Lecture 23

NPTEL Course

GROUND IMPROVEMENT

USING GEOSYNTHETICS

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A Brief Overview of Geosynthetics and Their Major Applications*

1. Geosynthetic Materials
2. Transportation and Geotechnical
3. Geoenvironmental
4. Hydraulic Engineering
5. Private Development
6. Concluding Comments

1. Geosynthetic Materials

- Polymer Background
- Types of Geosynthetics
- Various Functions
- Design Methods
- Application Areas

Polymer Background

- geosynthetics are really “geopolymers”
- feedstock is natural gas reacted to form resin in a flake form
- mixed with additives into a formulation
- manufactured into a particular type of geosynthetic material

Geosynthetic (GS) Materials

- geotextiles (GT)
- geogrids (GG)
- geonets (GN)
- geomembranes (GM)
- geosynthetic clay liners (GCL)
- geopipe (GP)
- geofoam (GF)
- geocomposites (G C)


GEOTEXTILES

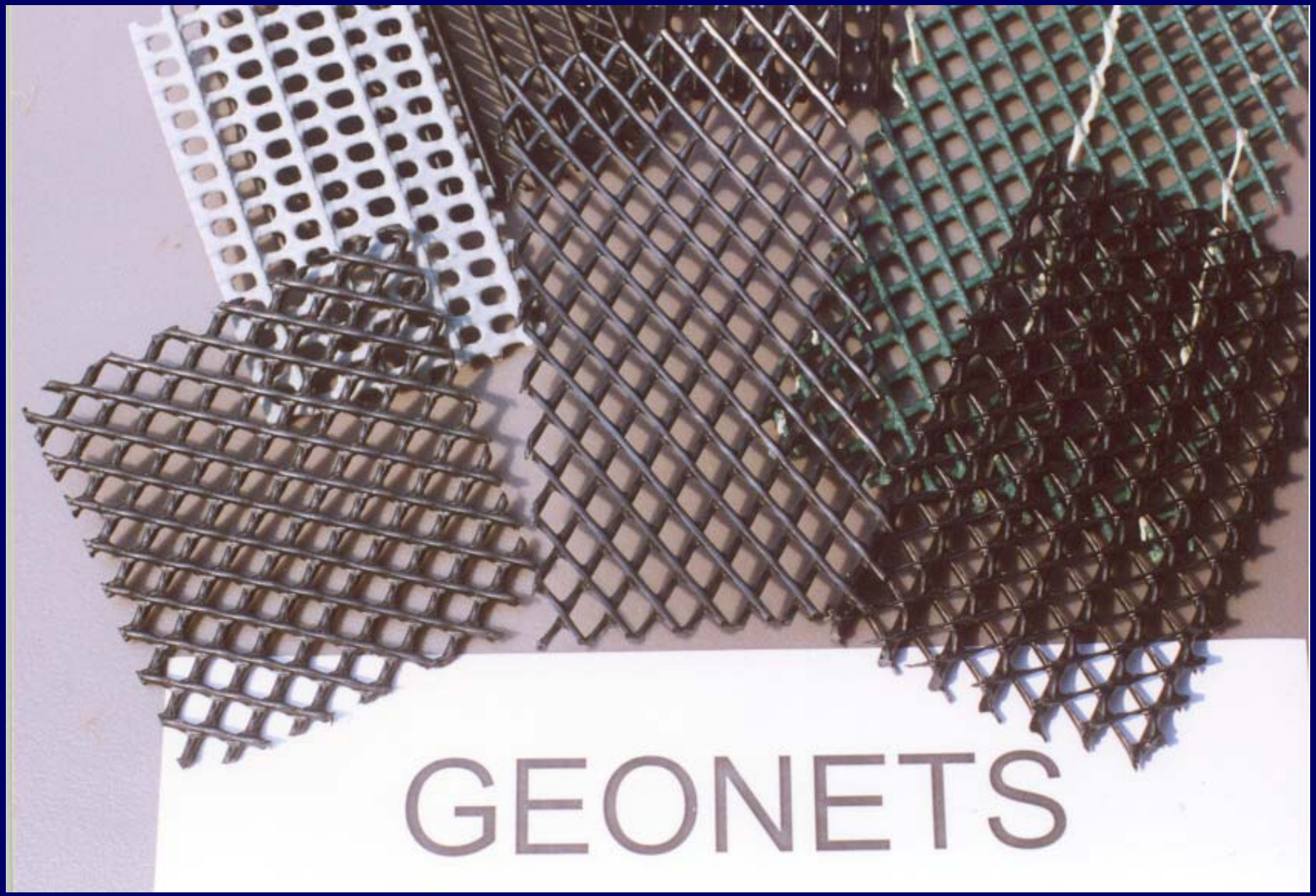
Geotextiles (GT)

- majority are made from polypropylene fibers
- standard textile manufacturing
- woven (slit film, monofilament or multifilament)
- nonwoven (needle punched or heat bonded)
- characterized by an open and porous structure
- mechanical and hydraulic properties vary widely
- very versatile in their primary function


GEOGRIDS

Geogrids (GG)

- unitized, woven yarns or bonded straps
- structure allows for soil “strike-through”
- bidirectional – equal strength in both directions
- unidirectional – main strength in machine direction
- focuses entirely on reinforcement applications, e.g.,
- walls, steep slopes, base and foundation reinforcement


GEONETS

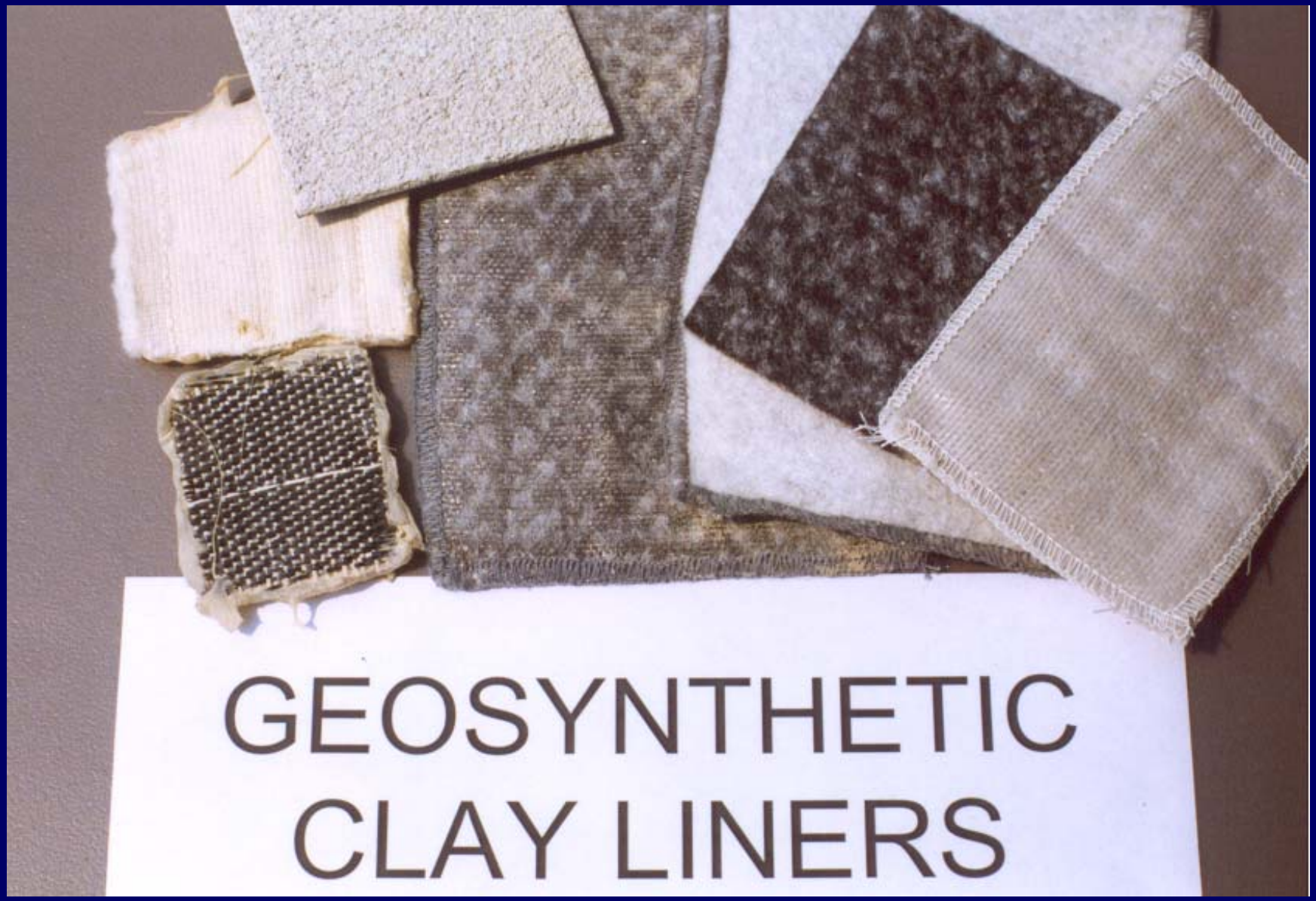
Geonets (GN)

- all are made from high density polyethylene
- results in parallel sets of ribs as a integral unit
- biplanar – flow is equal in all directions
- triplanar – flow much greater in machine direction
- function is always in-plane drainage
- surfaces must be covered; usually with GTs


GEOMEMBRANES

Geomembranes (GM)

- function is always containment
- represents a barrier to liquids and gases
- many types: HDPE, LLDPE, fPP, PVC, EPDM, etc.
- manufactured rolls are field seamed
- required by regulations for waste containment
- new applications in hydraulics and private development


GEOSYNTHETIC
CLAY LINERS

Geosynthetic Clay Liners (GCL)

- function is always containment
- common product is bentonite between 2-GTs
- internally reinforced by needle punched or stitching
- bentonite product bonded to GM is also available
- many other variations exist
- competitive with compacted clay liners (CCLs)
- beneath a GM; one has a composite liner

GEOPIPE

Geopipe

- its really buried plastic pipe!
- function is always drainage
- HDPE and PVC most common
- both can be smooth walled or corrugated
- corrugated HDPE growth is enormous

GEOFOAM

Geofoam (GF)

- EPS or XPS in block form
- lightweight fill on soft or sensitive soils
- relieves lateral pressure on walls
- also used for insulation of frost-sensitive soils


GEOCOMPOSITES

Geocomposites (GC)

- array of available products
- GT/GM; GT/GG; GT/GN; etc.
- considerable ongoing innovation
- primary function depends on final product

Function vs. Geosynthetic Type

Type of Geosynthetic	Separation	Reinforcement	Filtration	Drainage	Containment
geotextile	√	√	√	√	
geogrid		√			
geonet				√	
geomembrane					√
geosynthetic clay liner					√
geopipe				√	
geofoam	√				
geocomposite	√	√	√	√	√

Design Methods

(a) “Cost”-based on experience/availability

(b) “Specification” – for common applications

(c) “Function” – for specialty, critical and/or permanent applications

Design-by-Function

$$FS = \frac{Allowable\ (Test)\ Property}{Required\ \ (Design)\ Property}$$

where

- test Methods are from ASTM, ISO or GRI
- design Models from the Literature
- factor-of-Safety is Application Specific

Application Areas

Transportation/Geotechnical – GT, GG & GC mainly

Geoenvironmental – GM, GCL & GN mainly

Hydraulic Systems – GM, GP & GC mainly

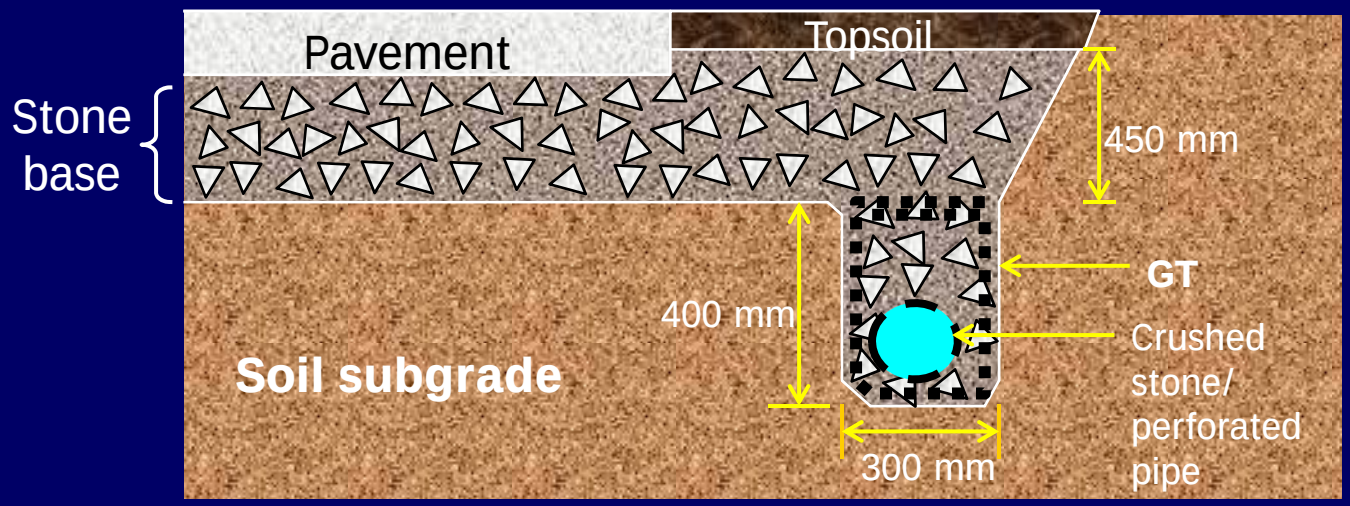
Private Development – all types of GSs

2. Transportation and Geotechnical Applications

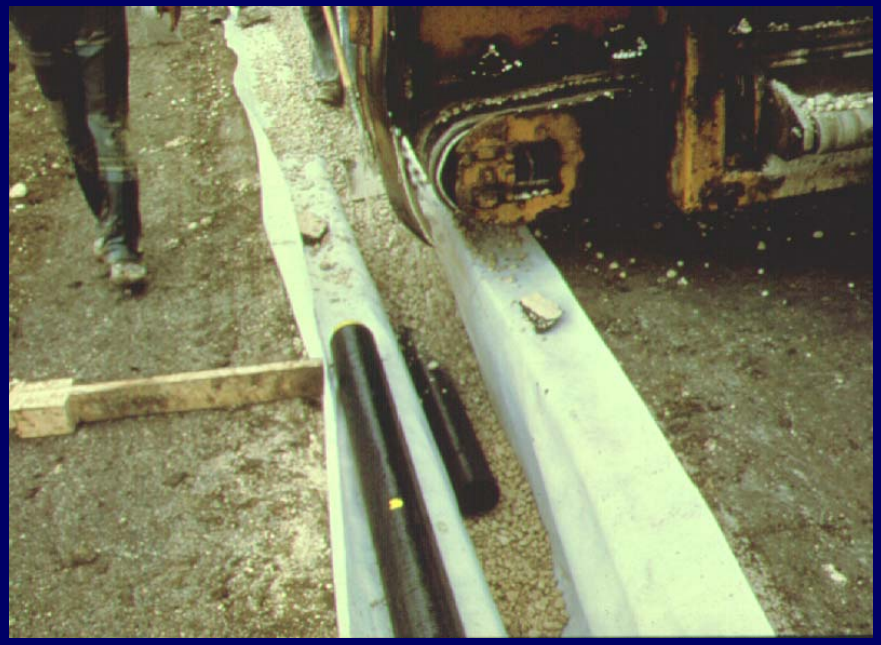
- GTs as filters
- GTs and GGs as wall reinforcement
- GTs and GGs as slope reinforcement
- GC Wick Drains (also called PVDs)
- GC Erosion Control Systems

Geotextile Filtration

- refers to cross-plane flow, i.e., GT is acting as a filter not as a drain
- three design requirements:
  1. adequate flow
  2. proper soil retention
  3. long-term flow equilibrium
- many applications, e.g.,
  - behind retaining walls
  - under erosion control systems
  - around pavement underdrains (follows)



(GT Filter in Excavated Trench)

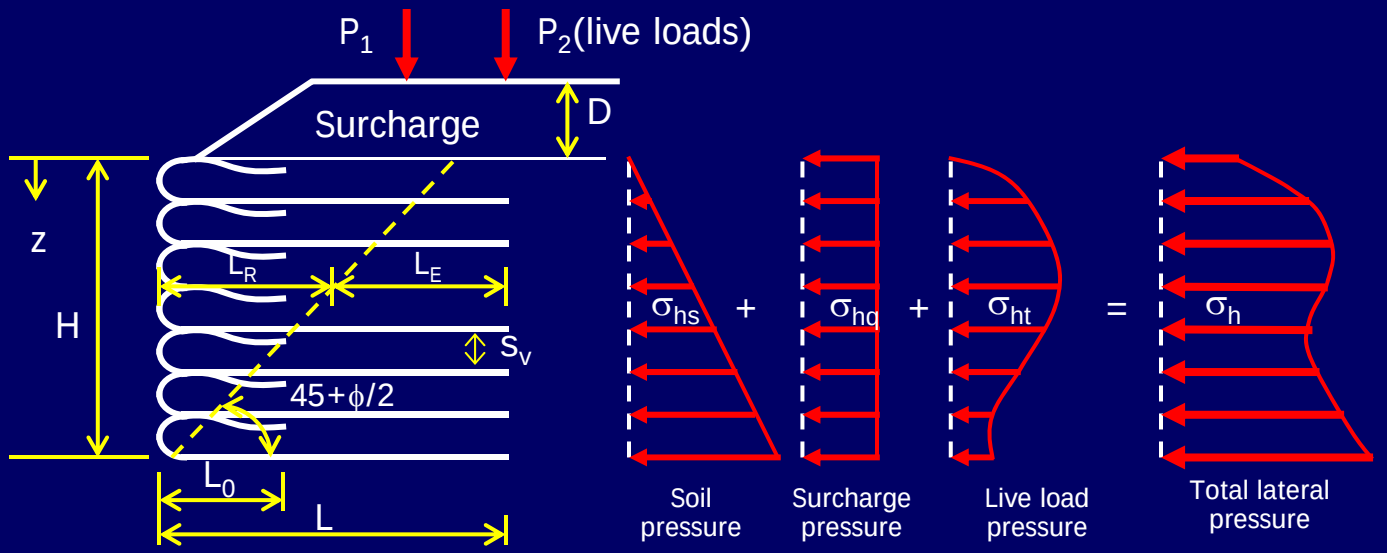


(Crushed Stone & Perforated Pipe)

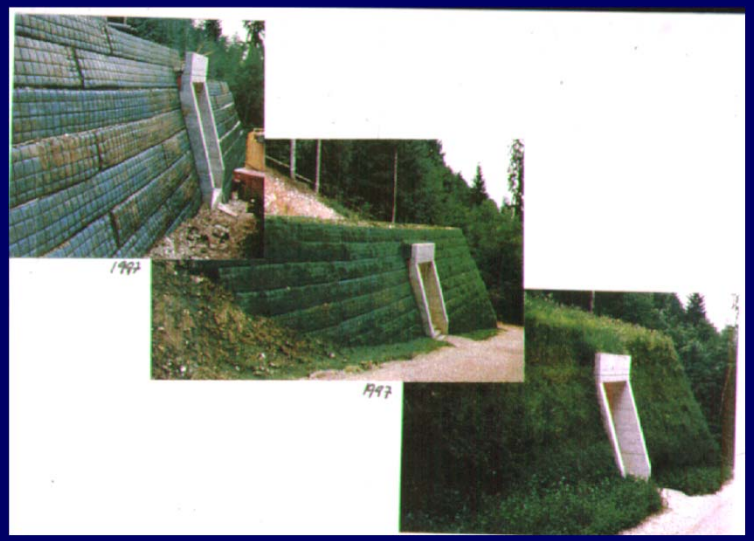
Wall Reinforcement Design Concepts

- internal design results in:
  - spacing of GT or GG
  - length of GT or GG
  - facing connection stress
- external design used to assess:
  - overturning stability
  - sliding stability
  - bearing capacity
- reduction factors on reinforcement
  - put on laboratory values for allowable strength
- factor-of-safety
  - on each design aspect to resist the “unknown”

Elements of a GT or GG Wall Design



(With Concrete Facing)



(Green Wall with Vegetated Facing)

Segmental Retaining Walls (SRWs)
(also called modular block walls)

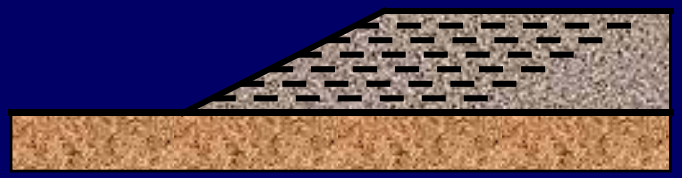
- design is same as described before
- refers to type of wall facing
- great variety of aesthetic blocks
- usually GG reinforced MSE system
- generic computer design codes available


Tiered Wall with Surcharge

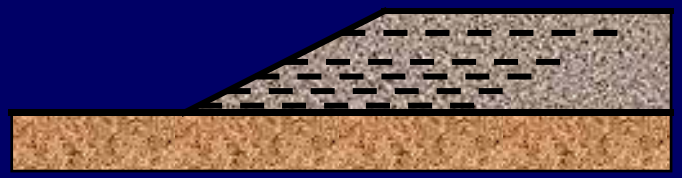
Reinforcement for Soil Slopes

- most soil slopes become unstable steeper than 2(H)-to-1(V) (26.5°)
- use GT or GG reinforcement to increase either the slope angle or height
- essentially no limit, except for erosion
- various placement patterns are possible

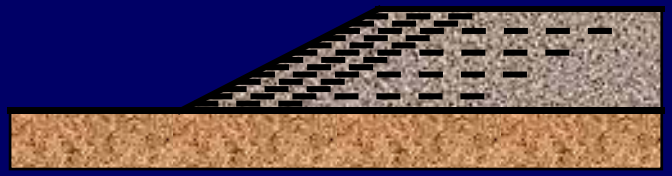
Placement patterns for reinforcement



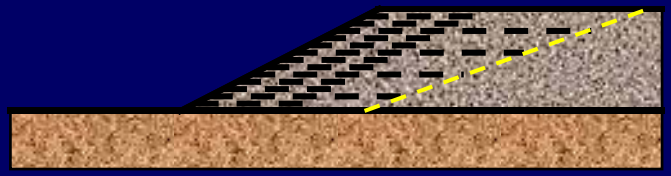
(a) Even spaced-even length



(b) Uneven spaced-even length



(c) Even spaced-even length
with short facing layers



(d) Even spaced-uneven length
with short facing layers

(One that Failed)!

(With Reinforcement-Steep & Stable)

Geocomposite Wick Drains

- also called prefabricated vertical drains (PVDs)
- used for rapid consolidation of saturated fine grained soils
- consists of a drainage core with a GT filter/separator wrapped completely around it
- typically 100 mm wide, by 2 to 10 mm thick, by ±100 m long (in roll or coil form)

(Driving Wick Drains)

(Ready for Surcharge Fill)

Geocomposite Erosion Control Systems

- huge array of products
- slope protection – modify USLE
- channel protection – increase shear stress
- temporary; permanent (soft); permanent (hard)

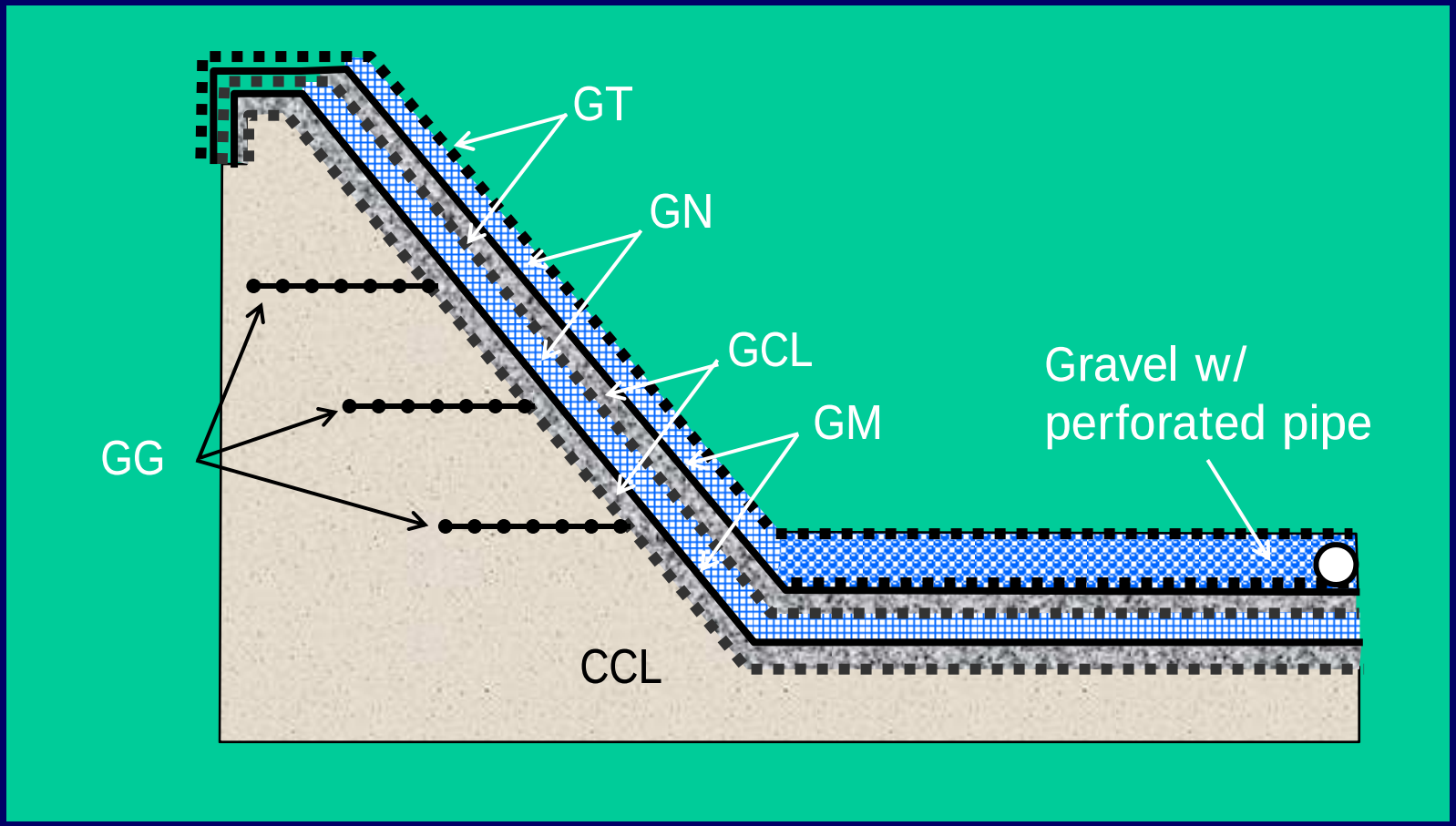
3. Geoenvironmental Applications

- Landfill liner systems
- Landfill cover systems
- Vertical Cutoff Barriers
- Liners for Surface Impoundments
- Liners for Heap Leach Ponds

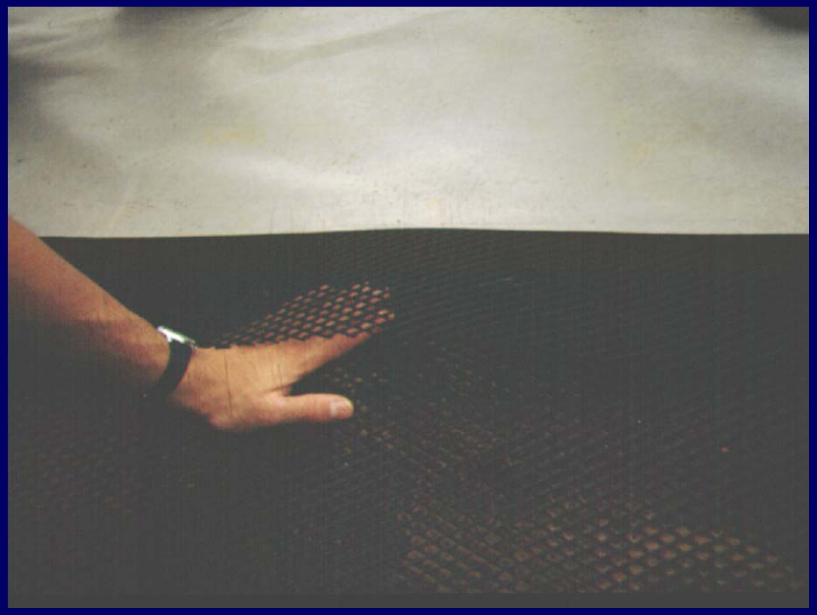
Nature of Waste Problem

- moisture within and precipitation on the waste generates leachate
- leachate takes the characteristics of the waste
- thus leachate is very variable and is site-specific
- flows gravitationally downward
- enters groundwater unless a suitable barrier layer and collection system is provided

Double Liner System
(with leak detection layer)



(Secondary Composite Liner)

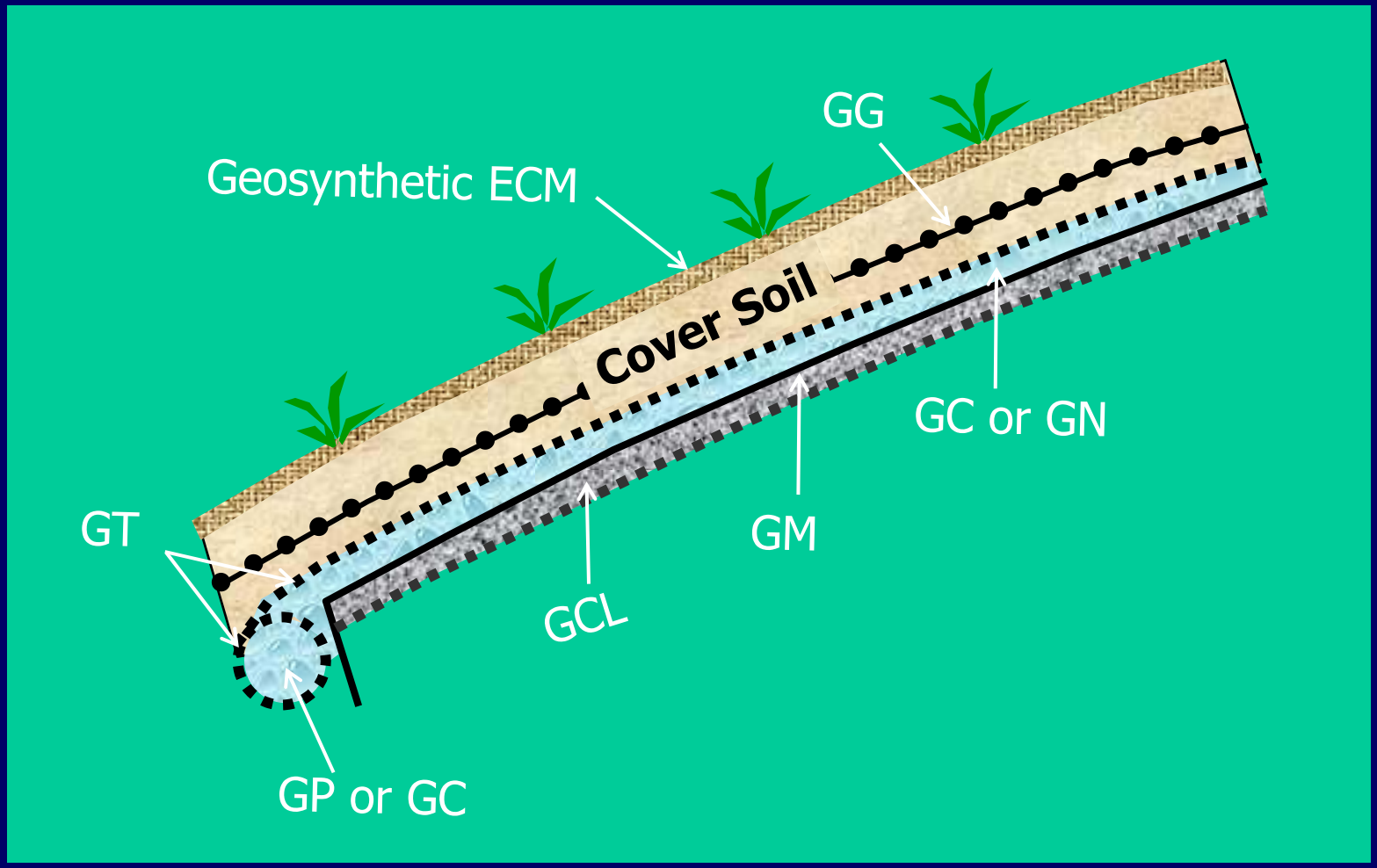


(Geonet Leak Detection)

(Primary Composite Liner)

(Nine Layers of Geosynthetics)

Final Cover System



(Sequential Placement of GSs)

(Areal View of 70 ha Site)

(Seven Layers of Geosynthetics)

Possible Geosynthetic Layers in a Waste Containment System

in Final Cover - 7

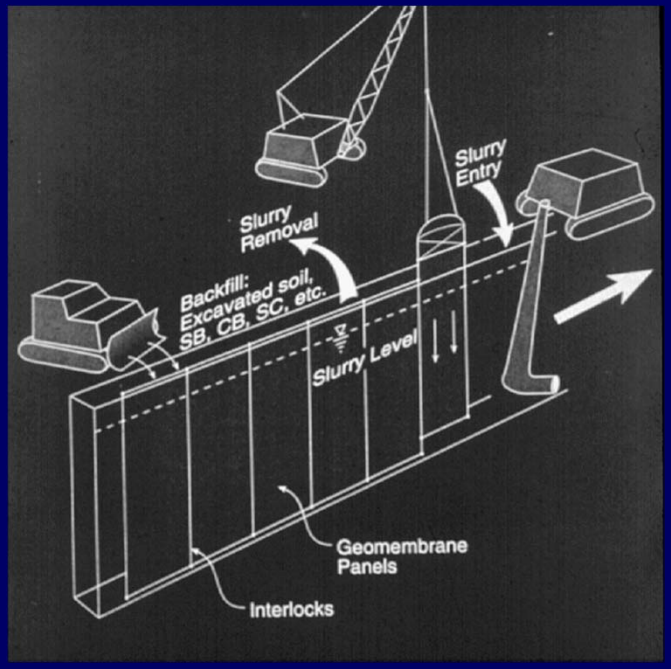
in Waste Itself - 2

in Base Liner - 9

18 Layers!

Vertical Geomembrane Cutoff Walls

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



(Placement of GM Panels)

Liners for Surface Impoundments

- design is progressive with each decision leading to the input for next consideration; i.e.,
  - geometry
  - cross section
  - GM type selection
  - GM thickness selection
  - subgrade stability
  - cover soil stability
  - runout and anchor trench

(Double Lined Hazardous Waste Pond)

(Lined Pond With Ugly Whales)

(Pond With Failed Subgrade)

(Electrical Leak Detection in Progress)

Commentary:

- major decision is whether to leave GM exposed or cover it with soil
- exposed; durability is key to GM selection
- covered; many GMs are possible (depending on liquid to be contained)
- if covered, slopes will be relatively flat and stability is a major design issue

Heap Leach Mining

- practiced in existing mining areas
- target metals are gold, silver and copper
- process uses cyanide and sulfuric acid
- chemicals strip trace amounts from the ore which has been placed in “heaps”
- needs GM liner and collection system

4. Hydraulic Engineering Applications

- Waterproofing of Dams
- Waterproofing of Canals
- Reservoir Liners/Floating Covers
- Tunnel Waterproofing & Rehabilitation
- Pipe Rehabilitation & Remediation

Waterproofing of Dams

- masonry, concrete, earth and RCC dams
- GM is not a structural element, its waterproofing
- many dams over 50-years old often have leakage; sometimes excessive leakage
- methods are under rapid development mainly in European Alps and in China

(Concrete Dam Leaking!)

(Lining a Concrete Dam)

(Completed Concrete Dam Lining)

(Lined Earth Dam: Before Rip-Rap)

Waterproofing of Canals

- conveyance of all liquids; however, water is the most common
- distances and quantities vary greatly
- fundamental issue is leakage (i.e., how much, if any, is allowable)
- some type of liner (GM or GCL) is necessary
- many federal agencies involved (BuRec, COE, DOA and NRCA)

(Lining a Canal: Before Soil Covering)

(GCL Lining of a Canal)

(GM Canal 18 years after GM Lined)

(Lining a “Live” Canal)

Reservoir Liners/Floating Covers

- GM pond liners date back to 1930's
- used to contain all types of liquids

  - potable water
  - architectural ponds
  - shutdown water
  - gray water
  - industrial waters
  - process waste waters
  - sewage sludge
  - industrial sludge
  - agricultural wastes
  - hazardous liquids*

*EPA estimates 206,000 in USA alone!

Common Characteristics

- generally shallow liquid depths
- typically 2 to 7 m
- side slopes from 4(H)-to-1(V) to 1(H)-to-1(V), i.e., $\beta = 14^\circ$ to 45°
- both exposed and covered
- exposed – GM durability issue
- covered – soil stability issue

(Lined Potable Water Reservoir)

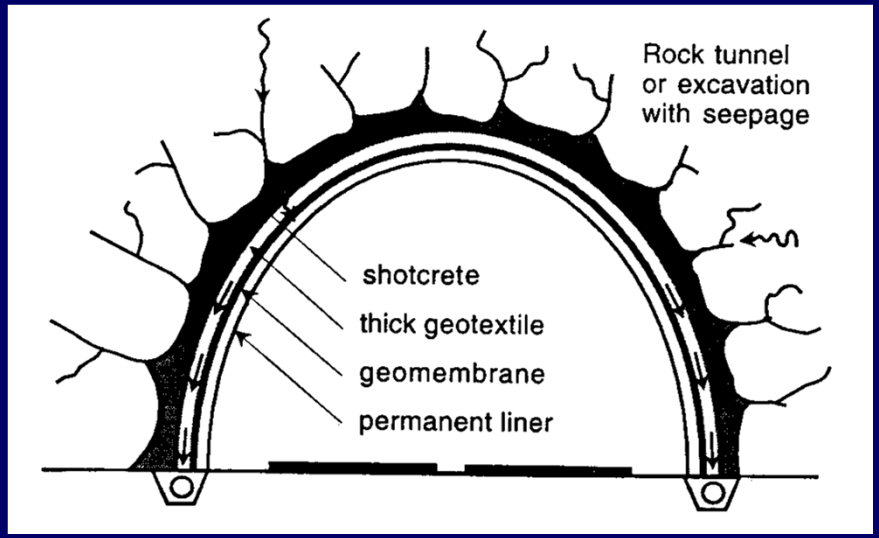
(Floating GM Cover)

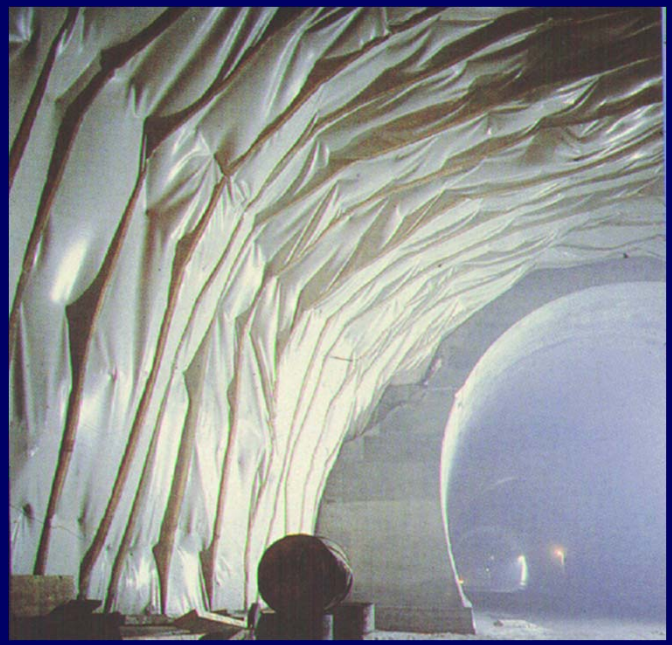
(Another Floating GM Cover)

(Huge GM Bag Transporting Potable Water)

New Tunnel Waterproofing

- many old tunnels without GMs are leaking
- white staining on surface is the “tell-tale”
- key is to use a GT and GM behind the permanent concrete surfacing
- in turn, this requires a GP drainage system



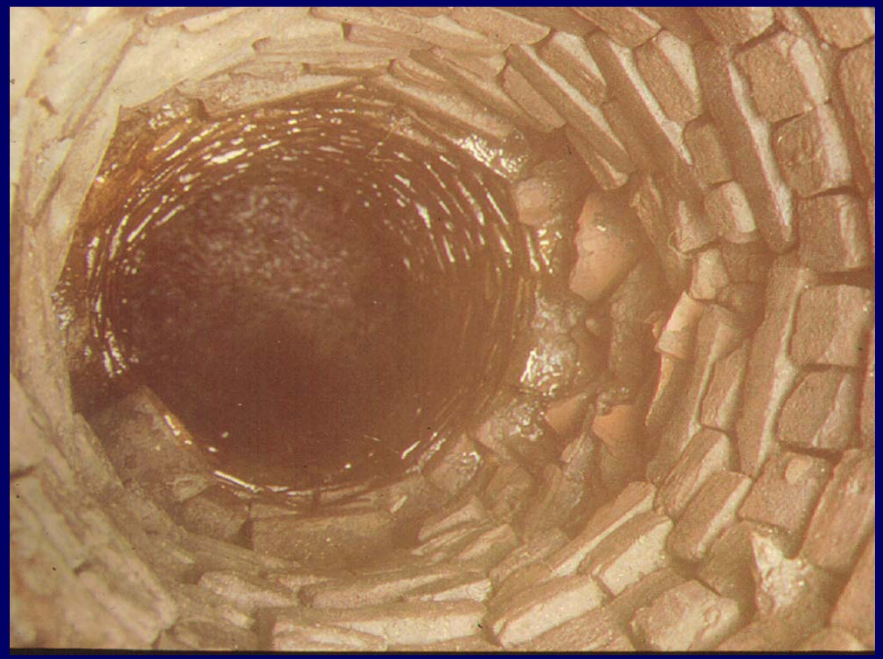


Tunnel Rehabilitation

- concern is over excessive leakage
- leakage can lead to instability
- tunnels are essentially accessible pipes
- obviously, they are usually more critical
- water tunnels are the general target

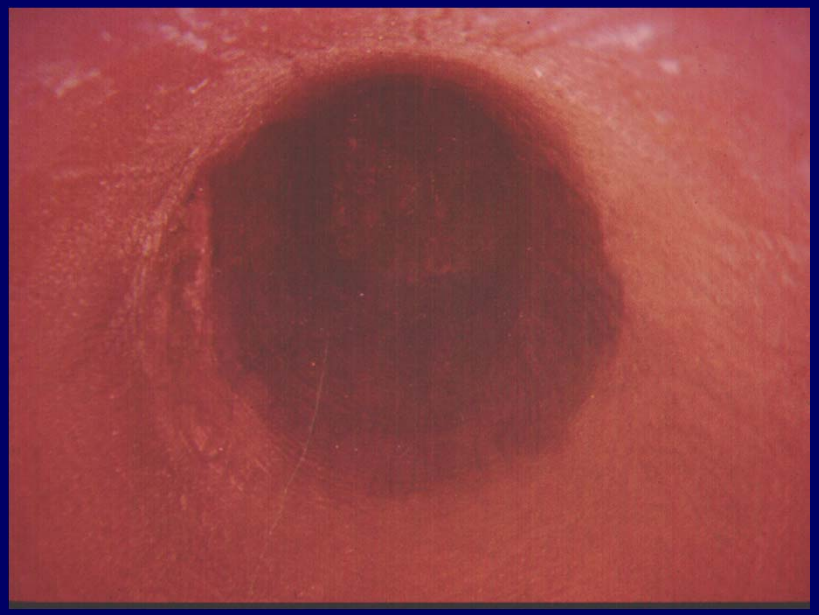
Pipe Rehabilitation and Remediation

- focuses on old lifeline systems
- transmission lines (water, gas, oil)
- drainage (conduits, canals)
- sewers (sanitary and storm) ... see photos



Methods of Pipe Rehabilitation

- Coatings
- Slip Liners (Pipe-within-Pipe)
- Cured-in-Place Pipe
- Fold-and-Formed Pipe
- In-Situ Liners



(Epoxy Coated Pipe)

(Pipe-within-Pipe)

Private Development Applications

Selected Areas of Focus

- various dwellings
- industrial buildings
- storage/staging areas
- tank farms
- parks and playgrounds
- pools and lakes
- sport fields
- golf courses
- airfields
- agriculture
- aquaculture
- liquid transportation

Tank Farms/Gas Stations

- concern is spillage into surface water
- also, leakage into ground water
- requires a GM or GCL Barrier
- classified as “secondary containment”
- barrier must be resistant to liquid

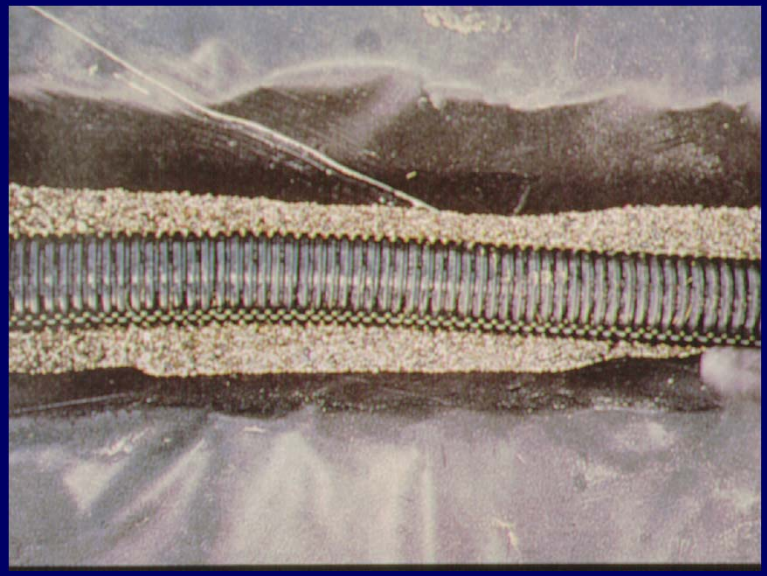
Pools, Ponds and Lakes

- sites vary from small-to-huge
- usually access is limited
- liners required for leakage control
- covers sometimes required for contamination control and for safety

Golf Courses

- aesthetics, aesthetics, aesthetics
- drainage, drainage, drainage
- turf maintenance is a major issue
- essentially all geosynthetics are involved
- opportunities available in new sites and in expansion/remediation of existing sites

(GM Lined Bunker)



(Gravel & GP Drainage)

Agriculture

- mega-farming is big business
- animal populations are enormous
- the major item of “non-point source pollution”
- animal waste conveyance, recovery and treatment are critical topics and invariably they are “newsworthy”

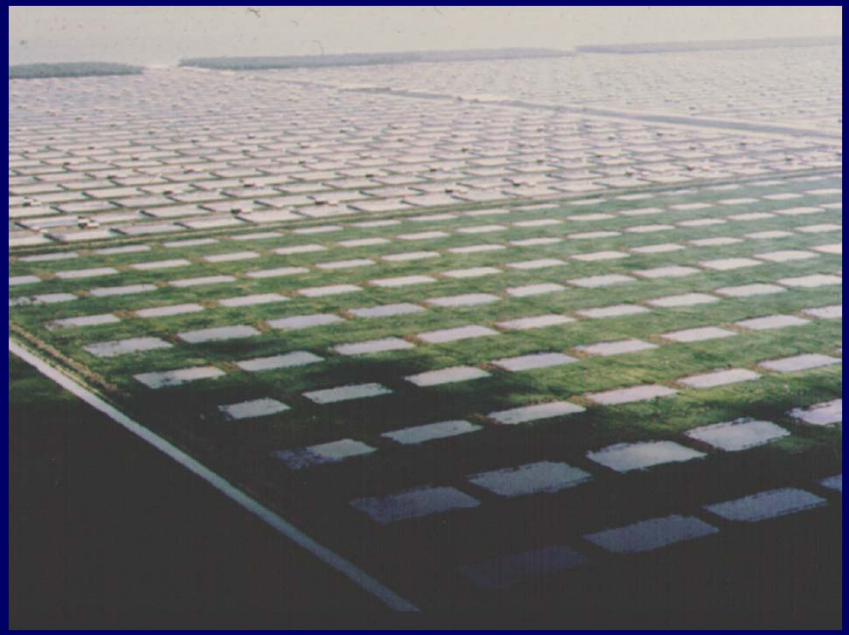
(Lined Pond Behind Cattle Stalls)

(Aerobic Decomposition of Waste)

Aquaculture

- fish-farming is also big business
- generally shallow GM-lined ponds
- lining required for control purposes (nutrition, oxygen, contamination)
- some enterprises are “awesome”

(GM Lined Shrimp Farm)



(Lots & Lots of Them!)

6. Concluding Remarks

- Organizations
- Publications
- Current Status
- Summary

Web Sites of Geosynthetic Organizations

- Geosynthetic Institute (GSI)
  <http://www.geosynthetic-institute.org>
- International Geosynthetics Society (IGS)
  <http://www.igs.rmc.ca>
- Geosynthetics Materials Association (GMA)
  <http://www.gmanow.com>
- International Standards Organization (ISO)
  <http://www.iso.ch/iso/en/ISOOnline.frontpage>
- ASTM International
  <http://www.astm.org>

Publications

- Journal of Geotextiles and Geomembranes - Prof. R. K. Rowe, Editor
  <www.sciencedirect.com>
- Geosynthetics International Journal - Dr. T. S. Ingold, Editor
  <www.ifai.com>
- GFR Magazine - Mr. Chris Kelsey, Editor
  <www.ifai.com>
- Designing With Geosynthetics - Prof. R. M. Koerner, Author
  <www.geosynthetic-institute.org>

Comments on Current Status

Transportation & Geotechnical Applications

- most mature of application areas
- focuses on GTs, GGs and GCs
- moving toward generic specifications

Geoenvironmental Applications

- regulatory driven
- all GSs are involved with specs
- field performance is excellent

Hydraulic Engineering Applications

- lagging behind other applications
- focuses on GMs and GCLs
- tremendous opportunities available

Private Development Applications

- tremendous variety of applications
- all GSs are involved
- innovation and cost/benefit driven

Summary

- Geosynthetics are bona fide engineering materials and must be treated as such
- Test methods and designs are available – challenge them accordingly
- Basic advantage of geosynthetics is quality control of factory manufactured products
- Products must be accompanied by rigorous CQC/CQA
- Field performance has been excellent
- Geosynthetics potential is awesome!