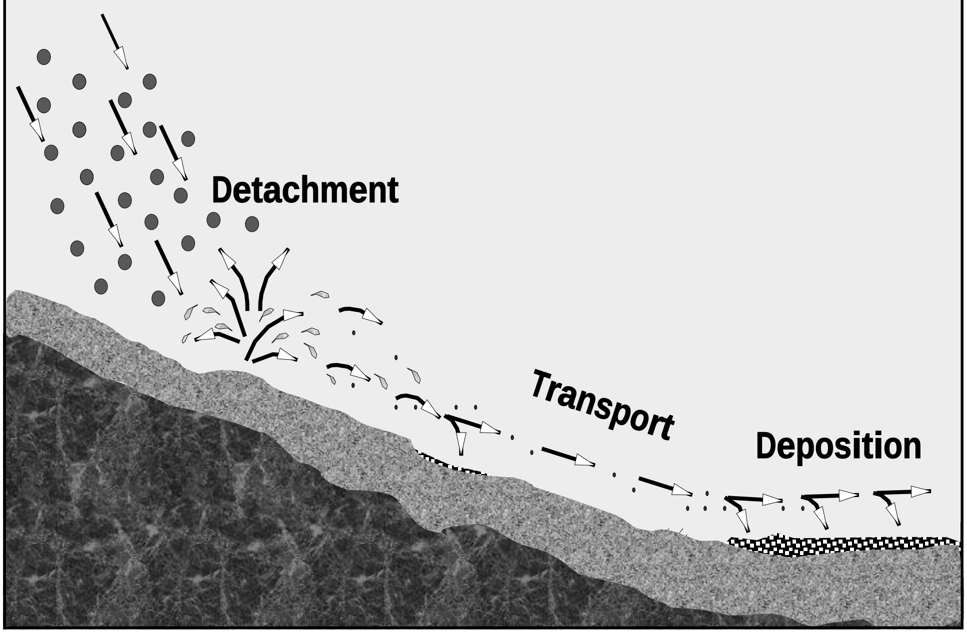
- **Act best by interlocking with stone or gravel fill**



Erosion Control Mats

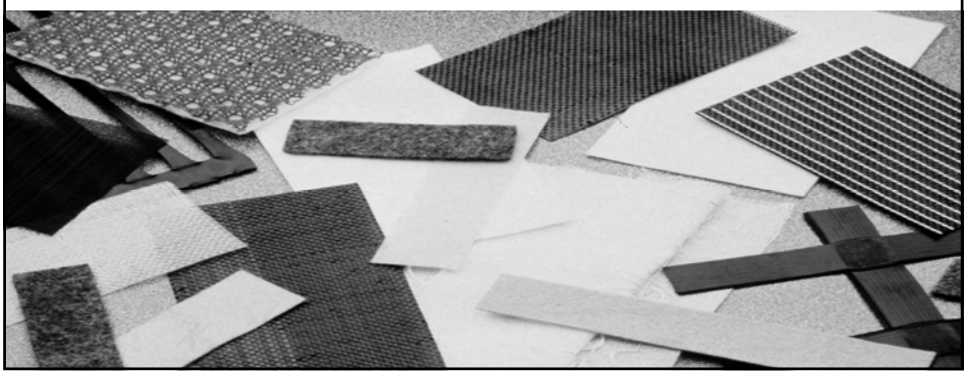
- Geosynthetic materials (synthetic and natural) that prevent erosion of soil surfaces and promote vegetation growth
- Applications:
  - Surface erosion control on top of landfill caps

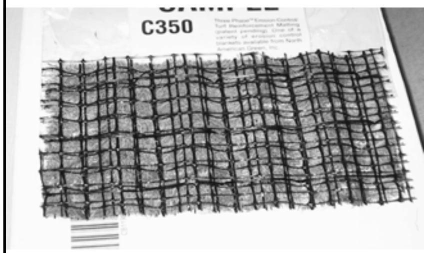
Three -Step Process of Soil Erosion

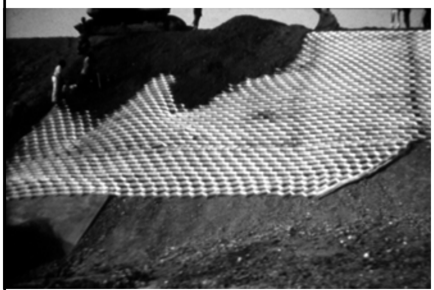


Geosynthetic functions include:

- Protection (from rain drop impact & stream flow erosion)
- Medium for plant growth



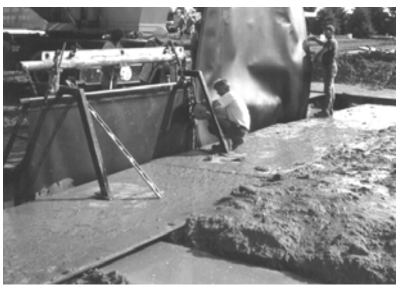




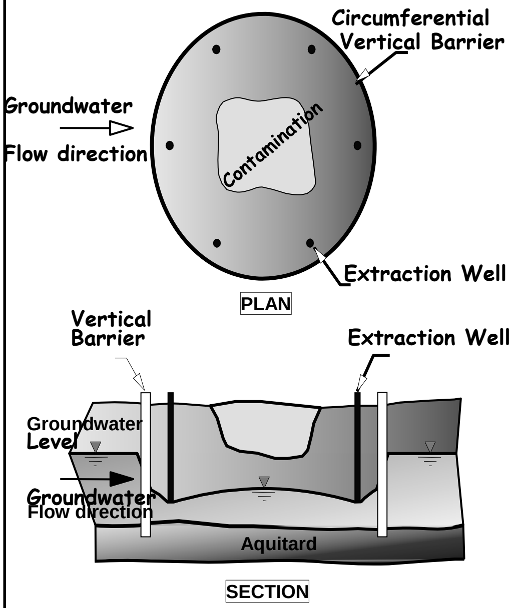
- *Geoblankets:*
  - Permeable, biodegradable structure placed over the soil for temporary erosion control applications while vegetation is being established
- *Geomats:*
  - 3-D permeable, polymeric structure used to reinforce roots of grass and small plants for permanent erosion control applications
- *Geocells:*
  - 3-D permeable, polymeric, honeycomb or web structure – soil or concrete filled

Vertical Geomembrane Cutoff Walls

- utilized at abandoned dumps or for the control of polluted groundwater
- typically placed in a slurry supported trench with soil/bentonite, or cement/bentonite
- system is greatly enhanced with a geomembrane placed up gradient, thereby forming a vertical composite liner system



(Placement of GM Panels)



- The cut off barrier can be placed around a contamination source to contain contaminants and inhibit the inflow of groundwater
- It can also be placed upstream to prevent flow into the contaminated region, down stream to prohibit flow of contaminant offsite

Design Methods

(a) "Cost"-based on experience/availability
(b) "Specification" – for common applications
(c) "Function" – for specialty, critical and/or permanent applications

Conclusions

- No standard solutions. Each application asks for individual design.
- Geosynthetic solutions allow economic and effective constructions.
- There is no one size to fit them all
- A good performance will be more function of installation quality.