HANDBOOK
OF
GEOSYNTHETICS

For more information please contact the Geosynthetic Materials Association at www.gmanow.com.

The Geosynthetic Materials Association (GMA) represents all segments of the geosynthetics industry, including manufacturers as well as companies that test or supply material or services to the industry. GMA activities further the acceptance and use of geosynthetic materials in a variety of applications.

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Handbook of Geosynthetics

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PREFACE

Dealing with Difficult Sites

In the past, when dealing with difficult sites for construction purposes, the conventional practice was limited to either replacing the unsuitable soils, or bypassing them with costly deep foundations. Additionally, the age-old problem of land scarcity and the need to rebuild aging infrastructure in urban areas, increased realization of seismic hazards, and regulations mandated for various environmental problems, have been the impetus for the the evolution of a number of ground improvement techniques during the past 25 years. Innovative ground modification approaches are routinely used now to solve unique soil-related problems, and often are considered to be the most economical means to improve an undesirable site condition.

Geosynthetics have proven to be among the most versatile and cost-effective ground modification materials. Their use has expanded rapidly into nearly all areas of civil, geotechnical, environmental, coastal, and hydraulic engineering.

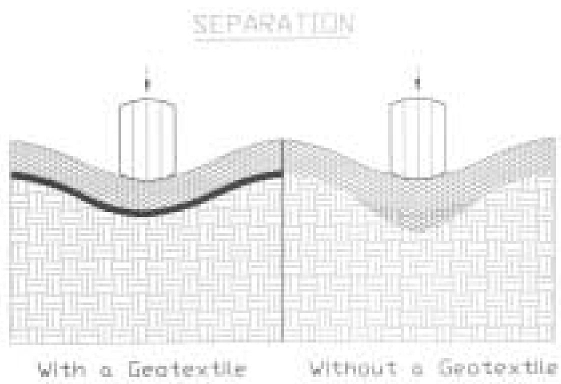
This handbook introduces geosynthetics from the perspective of practical application. It is intended to serve as a general reference in the field for those who are building structures that include geosynthetics.

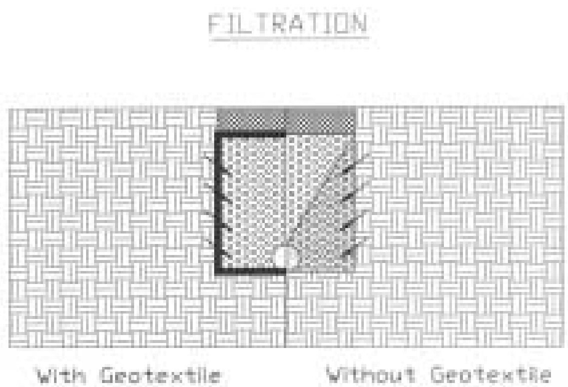
Geosynthetic Advantages

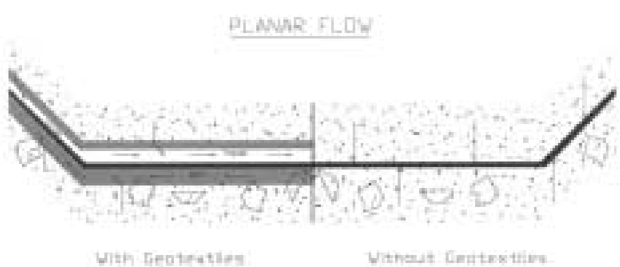
Geosynthetics, including geotextiles, geomembranes, geonets, geogrids, geocomposites and geosynthetic clay liners, often used in combination with conventional materials, offer the following advantages over traditional materials:

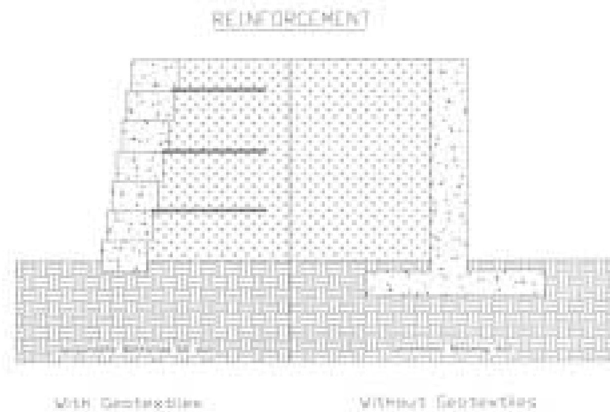
- **Space Savings** - Sheet-like, geosynthetics take up much less space in a landfill than do comparable soil and aggregate layers.
- **Material Quality Control** - Soil and aggregate are generally heterogeneous materials that may vary significantly across a site or borrow area. Geosynthetics on the other hand are relatively homogeneous because they are manufactured under tightly controlled conditions in a factory. They undergo rigorous quality control to minimize material variation.
- **Construction Quality Control** - Geosynthetics are manufactured and often factory “prefabricated” into large sheets. This minimizes the required number of field connections, or seams. Both factory and field seams are made and tested by trained technicians. Conversely, soil and aggregate layers are constructed in place and are subject to variations caused by weather, handling and placement.
- **Cost Savings** - Geosynthetic materials are generally less costly to purchase, transport and install than soils and aggregates.
- **Technical Superiority** - Geosynthetics have been engineered for optimal performance in the desired application.
- **Construction Timing -** Geosynthetics can be installed quickly, providing the flexibility to construct during short construction seasons, breaks in inclement weather, or without the need to demobilize and remobilize the earthwork contractor.
- **Material Deployment -** Layers of geosynthetics are deployed sequentially, but with a minimum of stagger between layers, allowing a single crew to efficiently deploy multiple geosynthetic layers.
- **Material Availability -** Numerous suppliers of most geosynthetics and ease of shipping insure competitive pricing and ready availability of materials.
- **Environmental Sensitivity –** Geosynthetic systems reduce the use of natural resources and the environmental damage associated quarrying, trucking, and other material handling activities.

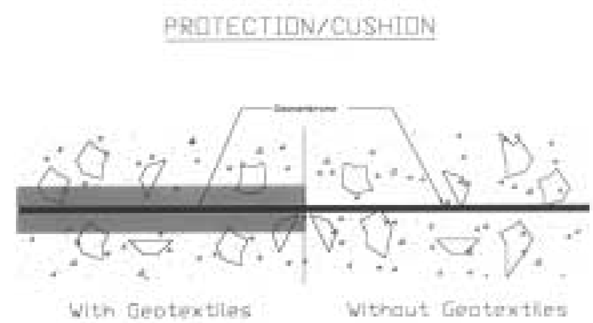
INTRODUCTION TO GEOSYNTHETICS

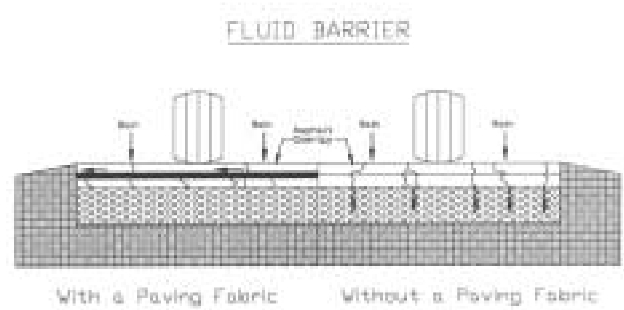












Geosynthetics

Geosynthetics are an established family of geomaterials used in a wide variety of civil engineering applications. Many polymers (plastics) common to everyday life are found in geosynthetics. The most common are polyolefins and polyester; although rubber, fiberglass, and natural materials are sometimes used. Geosynthetics may be used to function as a separator, filter, planar drain, reinforcement, cushion/protection, and/or as a liquid and gas barrier. The various types of geosynthetics available, along with their specific applications, are discussed in subsequent sections.

Geotextiles

Geotextile Polymers

Almost all geotextiles available in the United States are manufactured from either polyester or polypropylene.

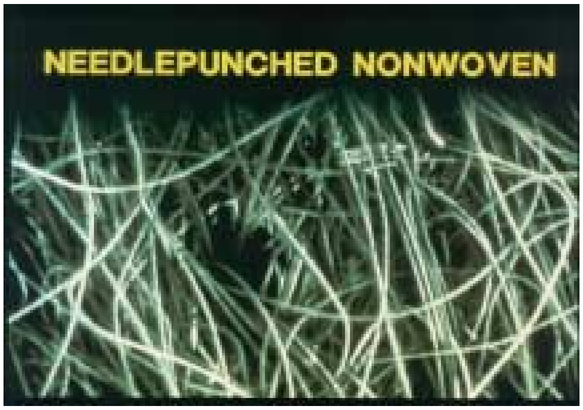
Polypropylene is lighter than water (specific gravity of 0.9), strong and very durable. Polypropylene filaments and staple fibers are used in manufacturing woven yarns and nonwoven geotextiles.

High tenacity polyester fibers and yarns are also used in the manufacturing of geotextiles. Polyester is heavier than water, has excellent strength and creep properties, and is compatible with most common soil environments.

Geotextile Structures

There are two principal geotextile types, or structures: wovens and nonwovens. Other manufacturing techniques, for example knitting and stitch bonding, are occasionally used in the manufacture of specialty products.

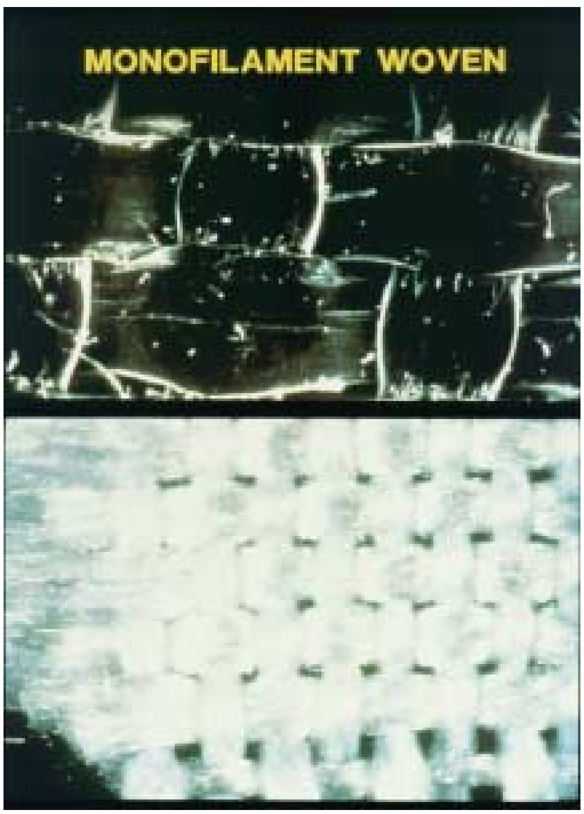
Nonwovens. Nonwoven geotextiles are manufactured from either staple fibers (staple fibers are short, usually 1 to 4 inches in length) or continuous filaments randomly distributed in layers onto a moving belt to form a felt-like "web". The web then passes through a needle loom and/or other bonding machine interlocking the fibers/filaments. Nonwoven geotextiles are highly desirable for subsurface drainage and erosion control applications as well as for road stabilization over wet moisture sensitive soils.



Wovens. Weaving is a process of interlacing yarns to make a fabric. Woven geotextiles are made from weaving monofilament, multifilament, or slit film yarns. Slit film yarns can be further subdivided into flat tapes and fibrillated (or spider web-like) yarns. There are two steps in this process of making a woven geotextile: first, manufacture of the filaments or slitting the film to create yarns; and second, weaving the yarns to form the geotextile.

Slit film fabrics are commonly used for sediment control, i.e. silt fence, and road stabilization applications but are poor choices for subsurface drainage and erosion control applications. Though the flat tape slit film yarns are quite strong, they form a fabric that has relatively poor permeability. Alternatively, fabrics made with fibrillated tape yarns have better permeability and more uniform openings than flat tape products.

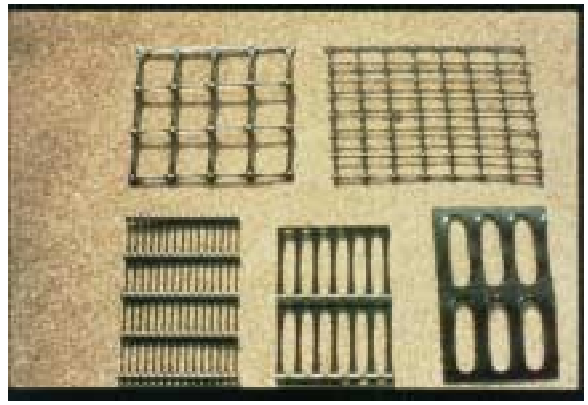
Monofilament wovens have better permeability, making them suitable for certain drainage and erosion control applications. High strength multifilament wovens are primarily used in reinforcement applications.



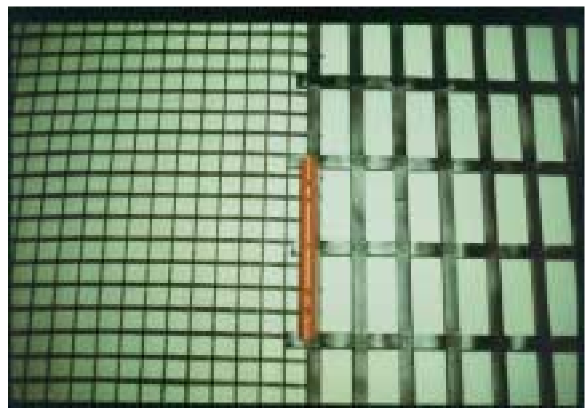
Multifilament Woven

Geogrids

Geogrids are single or multi-layer materials usually made from extruding and stretching high-density polyethylene or polypropylene or by weaving or knitting and coating high tenacity polyester yarns. The resulting grid structure possesses large openings (called apertures) that enhance interaction with the soil or aggregate. The high tensile strength and stiffness of geogrids make them especially effective as soil and aggregate reinforcement.



Punched/Drawn Geogrid



Woven/Coated Geogrid

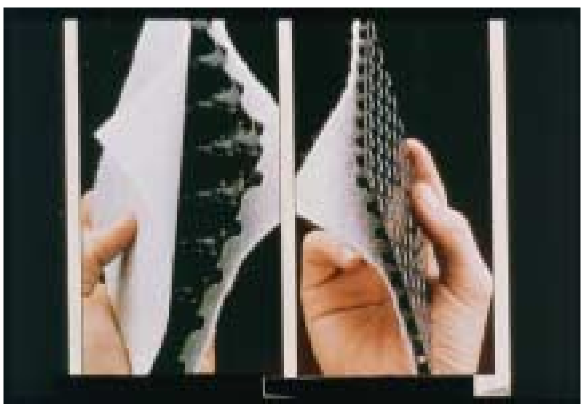
Geonets

Geonets are made of stacked, criss-crossing polymer strands that provide in-plane drainage. Nearly all geonets are made of polyethylene. The molten polymer is extruded through slits in counter-rotating dies, forming a matrix, or "net" of closely spaced "stacked" strands. Two layers of strands are called "bi-planar". Three layers are called "tri-planar".

Geonet

Geocomposites
The possibility of combining the superior features of various geosynthetics has rendered a host of so called "geocomposite" materials. There is a large number of possibilities in assembling different materials, only limited by one's ingenuity and imagination.

Drainage Geocomposites
The most common geocomposite configuration is known as a drainage geocomposite. Drainage geocomposites are composed of a geotextile filter surrounding either a geonet (blanket drain), a thick preformed core (panel or edge drain), or a thin preformed core (wick drain). Some applications of drainage geocomposites are blanket drains, panel drains, edge drains and wick drains.

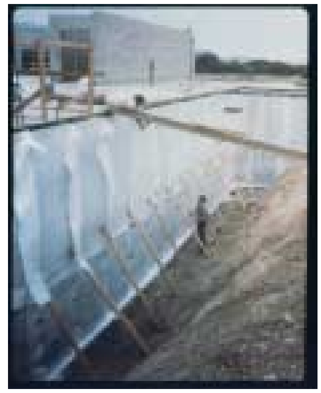


Double- and single-sided geocomposite drains

Blanket Drains – Blanket drains are commonly used as leachate or infiltration collection and removal layers within landfills. Recently, geocomposite blanket drains have been used to enhance road base drainage.

Blanket Drain

Panel Drains - Panel drains can be placed adjacent to structures to reduce hydrostatic pressures.



Panel Drain

Edge Drain

Edge Drains – Edge drains are often used adjacent to pavement structures to collect and remove lateral seepage from the road base.

Wick Drains – Wick drains are pushed deep into the ground, providing drainage paths to expedite the consolidation of saturated soils, significantly decreasing the settlement time of embankments over soft soils.

Wick Drain

Other Geocomposites - Many other geocomposite products have been developed. For example, high strength yarns have been knitted into a nonwoven to produce a product that is both strong (via the yarns) and which has controlled permeability characteristics (provided by the non woven).

Geomembranes

Geomembranes are relatively impermeable sheets of plastic. There are two general categories of geomembranes: calendered and extruded.

Calendered Geomembranes

Calendered geomembranes are formed by working and flattening a molten viscous formulation between counterrotating rollers. Polyvinyl chloride (PVC), chlorosulfonated polyethylene (CSPE), chlorinated polyethylene (CPE), and, more recently, polypropylene (PP) are the most common calendered geomembranes. Specialty ethylene interpolymer alloy (EIA) geomembranes are used for unique applications. In most cases these engineered films are supported by a textile that provides tensile strength and enhances tear and puncture resistance.

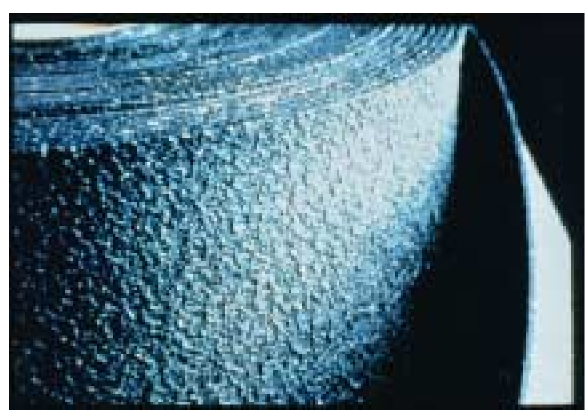
Calendared Geomembrane

Extruded Geomembranes

Extruded geomembranes are manufactured by melting polymer resin, or chips, and forcing the molten polymer through a die using a screw-extruder. The sheet is formed either by a flat horizontal die or through a vertically oriented circular die to form either a flat wide sheet advanced on a conveyor belt, or cylindrical tube of “blown film", filled with air which is collapsed and pulled by nip rollers mounted high above the die. Blown film geomembranes must be slit prior to wind-up. Common extruded geomembranes include high-density polyethylene (HDPE) and various lower density, or very flexible, polyethylenes (VFPE). Polypropylene (PP) is a relatively new type of extruded (as well as calendered) geomembrane.

Extruded Geomembrane

Variations in the manufacturing of geomembranes include texturing to enhance the interface friction between the geomembrane and adjacent soils or other geosynthetics; co-extruding different polymers into a single sheet to provide enhanced durability; and the availability of multiple thicknesses and sheet sizes.



Close-up of texturing

Geosynthetic Clay Liners (GCLs)

Geosynthetic clay liners (GCLs) include a thin layer of finely-ground bentonite clay. When wetted, the clay swells and becomes a very effective hydraulic barrier. GCLs are manufactured by sandwiching the bentonite within or layering it on geotextiles and/or geomembranes, bonding the layers with needling, stitching and/or chemical adhesives. The preferred sodium bentonite clay occurs naturally in Wyoming, North Dakota and Montana in the U.S. GCLs are commonly used to augment or replace compacted clay layers.

GCL

Geopipe

Another significant product which has been "adopted" as a geosynthetic is plastic pipe. The specific polymer resins used in the manufacturing of plastic pipes are: high-density polyethylene (HDPE), polyvinyl chloride (PVC), polypropylene (PP), polybutylene (PB), acrylonitrile butadiene styrene (ABS), and cellulose acetate buytrate (CAB). There is a wide variety of civil engineering applications for these products, including: highway and railway edge drains, interceptor drains, and leachate removal systems.

Geopipe

Geofoam

A newer category of geosynthetic product is geofoam, which is the generic name for any foam material utilized for geotechnical applications. Geofoam is manufactured into large blocks which are stacked to form a light-weight, thermally insulating mass buried within a soil or pavement structure. The most common type of polymer used in manufacturing of geo-foam materials is polystyrene. Typical applications of geofoams include: within soil embankments built over soft, weak soils; under roads, airfield pavements and railway track systems subject to excessive freeze-thaw conditions; and beneath on-grade storage tanks containing cold liquids.

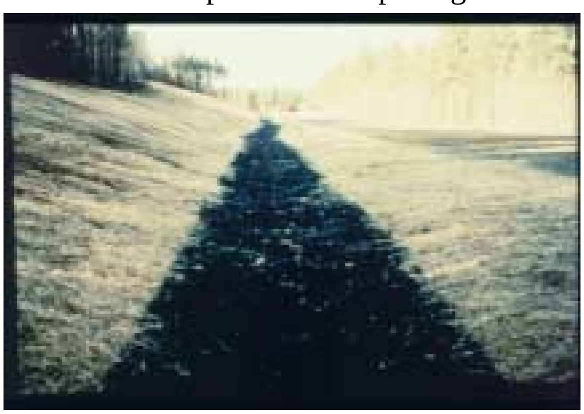
Geofoam

Erosion Control Nets, Meshes, and Blankets

Temporary, degradable geosynthetics are used to prevent loss of soil from the seedbed and to enhance the establishment of vegetation where the vegetation alone should provide sufficient site protection once established. Erosion control netting (ECN), open weave meshes (ECM), and erosion control blankets (ECB) are the most common temporary, degradable systems. Typically natural fibers are used in these materials. The fibers are derived from the cultivation of various types of straw/hay or jute, or by the processing of coconut hulls (coir) or wood shavings (excelsior).

Turf Reinforcement Mats

Turf reinforcement mats (TRMs) are 3-dimensional structures composed of fused polymer nettings, randomly laid monofilaments, or yarns woven or tufted into an open, dimensionally stable mat. These flexible, synthetic, 3-dimensional mats are designed to be used in conjunction with topsoil and seed or turf to create strong, durable and continuous soil-root-mat matrices which can provide nearly twice the erosion protection of plain grass alone.



Turf Reinforcement Mats (before and after germination)

Fabric Formed Revetments

Fabric formed revetments (FFR) are constructed by pumping a very fluid fine-aggregate grout into a fabric envelope consisting of 2 layers connected by tie-chords or by interweaving. FFRs provide the durability of rigid linings, such as cast-in-place concrete or asphaltic concrete. FFRs can be engineered to perform as barriers or to be highly permeable, and they can be stiff or as flexible as protective rock systems such as riprap or gabions.

Fabric Formed Revetments

Geocellular Confinement Systems

Geocellular confinement systems (GCS) are 3-dimensional honeycomb-like structures filled with soil, rock or concrete. The GCS structure, often called a geocell, is made of strips of polymer sheet or geotextile connected at staggered points so that, when the strips are pulled apart, a large honey-comb mat is formed. The GCS provides both a physical containment of a depth of soil and a transfer of load through the GCS.

Geocellular Confinement Systems

Silt Fence

A well-designed silt fence is made of a durable geotextile attached to support posts with the bottom edge securely buried. It performs as follows:

- It initially screens silt and sand particles from runoff.
- A soil filter is formed adjacent to the silt fence and reduces the ability of water to flow through the fence.
- This leads to the creation of a pond behind the fence, which serves as a sedimentation basin to collect suspended soils from runoff water.

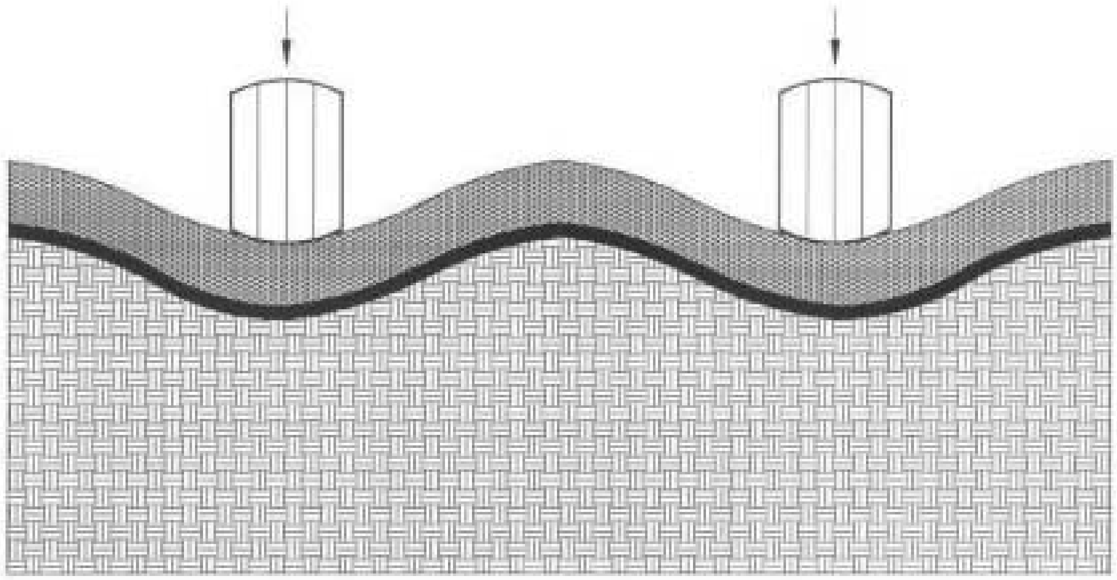
Silt Fence

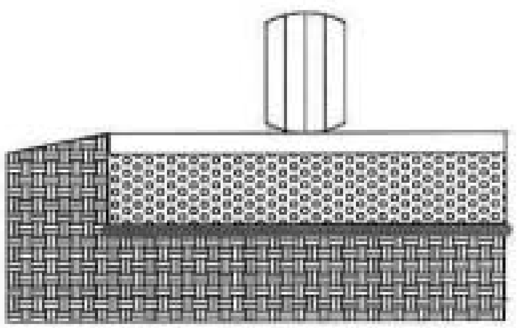
Turbidity Curtains

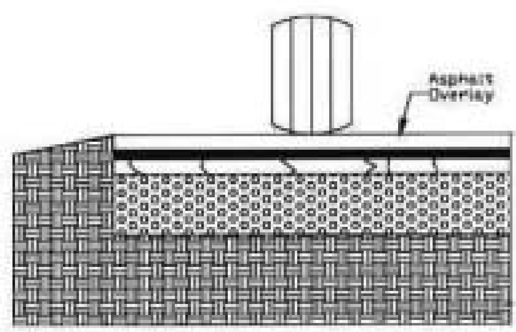
Turbidity curtains are reusable floating geosynthetic panels that prevent water-polluting sediment from shore-side construction or off-shore filling and dredging operations from moving off-site. The top edge of each curtain contains floats and a cable or chain. Weights are attached to the lower edge of the curtain to keep it vertical in the water. Posts, piling, or anchors hold the curtains in place. Generally, they are intended for use with currents no greater than about 5 ft/s (1.5 m/s) and to depths of no more than 15 to 25 ft (5 to 8 m).

Turbidity Curtain

GEOSYNTHETICS IN ROADS AND PAVEMENTS: Subgrade Separation and Stabilization, Base Reinforcement, Overlay Stress Absorption and Reinforcement







OVERVIEW

A large variety of detrimental factors affect the service life of roads and pavements including environmental factors, subgrade conditions, traffic loading, utility cuts, road widenings, and aging. These factors contribute to an equally wide variety of pavement conditions and problems which must be addressed in the maintenance or rehabilitation of the pavements, if not dealt with during initial construction.

Pavement maintenance treatments are often ineffective and short lived due to their inability to both treat the cause of the problems and renew the existing pavement condition. The main cause of distress in pavements is that they are quite permeable with 30 to 50% of precipitation surface water infiltrating through the pavement, softening and weakening the pavement subgrade and base, accelerating pavement degradation. Existing pavement distress such as surface cracks, rocking joints, and subgrade failures cause the rapid reflection of cracking up through the maintenance treatment.

Therefore, the preferred strategy for long-term road and pavement performance is to build in safeguards during initial construction. These performance safeguards include stabilizing the subgrade against moisture intrusion and associated weakening; strengthening road base aggregate without preventing efficient drainage of infiltrated water; and, as a last resort, enhancing the stress absorption and moisture proofing capabilities of selected maintenance treatments. Geosynthetics are the most cost-effective tools for safeguarding roads and pavements in these ways.

The four main applications for geosynthetics in roads are subgrade separation and stabilization, base reinforcement, overlay stress absorption, and overlay reinforcement. Subgrade stabilization and base reinforcement involve improving the road structure as it is constructed by inserting an appropriate geosynthetic layer. Subgrade separation and stabilization applies geosynthetics to both unpaved and paved roads. Base reinforcement is the use of geosynthetics to improve the structure of a paved road.

Geosynthetics are also helpful in rehabilitating distressed road surfaces. The application of a layer of asphalt concrete called an overlay is often the solution for damaged pavement. Geosynthetics can be used as interlayers by placing them below or within the overlay. Some geosynthetics relieve stress and others are able to reinforce the overlay. The products may also provide a moisture barrier.

Though only widely recognized since the latter half of the 1900s, these advantages were initially demonstrated as early as the 1930's using conventional textile materials.

Early Use of Geosynthetics in Road Structures in South Carolina in the 1930's

SUBGRADE SEPARATION AND STABILIZATION

Introduction to the Problem

Temporary roads used for hauling and access roads that are subject to low volumes of traffic are often constructed without asphalt or cement concrete surfacing. In these cases, a layer of aggregate is placed on the prepared subgrade of these roads to improve their load carrying capacity. Problems are usually encountered when the subgrade consists of soft clays, silts and organic soils. This type of subgrade is often unable to adequately support traffic loads and must be improved.

Typical poor subgrade conditions

Typical Solutions

Excavating and replacing unsuitable materials is costly and time consuming. Other methods of subgrade improvement include deep compaction, chemical stabilization and pre-loading.

The Geosynthetic Solution

Geosynthetics are proving to be a cost effective alternative to traditional road construction methods. As a result, the application of geosynthetics to the construction of unpaved roads over soft subsoils has become quite popular. Design has focused on the stabilization of the subgrade and the reinforcement of the aggregate, leading to the identification of two important functions: membrane action and lateral restraint. Membrane action is the ability of a geosynthetic material to reduce and spread stress arising from the weak subgrade. Lateral restraint, sometimes called confinement, is the lateral interaction between the aggregate and the subgrade with the geosynthetic. The presence of the geosynthetic restrains lateral movement of both the aggregate and the subgrade, improving the strength and stiffness of the road structure.

Separation

At small rut depth, the strain in the geosynthetic is also small. In this case, the geosynthetic acts primarily as a separator between the soft subgrade and the aggregate. Any geosynthetic that survives construction will work as a separator.

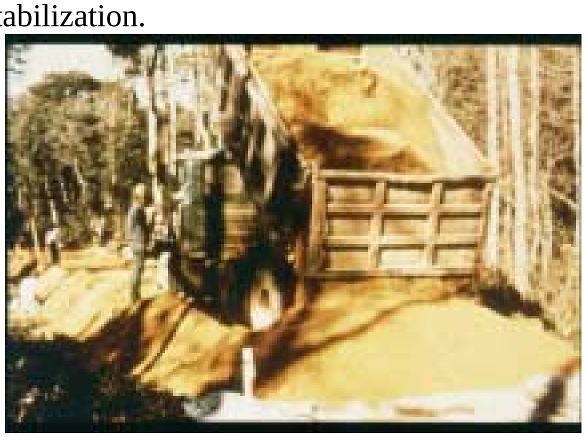
A separation geotextile prevents the engineered fill for this parking area from mixing with the soft subgrade.

Stabilization

For larger rut depths, more strain is induced in the geosynthetic. Thus the stiffness properties of the geosynthetic are essential. A considerable reduction in aggregate thickness is possible by the use of a geosynthetic having a high modulus in the direction perpendicular to the road centerline; however, the benefits of the geosynthetic are not wholly dependent on the membrane action achieved with a stiff geosynthetic. Lateral restraint produced by the interaction between the geosynthetic and the aggregate is equally important. The following general conclusions can be drawn relating to a typical road base.

- A geosynthetic element that functions primarily as a separator (typically when the subgrade CBR ≥ 3) will increase the allowable bearing capacity of the subgrade by 40 to 50 percent. (*separation geotextiles*)
- A geosynthetic element that functions primarily to provide confinement of the aggregate and lateral restraint to the subgrade (typically when the subgrade CBR < 3) will both increase the allowable bearing capacity of the subgrade and provide an improved load distribution ratio in the aggregate. The combined benefits can enhance load carrying capacity of the road by well over 50 percent. (*stabilization geogrids and geotextiles*)

With very weak subgrades, it is often beneficial to combine the benefits of both separation and stabilization.



A stabilization geotextile facilitates construction over weak subgrades

A geogrid is effective in reducing the required fill over a weak subgrade

Stabilization geotextiles can be fabricated into large panels and deployed to expedite road embankment construction

Design for Stabilization

The design of geosynthetic-reinforced unpaved roadways has been simplified into design charts that relate aggregate thickness requirements to a range of subgrade strengths, based on standard highway design loading and various allowable rut depths.

BASE REINFORCEMENT

Introduction to the Problem

Permanent roads carry larger traffic volumes and typically have asphalt or portland cement concrete surfacing over a base layer of aggregate. The combined surface and base layers act together to support and distribute traffic loading to the subgrade. Problems are usually encountered when the subgrade consists of soft clays, silts and organic soils. This type of subgrade is often water sensitive and, when wet, unable to adequately support traffic loads. If unimproved, the subgrade will mix with the road base aggregate – degrading the road structure - whenever the subgrade gets wet.

Poor roads often result from poor subgrades

Typical Solutions

As with unpaved roads, a problematic subgrade is typically excavated and replaced, or it is improved by the addition of cement, lime, or excess aggregate. In any case, the traditional solution is often costly and always time consuming.

The Geosynthetic Solution

As was noted earlier, geosynthetics are proving to be a cost effective alternative to traditional road construction methods. In paved roads, lateral restraint also called confinement is considered to be the primary function of the geosynthetic. With the addition of an appropriate geosynthetic, the Soil-Geosynthetic-Aggregate (SGA) system gains stiffness. The stiffened SGA system is better able to provide the following structural benefits:

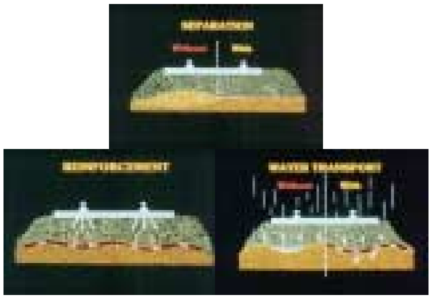
- Preventing lateral spreading of the base
- Increasing confinement and thus stiffness of the base
- Improving vertical stress distribution on the subgrade
- Reducing shear stress in the subgrade

Geogrid base reinforcement stiffens the aggregate base layer providing long-term support for the paved surface.

Geosynthetic Benefits

A Geosynthetic Materials Association (GMA) review of geosynthetic base reinforcement identified the most common method for quantifying geosynthetic benefits as the determination of a Traffic Benefit Ratio (TBR). The TBR relates the ratio of reinforced load cycles to failure (excessive rutting) to the number of cycles that cause failure of an unreinforced road section. In general, geosynthetics have been found to provide a TBR in the range of 1.5 to 70, depending on the type of geosynthetic, its location in the road, and the testing scenario.

THE SPECIAL CASE OF RAILROADS – Separation + Reinforcement + Planar Flow



"stabilized" (upper) vs. "unstabilized" (lower) track

A new rail line in an area of high groundwater is built over a heavy weight nonwoven geotextile

Railroad maintenance operations can include the insertion of a geotextile during undercutting

This rail line reconstruction benefitted from both a nonwoven geotextile and a reinforcing geogrid

INSTALLATION OF GEOSYNTHETICS FOR SEPARATION, STABILIZATION, AND BASE REINFORCEMENT

Site Preparation

Clear and grade the installation area. Remove all sharp objects and large stones. Cut trees and shrubs flush with the subgrade. Removal of topsoil and vegetation mat is not necessary, but is recommended where practical.

Excessively soft spots or voids may be unsuitable for geosynthetic installation. Fill these areas with select material and compact prior to geosynthetic installation. The problem area may be enhanced by using a geosynthetic at the bottom of the excavation prior to backfilling.

Deployment of the Geosynthetic

Unroll the geosynthetic on the prepared subgrade in the direction of construction traffic. Hold the geosynthetic in place with pins, staples, fill material or rocks. Adjacent rolls should overlap in the direction of the construction. Depending on the strength of the subgrade, the overlaps may have to be sewn.

Overlap Specifications

Soil Strength (CBR)	Overlap Unsewn in (cm)	Overlap Sewn in (cm)
Less than 1	-	9 (23)
1 – 2	38 (97)	8 (20)
2 – 3	30 (76)	3 (8)
3 & Above	24 (60)	-

Water sensitive subgrades can often be graded when dry

When more challenging subgrades are encountered it is often more effective to leave vegetation and construction debris in place. The geosynthetic will prevent migration of fill soils into the voids within the debris.

Placement of the Aggregate

Place the aggregate over firm subgrades by back dumping aggregate onto the geosynthetic and then spreading it with a motor grader. For weaker subgrades, dump onto previously placed aggregate and then spread the aggregate onto the geosynthetic with a bulldozer. On weaker subgrades, a sufficient layer of aggregate must be maintained beneath all equipment while dumping and spreading to minimize the potential of localized subgrade failure.

Avoid traffic directly on the geosynthetic. When using construction equipment on the aggregate, try to avoid any sudden stops, starts or sharp turns.

Maintain a minimum lift thickness of 6-inches (15 cm) except in cases of low volume roads. Compact the aggregate to the specified density using a drum roller. Fill any ruts with additional aggregate and compact as specified.


Fabric Rolled Out and Overlapped (or seamed)


If the subgrade is firm and free of debris, run and dump placement of aggregate may be used


When constructing over weak subgrades, back-dumping of the aggregate is required

Normal construction activities, including aggregate spreading and compaction are used. Caution should be used when selecting compaction equipment. When thin lifts are used, vibratory compaction is not recommended until a minimum 12-in (30 cm) compacted thickness is achieved. Use of such equipment may result in damage to the geosynthetic.


Aggregate spreading


Aggregate compaction

Damage Repair

Repair damaged geosynthetics immediately. Clear the damaged area and an additional three feet around it of all fill material. Cover the cleared area with a piece of the geosynthetic. The patch should extend at least three feet beyond the perimeter of damage. Replace the aggregate and compact to the specified density.


A surface treatment such as an asphalt layer or a double or triple-treatment can be placed once the base course is complete and structurally sound.

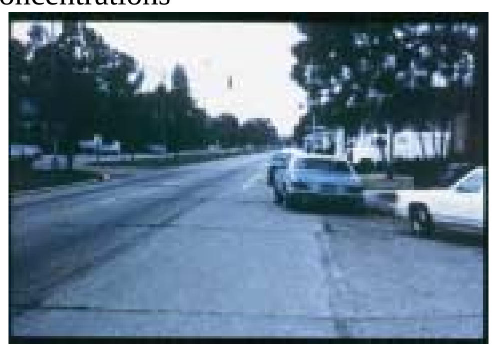
OVERLAY STRESS ABSORPTION AND REINFORCEMENT

Introduction to the Problem

Road surfaces must be maintained regularly. Commonly, a paved road becomes a candidate for maintenance when its surface shows significant cracks and potholes. The rehabilitation of cracked roads by simple overlaying is rarely a durable solution. The cracks under the overlay rapidly propagate through to the new surface. This phenomenon is called reflective cracking.

Cracks in the pavement surface cause numerous problems, including:

- Riding discomfort for the users
- Reduction of safety
- Infiltration of water and subsequent reduction of the bearing capacity of the subgrade
- Pumping of soil particles through the crack
- Progressive degradation of the road structure in the vicinity of the cracks due to stress concentrations



Typical Cracked Pavement

Typical Solutions

In spite of reflective cracking, overlays are still the most viable option for extending the life of distressed pavement. To lengthen the lifetime of an overlay, special asphalt mixes can be specified. Also, the thicker the overlay the longer it will last. Thick overlays are expensive as are special asphalt mixes, but the alternative is reconstruction. Depending on the cause of the problem, this can involve removing layers of pavement, improving subgrades, and repaving. This is extraordinarily expensive and time consuming.

The Geosynthetic Solution

A geosynthetic interlayer can be placed over the distressed pavement or within the overlay to create an overlay system. The geosynthetic interlayer contributes to the life of the overlay via stress relief and/or reinforcement and by providing a pavement moisture barrier.

A stress relieving interlayer retards the development of reflective cracks by absorbing the stresses that arise from the damaged pavement. It also waterproofs pavements that typically allow 30 to 60% of precipitation to infiltrate and weaken the road structure. Reinforcement occurs when an interlayer is able to contribute significant tensile strength to the overlay system. The reinforcement limits the movement of the cracked old pavement under traffic loads and thermal stress by holding the cracks together.

The benefits of geosynthetic interlayers include:

- Delaying the appearance of reflective cracks
- Lengthening the useful life of the overlay
- Added resistance to fatigue cracking
- Saving up to 2 inches of overlay thickness

Paving Fabric for Stress Absorption

Paving Grid for Overlay Reinforcement

Geosynthetic Benefits

Stress Relief

Nonwoven geotextiles, a.k.a. paving fabrics, have high elongation and low tensile strength and are used for stress relief. When saturated with asphalt, the flexible interlayer allows considerable movement around a crack but nullifies or at least lessens the effect the movements have on the overlay.

Waterproofing

When saturated with an asphalt cement tack coat, the fabric interlayer becomes a moisture barrier within the pavement, preventing infiltration. Lower moisture content in the roadbase and in the soil subgrade increases the strength of these materials.

Reinforcement

A reinforcing interlayer resists horizontal movement of cracks in the old pavement and/or, when used over a leveling course or a paving fabric, holds the overlay together while allowing the cracked pavement underneath to move independently. Both approaches reduce reflective cracking in the overlay.

Other Composites

Pre-formed strip membranes have been developed to provide localized stress relief by combining very high strength reinforcement with a self-adhering membrane. These products are designed for construction and expansion joints.

The benefits of paving fabric are important in this overlay of I-70

THE SPECIAL CASE OF CHIP SEALS
Moisture Proofing + Low Cost Resurfacing

As with overlays, paving fabric is installed over the distressed pavement. A typical chip seal is then applied over the fabric providing a moisture proofing layer that also prevents surface raveling

INSTALLATION OF INTERLAYERS

There are four basic steps in the proper installation of an overlay system with a geosynthetic interlayer. Surface preparation is followed by the application of the tack coat, installation of the geosynthetic, and finally the placement of the asphalt overlay.

Surface Preparation

Clean the roadway of dirt, water, oil and debris. Smaller cracks should be sealed. Large cracks in excess of 1/8 inch (3.2 mm) and potholes should be filled. The surface on which a moisture barrier interlayer is place must have a grade which will drain water off the pavement. Milling of severely cracked or rutted pavement may be required, or a thin layer of asphalt called a leveling course may be applied. Sections of broken asphalt that move under traffic loading should be removed down to the subgrade and reconstructed.

Sweeping is an important part of surface preparation

Tack Coat Application and Fabric Laydown

Application of the Tack Coat

Proper installation of the asphalt cement tack coat is crucial; mistakes can lead to early failure of the overlay. Uncut paving grade asphalt cements are recommended with AC-20 and AR-4000 being the most popular. The grade of the tack coat is typically the same grade as used in the asphalt concrete overlay. The maximum temperature of the tack coat is 325°F (163°C), and the minimum is between 280-290°F (138-143°C). Emulsions can be used successfully, but they must be applied at a higher rate and allowed to cure completely.

The asphalt cement distributor truck must be capable of uniform application of the tack coat. The bar should be adjusted to obtain uniformity and the correct width of spray, usually 2 to 3 inches (5.1 to 7.6 cm) past the edge of the geosynthetic. The spray of the nozzles should overlap so that uniform double coverage occurs. Heavy spots, streaks, or gaps will cause problems in the system.

For a typical paving fabric, the application rate is 0.25 gal/yd^2 (1.13 l/m^2). The waterproofing element of an interlayer system is dependent on the uniform application of this specified amount of tack coat. The roughness of the surface, the porosity of the road, and the presence or absence of a leveling course will require slight modification of this application rate. Once in progress, the rate of application should be measured and verified.

Paving Grid Laydown

Geogrid and geocomposite systems vary. Therefore, the manufacturer's recommendations for tack coat, if any, should be followed.

Deployment of the Geosynthetic

Geosynthetics may be deployed manually or mechanically with equipment designed specifically for this application. In either case, the geosynthetic should not be allowed to wrinkle. The surface temperature of the tack coat should not exceed 325°F (163°C) when a paving fabric is deployed. In cool weather, the paving fabric needs to be placed as soon after the tack coat as possible. Allowing time for the tack coat to set and become sticky is advisable in hot weather.

The fuzzy side of the paving fabric should be laid down into the tack coat leaving the smooth side up. The fabric should be broomed into the tack coat. When two segments of fabric come together, an overlap of 2 to 6 inches (50 to 150 mm) should be created and treated with extra tack coat. The overlap should be shingled in the direction of the paving operation.

If a reinforcing grid only is used, it may be attached to the existing pavement by mechanical means (nailing) or by adhesives. Composites of grid and paving fabric are installed with a tack coat the same as a paving fabric alone. Overlaps are again 2 to 6 inches (50 to 150 mm).

In the case of drains, joints, or other irregularities, the geosynthetic should be placed normally and then cut out around the obstruction. Any wrinkles over one inch (25 mm) should be slit open and treated as overlaps. Any traffic on the geosynthetic should be carefully controlled. Sharp turning and braking will damage the fabric. Sand may be broadcast to reduce the likelihood of skidding. For safety reasons, only construction traffic should be allowed on the installed paving fabric.

Standard placement and compaction techniques are used

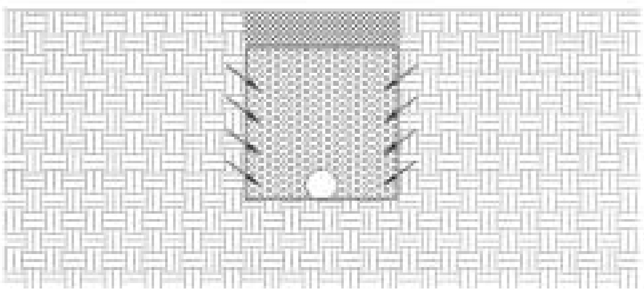
Installation of the Overlay

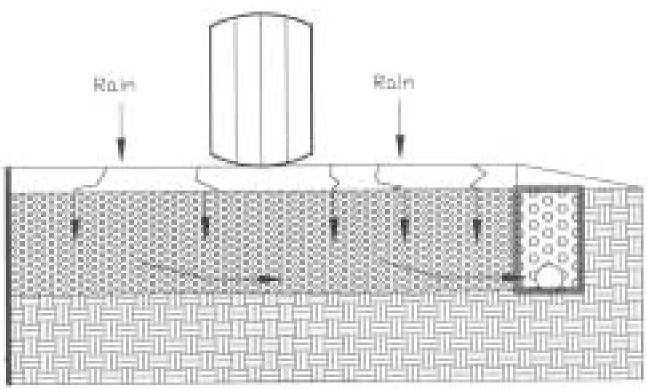
Installation of the geosynthetic and the asphalt concrete overlay should take place on the same day. Paving can commence as soon as the fabric is laid down. The temperature of the asphalt should not be less than 250°F (121°C) or exceed 325°F (163°C). The minimum compacted thickness of the first lift of the overlay at its thinnest point is 1.5 inch (38 mm). This thickness is necessary to produce enough heat to guarantee saturation of the paving fabric and bonding of the pavement layers. In cold weather, a thicker overlay may be necessary to achieve the same objective.

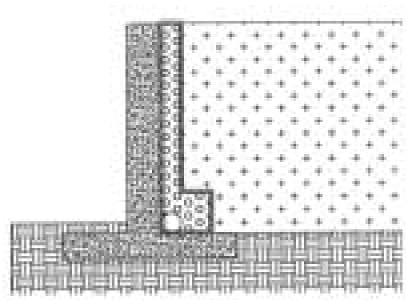
Asphalt can be placed by any conventional means. Compaction should take place immediately after dumping in order to ensure that the different layers are bonded together.

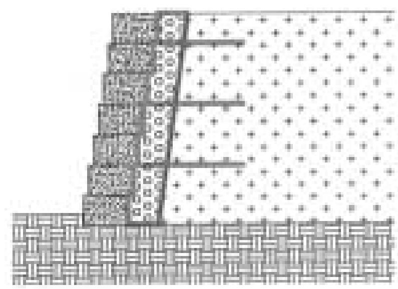
(Note: Additional, more detailed, installation guidelines are available directly from interlayer manufacturers.)

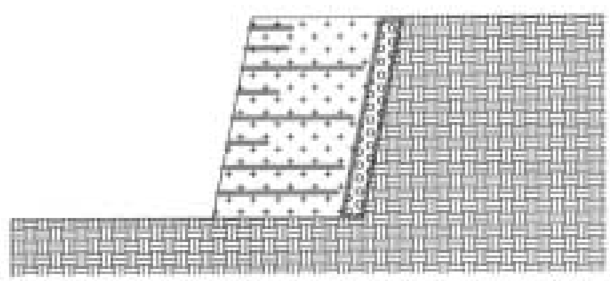
GEOSYNTHETICS IN SUBSURFACE DRAINAGE:
Subgrade Dewatering, Road Base Drainage, and Structure Drainage











SUBGRADE DEWATERING

Introduction to the Problem

A high groundwater table can, and often does, interfere with the stability of subgrade soils. For instance, some clay soils can swell or shrink as their water content increases or decreases, respectively. Also, most soils are considerably weaker when they have high water contents or have not been drained prior to loading. This means that weather-related or seasonal fluctuations in groundwater levels can adversely affect permanent structures founded on undrained soils.

Draining saturated soils can increase their strength and stability. Unfortunately, soils will only drain if there is an adjacent soil layer or zone of higher permeability into which the water can escape. The lower the permeability of the subgrade soils, the closer together the drainage layers/zones must be to provide effective dewatering.

High groundwater is a threat to any construction project

Typical Solutions

The traditional approach to subgrade dewatering is to dig a trench to the depth to which the water table is to be lowered and filling the trench with coarse drainage stone. Sometimes a perforated pipe is placed at the base of the trench to more efficiently transport collected seepage to an outlet. Trenches are spaced to assure drainage of the soil within a desired time period.

Alternatively, in new construction, a coarse aggregate drainage layer or "blanket" can be constructed beneath and before placing the subgrade soil. Similarly, a pipe system is commonly placed within the drainage layer to transport collected seepage.

Since groundwater seeping into a drainage layer can carry subgrade soil particles with it – a phenomenon called "piping". To prevent piping, a layer of fine sand is commonly used as a filter over a drainage layer or in lieu of coarse stone in a trench.

The Geosynthetic Solution

Effective subgrade dewatering requires a very porous drainage media to accept seepage and a properly graded filter to prevent piping. Geosynthetic materials have become commonplace in subsurface drainage applications. Commonly, geotextiles are being used in lieu of select grades of sand because they are less expensive, provide more consistent properties, and are much easier to install.

Subsurface drains are a common approach to controlling groundwater levels.


Coarse aggregate drains must be protected by a geotextile


A geotextile sandwiched aggregate blanket drain protects this highway fill

The advantages of geotextile filters can be extended to the drainage medium. Where coarse aggregate can be costly, have variable gradations, and be costly and burdensome to install, a geocomposite drain incorporating a 3-dimensional plastic drainage core wrapped with a filtration geotextile overcomes all of these limitations.


Geotextile filter and 3-dimensional plastic drainage core

INSTALLATION OF GEOSYNTHETICS FOR SUBGRADE DEWATERING

Trench excavation shall be performed in accordance with details of the project plans. In all instances excavation shall be done in such a way as to prevent large voids from occurring in the sides and bottom of the trench. The graded surface shall be smooth and free of debris.

The geotextile shall be placed in the trench loosely with no wrinkles or folds, and with no void spaces between the geotextile and the ground surface. Successive sheets of geotextiles shall be overlapped a minimum of 12-in. (300 mm), with the upstream sheet overlapping the downstream sheet.

After placing the drainage aggregate in trenches equal to or greater than 12-in. (300 mm) wide, the geotextile shall be folded over the top of the backfill material in a manner to produce a minimum overlap of 12-in. (300 mm). In trenches less than 12-in. (300 mm) but greater than 4-in. (100 mm) wide, the overlap shall be equal to the width of the trench. Where the trench is less than 4-in. (100 mm), the geotextile overlap shall be sewn or otherwise bonded.

Should the geotextile be damaged during installation, or drainage aggregate placement, a geotextile patch shall be placed over the damaged area extending beyond the damaged area a distance of 12-in. (300 mm), or the specified seam overlap, whichever is greater.

Placement of drainage aggregate should proceed immediately following placement of the geotextile. The geotextile should be covered with a minimum of 12-in. (300 mm) of loosely placed aggregate prior to compaction. If a perforated collector pipe is to be installed in the trench, a bedding layer of drainage aggregate should be placed below the pipe, with the remainder of the aggregate placed to a minimum required construction depth. The aggregate should be compacted with vibratory equipment unless the trench is required for structural support.


Trench is excavated


Placement of coarse aggregate and pipe


Geotextile filter installed


Competion of drain by wrapping the geotextile. Then backfill to grade.

ROAD BASE DRAINAGE

Introduction to the Problem
Designing without positive rapid subsurface drainage costs billions of dollars a year due to increased rates of pavement damage caused by poor drainage. Most road builders recognize the role of water in pavement deterioration. Yet, most emphasize strength and quality of pavement improvement, neglecting improved drainage techniques.

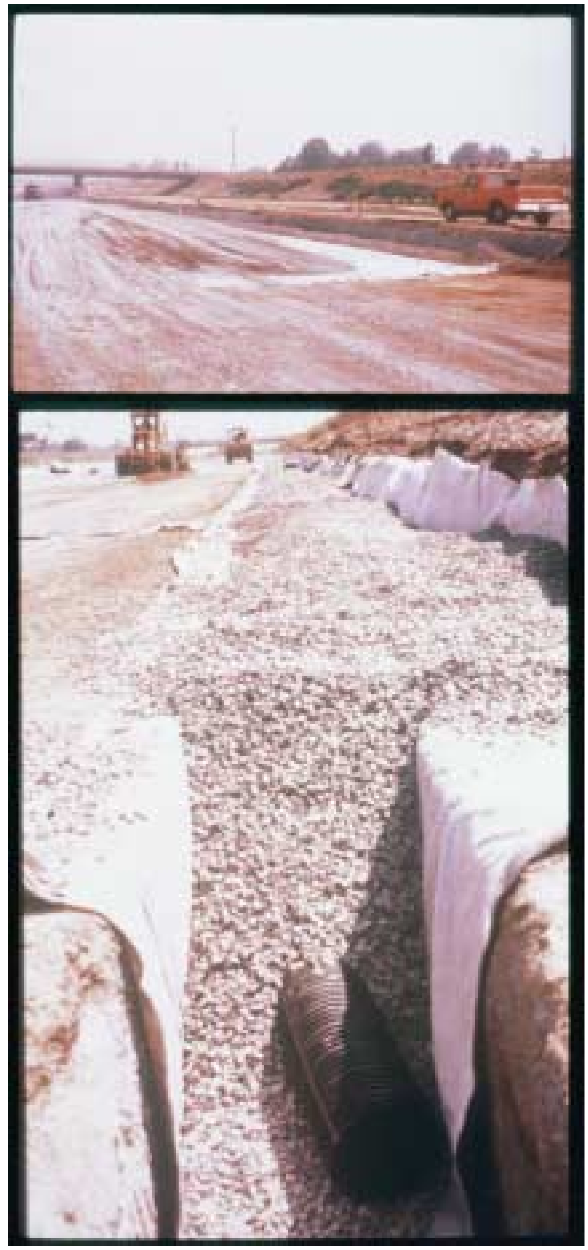
Typical Solutions
Most traditional drainage systems use an open-graded drainage layer under the full width of a roadbed with adequate collector pipes and outlet pipe. Additionally, pavement edge drains can be retrofitted to greatly reduce the rate of water-related damage to existing pavements if the road base is reasonably free draining.

The Geosynthetic Solution
Recent moves toward greater use of subsurface pavement drainage stem from the development of improved and economical drainage materials, along with greater awareness of the nature and extent of the problem.

The introduction of geotextiles into drainage applications has enhanced the economical application of blanket and trench drains under and adjacent to the pavement structure, respectively. The excellent filtration and separation characteristics associated with filtration geotextiles permits the use of a single layer of open-graded base or trench aggregate enveloped in a geotextile. The thin filtration geotextile reduces the required excavation as well as the cost of the drained structural section.

The following enhanced performance has been identified for pavements having an efficient functioning edge drain system:

<u>Flexible Pavements</u>:
25% increase in service life.
<u>Rigid Pavements</u>:
50% increase in service life.



The open-graded base course (above) ties into an edge drain (below). Both are protected by geotextiles.

INSTALLATION OF GEOSYNTHETICS FOR ROADBASE DRAINAGE

New Construction
When constructing a new road with an open graded base course designed to also provide blanket drainage, a filtration geotextile is deployed prior to placement of the base course in the same manner as a separation geotextile Commonly, the base course terminates along the road edges into deepened edge drains. These edge drains should also be wrapped with the geotextile as shown in the above photos.

Retrofit

Excavations for retrofit edge drains should be done in such a way so as to prevent large voids from occurring in the sides and bottom of the trench. The edge drain can be an aggregate trench drain with a collector pipe in the bottom.

The trench is "lined" with the filtration geotextile prior to pipe and aggregate placement.

Geocomposite Edge Drain

Alternately, a geocomposite edge drain can be used. The excavator, if appropriately equipped, will lay a geocomposite drain into a narrow trench and backfill with sand between the drain and the exposed base course.

The geocomposite drain is "inserted" into the narrow trench in a continuous process. The trench is completed by backfilling with sand between the geocomposite and the exposed base course.

STRUCTURE DRAINAGE

Introduction to the Problem

According to Cedergren, 1989, any well drained structure is inherently safer and more economical than if constructed without drainage. This is because the placement of relatively impermeable structural elements, such as a concrete foundation or retaining walls, against water-bearing earth leads to two damaging conditions:

1. Excess uplifting or overturning pressures caused by trapped water.
2. Channeling of seepage and piping caused by the presence of permeable discontinuities.

Strict adherence to sound drainage principles is probably the most important single aspect of the design of structures constructed adjacent to water-bearing soils. Almost every serious failure of structures of these kinds has been caused by lack of control of groundwater or seepage.

Typical Solutions

The objective of structural drainage is to control water pressures and seepage forces in the earth adjacent to structures and thus prevent their untimely damage, deterioration, or failure.

It has been customary to place a vertical blanket of "pervious" sand or gravel behind retaining walls for protection against hydrostatic pressures. Yet, it has been demonstrated that even when the back face of a wall is drained with a vertical blanket significant pore pressures can exist in the earth behind the blanket. This leads to increased pressure on the wall. An inclined drainage layer overcomes this deficiency by causing seepage to occur in the vertical direction.

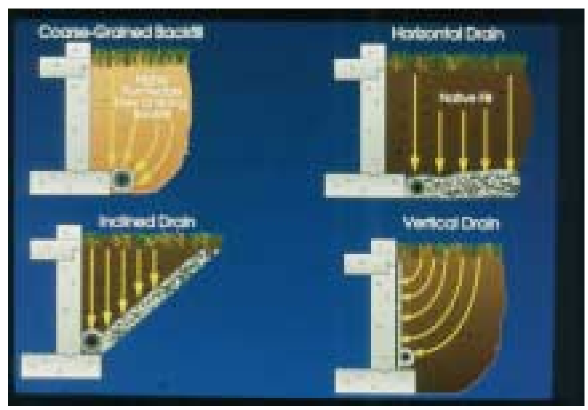
Still, whether vertical or inclined, a drainage layer is difficult to construct using sands and gravels. The drainage layer should be protected by a thin filter layer of carefully graded sand which is even more difficult, or impossible, to place at a steep angle.

The Geosynthetic Solution

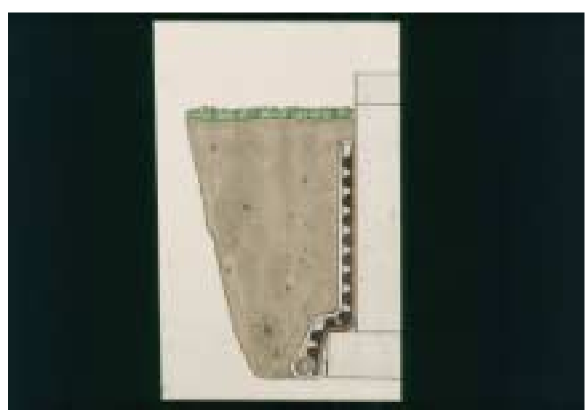
Geosynthetic drainage materials eliminate the difficulties associated with conventional gravel and sand drains and filters.

One of the best ways to assure effective aggregate drainage is to sandwich an aggregate layer within layers of filtration geotextiles. The inclusion of a perforated drain pipe that collects and discharges seepage will increase the drain's efficiency. Back fill is placed directly against the drain..

A prefabricated geocomposite drain is a complete geosynthetic alternative. The geocomposite drain replaces the aggregate with 3-dimensional plastic core and comes to the site already covered with the necessary filtration geotextile. This allows the entire drain to be installed in one step, saving considerable construction costs.



Wall Drainage Options



The Best Drainage Option: Geocomposite Drain

INSTALLATION OF DRAINS AROUND STRUCTURES

Excavations will be done according to project plans and in such a way so as to prevent large voids from occurring in the sides and bottom of the trench.

To assure an effective aggregate drain, place a filtration geotextile on the excavated stable slope in back of the wall, place a few inches of permeable crushed rock ¼ to 1 inch (6-25 mm) in size over the geotextile, and cover the rock with another layer of the filtration geotextile.

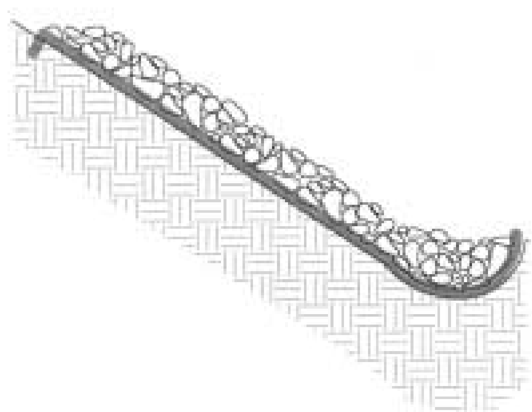
A prefabricated geocomposite drain may be used in horizontal or vertical applications. In vertical applications, install the drain over the waterproofed wall with the filter fabric side away from the wall surface. As additional drain sections are added, insure that there's a positive fabric overlap. Overlap panels in the direction of water flow. If a drainpipe discharge system is used, place the bottom of the drain behind the geotextile-covered drain pipe and aggregate. Soil should be placed and compacted adjacent to the drain.

In horizontal applications (e.g. plaza decks), lay the initial drain section horizontally, filter fabric side up. Make sure that the drain properly attaches to an outflow drain and that additional drain sections properly overlap, insuring a continuous flow path. Place temporary ballast atop the drain until the permanent decking is placed.

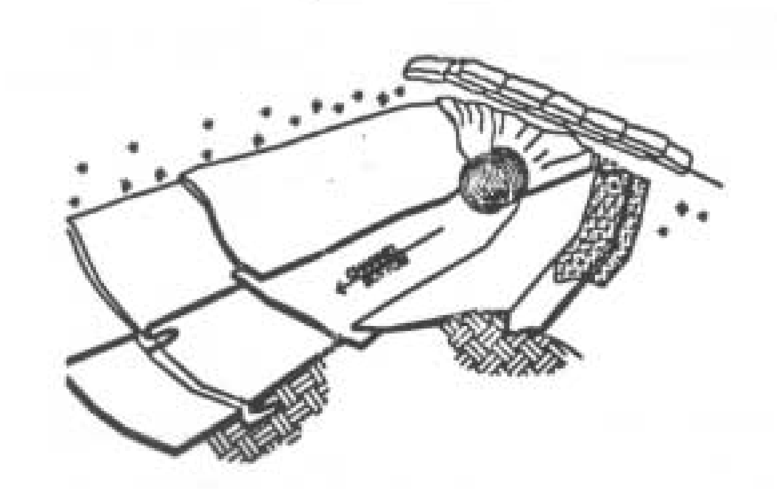
Unlike aggregate, geocomposite drains are easy to install with deep basement walls.

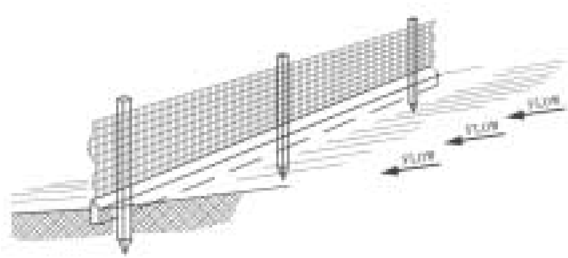
Roof drains enhance the removal of water from around critical structures.

GEOSYNTHETICS IN EROSION AND SEDIMENT CONTROL:
Hard Armor Systems, Rolled Erosion Control Products, Silt Fence



ARMOURED SLOPE





OVERVIEW

Man-made changes to the environment including unrestricted development, overtaxed resources, removal of surface cover, paving, or simply poor stewardship expose more soil to greater erosive forces and thereby substantially accelerate the rate of erosion.

Negative Effects of Erosion

- Turbidity caused by eroded soil particles reduces beneficial uses of water by people and can harm aquatic wildlife.
- Eroded sediments carrying chemical molecules have become a major water pollutant.
- As sediments accumulate, they fill up drainage channels and reduce the area available for storm water runoff.
- Flooding occurs when the outlets for storm water are clogged with sediment.

Erosion vs. Sedimentation

Erosion occurs when soil particles are displaced due to the impact of raindrops, moving water, or wind. Sedimentation occurs when eroded particles (sediments), carried by water or wind, are deposited in another location where they can cause problems. Clearly, sediments (suspended eroded particles) and sedimentation (redeposited soil particles) cause the problems commonly associated with erosion.

Erosion control can prevent problems from ever starting. Sediment control can only attempt to minimize the extent of the problems.

Erosion Basics

- Raindrops dislodge soil particles and seal the surface. Water cannot infiltrate the sealed surface so overland flow increases.
- Vegetation or any other cover can reduce the momentum or energy of raindrops and prevent sealing of the surface.
- Most construction site erosion results from rainfall impact and overland, or sheet, flows.

Erosion

Sedimentation on Roads and in Channels

Flooding Caused by Sedimentation

HARD ARMOR SYSTEMS

Introduction to the Problem

Soil banks or slopes exposed to constant concentrated flows, currents, or waves cannot support vegetation so they must be protected from erosion by hard armor systems. Hard armor systems include fabric formed revetments, geocellular confinement systems, gabions, articulating concrete blocks, and, of course, riprap.

When a hard armor system is in place, water can seep in and out of the bank or slope, but the force of the water is resisted by the armor. As the water seeps, it can gradually carry soil particles with it. The resulting voids cause armor support to be lost over time. This process is called *piping*. Piping can culminate in shifting, rolling, or other instability in the hard armor system.

An Undermined Hard Armor System

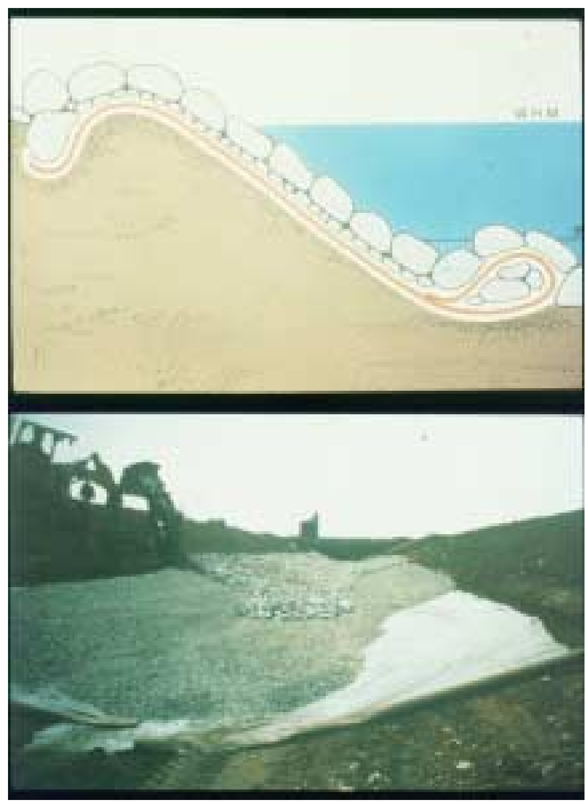
Typical Solutions

In a properly constructed armor system, a filter layer is placed between the bank soil and the armor to prevent piping. Traditional filter layers have been graded sand and aggregate layers. These graded filters are very costly to construct because they are constructed of select graded materials. Also, the filter layer must be a controlled thickness. On a steep slope, it can be very difficult to properly construct. For these two reasons, filter layers are often – and mistakenly - not included.

The Geosynthetic Solution

Hard armor systems are quite expensive to construct. Costs can range as high as $60 per square yard or more. The performance of even the most expensive system can only be assured if it is protected against piping. Consequently, a filter layer should <u>always</u> be used beneath hard armor system in an erosive environment.

Geotextiles have become standard filter layers for hard armor systems because they overcome the drawbacks of graded sand and aggregate filters. First, they are manufactured with specific hydraulic and soil retention properties, which can be easily selected to complement the soil that needs protection. Secondly, they can be installed with ease on slopes – even under water.



A Hard Armor System – Properly Constructed

Geotextile Properties

Depending on the gradation of the bank soil, either a nonwoven or a woven geotextile can be selected. AASHTO M288 provides guidance on selecting the appropriate geotextile properties.

INSTALLATION OF GEOTEXTILES UNDER HARD ARMOR

Site Preparation

The site should be prepared in accordance with good engineering practices. The slope or bank should be graded smoothly and be free from stumps or debris. The surface should be compacted. Any pockets of soft soil should be removed and replaced with compacted earth material to provide a consistently uniform and strong, stable surface.

Deployment of the Geotextile

Unroll the geotextile on the prepared soil. The geotextile should be placed parallel to small ditch and stream alignments and perpendicular to lake or ocean shores. This arrangement minimizes the exposure of the geotextile to current or wave uplift.

Overlap the geotextile a minimum of 1.5 ft (0.5 m) in order to provide continuous erosion protection. Secure the geotextile in place using 6-18 in (15-45 cm) pins or staples, fill material or rocks.

Placement of the Armor Layer

The armor, such as riprap or concrete blocks, should be placed in accordance with accepted practices. The drop height should be held to a minimum, and care must be exercised to avoid damage to the geotextile. If a drop height greater than 3 feet is anticipated, a heavier, more durable geotextile will be required.

Damage Repair

To repair portions of the geotextile damaged during placement of the armor, clear the damaged area, plus an additional three feet around it, of all armor material. Cover the area with a geotextile patch that extends three feet beyond the perimeter of damage. The patch should be placed beneath the damaged geotextile and pinned. Then carefully replace the armor material.

Placing Armor Stone on Woven Geotextle

Placing Armor Stone on Nonwoven Geotextle

Excessive Drop Height / Damage

ROLLED EROSION CONTROL PRODUCTS ON SLOPES AND IN CHANNELS

Introduction to the Problem

Straw or hay can be chopped and blown onto a pre-seeded soil bed to provide mulching benefits during seed germination. The straw or hay fragments are secured to the ground surface by crimping, punching, tacking, netting or, in many cases, by nothing at all. Yet, the integrity of these mulches can be severely effected by:

- rain;
- wind;
- overland flow; and
- biological forces.

As a result, conventional mulches provide, at best, only a few weeks or months of protection to the bare soil often making grading and reapplication necessary.

Typical Solutions

Cellulose-based fibrous mulches can be hydraulically spray-applied with the seed. The fibers are dispersed in a solution that, when sprayed on bare soil, causes the fibers to stick to each other and to the soil. These “spray-on” mulch systems are somewhat more resistant to erosion than are dry-applied systems. Very heavy applications, called bonded fiber matrices, can be more erosion resistant, but are also more costly.

The Geosynthetic Solution – Green Engineering and RECPs

Erosion is often a problem when there is not enough protective cover on steep slopes or in drainage channels that have been designed to rely on vegetation for long-term erosion control. Vegetation is ideal for erosion control because it is relatively inexpensive to establish and maintain, it poses few safety problems, and it looks natural. Additionally, grasses can filter harmful chemicals out of contaminated water.

The maximum use of vegetation in erosion and sediment control is often referred to as ***green engineering*** and produces the following long-term benefits:

- modest cost
- improved visual aesthetics
- proven performance
- ease of installation
- enhanced infiltration/groundwater recharge
- reduced flow velocities
- capture of sediments
- hydrostatic pressure relief
- resistance to heaving and differential settlement
- self healing

Rolled erosion control products (RECPs) are designed to encourage and enhance the effectiveness of vegetation as an erosion control material. RECPs were introduced in the late 1960s to remedy the limitations of conventional mulches by dependably meeting the two principal objectives of mulches:

- reducing soil loss
- enhancing site re-vegetation.

Additionally, some RECPs can form a long-term composite layer with the vegetation - tying together the individual plants at the root level - to create “reinforced turf”.

RECPs, used in lieu of or in combination with conventional materials, offer the potential to limit erosion while providing the following advantages over traditional materials:

- RECPs undergo rigorous quality control in a controlled manufacturing environment to minimize material variation.
- Large RECPs rolls can be easily and efficiently deployed.
- RECPs are often less costly to purchase, transport and install than alternative hard systems.
- RECPs are engineered for optimal performance.
- RECPs can be installed quickly.
- RECPs are easily shipped, competitively priced and readily available to any location.
- RECPs performance is not dependent upon weather conditions.

Temporary, Degradable RECPs for Slopes

Temporary, degradable materials are used to prevent loss of soil from the seedbed and to enhance the establishment of vegetation where the vegetation alone should provide sufficient site protection once established. This commonly includes steep slopes and channels with flows imposing less than 3 psf (150 kPa) shear stress. Erosion control netting (ECN), open weave meshes (ECM), and erosion control blankets (ECB) are the most common temporary, degradable RECP systems. Typically they are made of natural fibers such as straw, jute, coconut (coir), or wood (excelsior).

Typical Temporary Degradable RECPs

Long-term, Nondegradable RECPs for Channel Lining

Long-term, nondegradable RECPs, often called turf reinforcement mats (TRMs), furnish erosion protection and extend the erosion control limits of vegetation, soil, rock, or other materials. These plastic materials are used for permanent and critical hydraulic application where design discharges exert shear stresses that exceed the limits of mature, natural vegetation.

Typical Non-degradable RECPs (TRMs)

INSTALLING RECPS ON SLOPES AND IN CHANNELS

Site Preparation

Grade the surface of installation areas so that the ground is smooth and compact. When seeding prior to installation, prepare for seeding by loosening the top 2 to 3 inches (50 – 75 mm) of soil. All gullies, rills, and any other disturbed areas must be fine graded prior to installation. Spread seed before or after mat installation as directed. (Important: Remove all large rocks, dirt clods, stumps, roots grass clumps, trash and other obstructions from the soil surface to allow for intimate contact between the soil surface and the mat.)

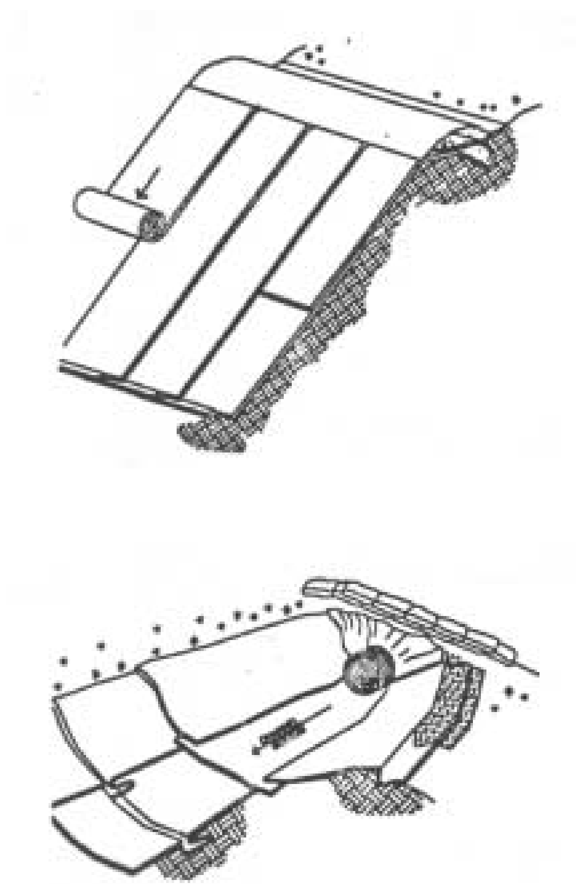
Terminal anchor trenches are required at mat ends and intermittent trenches must be constructed across channels at 25 ft (7.6 m) intervals. Terminal anchor trenches should be a minimum of 12-inch (30 cm) in depth and 6-inch (15 cm) in width, while intermittent trenches need be only 6-inch (15 cm) deep and 6-inch (15 cm) wide.

Installation on Slopes

Place the mat 2 to 3 ft (0.66 – 1.0 m) over the top of the slope and into an excavate end trench measuring approximately 12-inch (30 cm) deep by 6-inch (15 cm) wide. Pin the mat at 1-ft (0.3 m) intervals along the bottom of the trench, backfill and compact. (See note above for details of mat placement in trench.) Unroll the mat down (or along) the slope maintaining intimate contact between the soil and the mat. Overlap adjacent rolls a minimum of 3-inch (7.5 cm). Pin the mat to the ground using staples or pins in a 3-ft (1 m) center-to-center pattern. Less frequent stapling/pinning is acceptable on moderate slopes.

Installation in Channels

Excavate terminal trenches 12-inch (30 cm) deep and 6-inch (15 cm) wide across the channel at the upper and lower end of the lined channel sections. At 25' intervals along the channel, anchor the mat across the channel either in 6- x 6-inch (15 x 15 cm) trenches or by installing two closely spaced rows of anchors. Excavate longitudinal trenches 6-inch (15 cm) deep and wide along channel edges (above water line) in which to bury the outside mat edges.



RECPs are anchored in trenches at their ends and edges and overlapped downslope and in the direction of flow

Place the first mat at the downstream end of the channel. Place the end of the first mat in the terminal trench and pin it at one foot (0.3 m) intervals along the bottom of the trench. The RECP should be placed upside down in the trench with the roll on the downstream side of the trench. Once pinned and backfilled, the mat is deployed by wrapping it over the top of the trench and unrolling it upstream. If the channel is wider than the provided rolls, place ends of adjacent rolls in the terminal trench, overlapping the adjacent rolls a minimum of three feet (1 m). Pin at one foot (0.3 m) intervals, backfill and compact. Unroll the RECP in the upstream direction until reaching the first intermittent trench. Fold the mat back over itself, positioning the roll on the downstream side of

the trench, and allowing the mat to conform to the trench. Then pin the mat (two layers) to the bottom of the trench, backfill and compact.

Continue up the channel (wrapping over the top of the intermittent trench) repeating this step at other intermittent trenches, until reaching the upper terminal trench. At the upper terminal trench, allow the mat to conform to the trench and secure with pins or staples. Backfill, compact, and then bring the mat back over the top of the trench and onto the existing mat with an overlap of one to three feet (0.6-1.0 m) in the downstream direction. Finally pin across the mat at intervals of one foot (0.3 m).

When starting installation of a new roll, begin in a trench or shingle-lap ends of rolls a minimum of one foot (0.3 m) with upstream mat on top to prevent uplifting. Place the outside edges of the mat(s) in longitudinal trenches, pin, backfill and compact.

Anchoring Devices

Eleven (11) gauge, at least 6-inch (15 cm) L x 1-inch (2.5 cm) W staples, 18-inch (45 cm) pins with 1.5-inch (3.75 cm) diameter washers, wooden stakes, or 12-30 inch (30-75 cm) J-shaped pins (or bent rebar) having at least ¼-in (8 mm) diameter, are recommended for anchoring the RECP to the ground. Drive staples or pins so that the top of the staple or pin is flush with the ground surface. Anchor each mat every three feet (1 m) along its center. Longitudinal overlaps must be sufficient to accommodate a row of anchors and uniform along the entire length of overlap and anchored every three feet (1 m) along the overlap length. Roll ends may be spliced by overlapping one foot (0.3 m) in the direction of water flow, with the upstream/upslope mat placed on top of the downstream/downslope mat. This overlap should be anchored at one foot (0.3 m) spacing across the mat. When installing multiple width mats heat seamed in the factory, all factory seams and field overlaps should be similarly anchored.

Channel installation includes: fine grading and seeding; RECP deployment and pinning; and backfilling and compacting. The resulting channel provides all the benefits of vegetation.

SILT FENCE

Introduction to the Problem

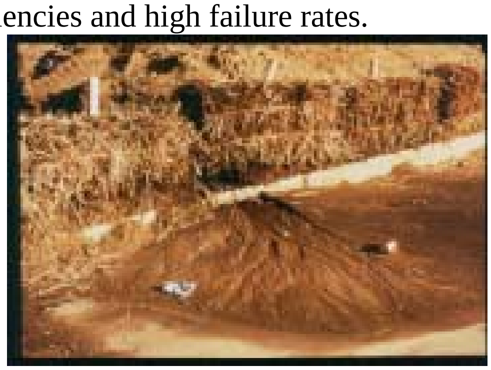
Because accelerated erosion can result from denuded areas during construction, sediment control measures are needed to prevent construction-generated silt from being carried into nearby waterways or onto adjoining properties. Various types of sediment control measures are used to impede the flow of sediment-laden waters and to filter out sediment.

Typical Solutions

Sediment control structures composed of permeable material are placed so as to intercept sheet flow and low level channel flow from denuded areas. These barriers serve (1) to decrease the velocity of moving water, and (2) to trap suspended sediment. Traditional measures include barriers made of straw, gravel or crushed stone, and brush.

Improper use of filter barriers has been a major problem. For instance, straw barriers have been used in streams and drainage ways where high water velocities and volumes have destroyed or impaired their effectiveness. Another major problem has been that improper placement of the barriers has allowed undercutting and end flow, which have actually resulted in additions to rather than removal of sediment from runoff waters. Finally, inadequate maintenance and cleaning efforts have tended to greatly lower the effectiveness of the barriers.

Because of the problems noted above, straw barriers have generally shown low trapping efficiencies and high failure rates.



Typical straw bale installation (failure)

The Geosynthetic Solution – Silt Fence

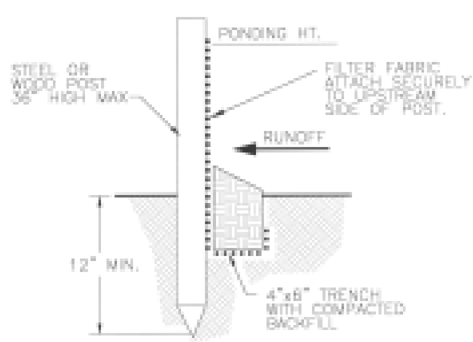
Faced with the ineffectiveness of straw barriers, a second type of filter barrier, the silt fence, has emerged. Silt fences are composed of tough, durable, geotextiles attached to support posts. Silt fences can trap a much higher percentage of the suspended sediments than can straw bales. When properly performing, a well designed silt fence will:

- initially screen silt and sand particles from runoff.
- form a soil filter adjacent to the sift fence, reducing the flow of water through the fence.
- create a pond behind the fence which serves as a sedimentation basin to collect runoff water and retain suspended sediments.

Silt fence retaining sediment laden runoff.

Over 40 million square yards of silt fence are used annually providing the following benefits over traditional sediment control structures:

- Minimal labor required to install;
- Low cost;
- Highly efficient in removing sediment;
- Very durable and sometimes reusable.



SILT FENCE DETAIL

SILT FENCE INSTALLATION

Proper installation of sediment control structures is critical to their proper functioning. For example, it is not uncommon to observe a silt fence around a construction site that is not toed in. In these cases, runoff will be allowed to run under the fence and cause off-site migration of sediments. Following are some generally accepted installation guidelines for silt fences.

The keys to silt fence performance are proper installation details, location, and maintenance.

Silt fence installed in trench, backfilled and compacted; posts installed, and fabric tied to posts.

Installation Details

1. Dig a minimum 6-inch deep x 4-inch wide (150 mm x 100 mm) trench where the silt fence will be installed.
2. Unroll the fence and position it on the down-slope side of the trench. Place at least six inches (150 mm) of the fabric below ground level. For greater effectiveness, lay a portion of fabric along the bottom of the trench.
3. Backfill and compact soil in the trench to prevent runoff from getting underneath the fence. Fill the trench with soil and tamp by foot or with equipment.
4. Place posts on the down-slope side of the fabric (the side away from the expected runoff flow) and drive them into the ground.
5. Attach fabric and mesh reinforcement (if required) to the up-slope side of the posts.

1 – 3 Alternative. “Slice” the silt fence into the ground and compact as directed by the slicing machine manufacturer.

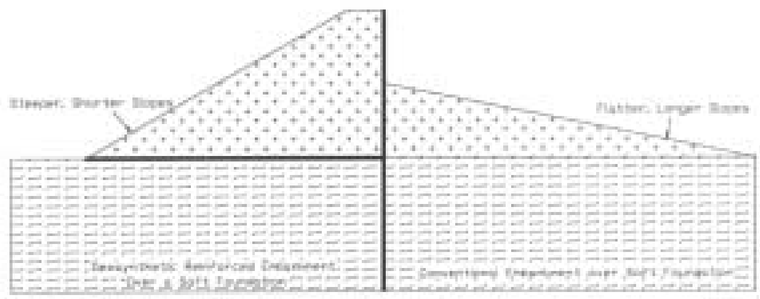
Location

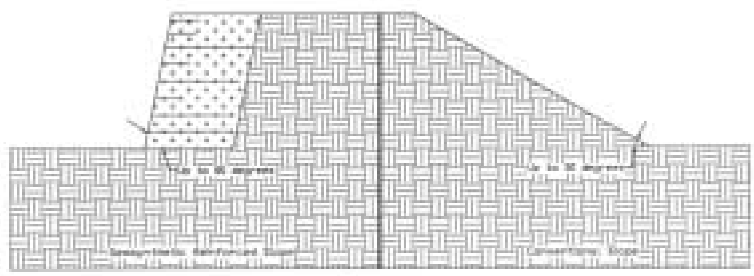
Unless otherwise specified, silt fence should be placed where it will intercept all runoff from the site. Extend the fence far enough uphill to prevent runoff from escaping around the ends. When continuing the fence line with a new roll of fencing, install the new fence to prevent silt from passing between the end of the existing fence and the beginning of the new.

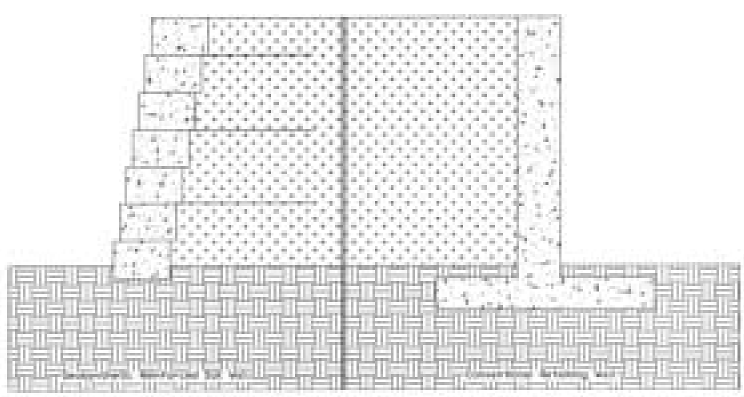
Silt Fence Maintenance

Over the time required for any given construction project, the control of erosion and sedimentation will be no better than the quality of the maintenance effort. The value of careful and prompt attention to maintenance cannot be overemphasized. Routine maintenance should be performed on all silt fencing. The fence line should be inspected after each significant rain event as well as at specified intervals. If silt buildup is discovered, it should be cleaned from the fabric either by sweeping or by hand shoveling. When fabric begins deteriorating either because of U.V. exposure or vandalism/debris, it should be replaced or a new fence should be installed adjacent to the old.

GEOSYNTHETICS IN REINFORCED SOIL SYSTEMS:
Embankments over Soft Foundations, Reinforced Steepened Slopes, Mechanically Stabilized Earth Walls





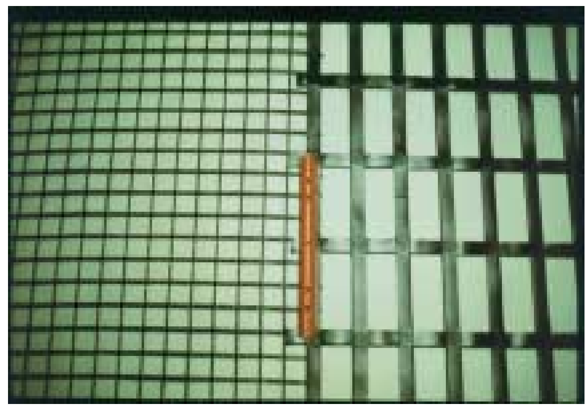


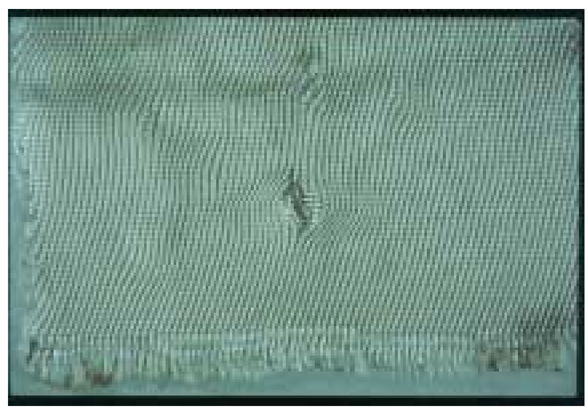
OVERVIEW

Though the use of tensile inclusions in soil structures dates back several thousand years to the construction of religious structures in ancient Babylonia, it was only three decades ago that Henri Vidal, a French architect, pioneered modern earth reinforcement techniques. These techniques involved the incorporation of tensile elements into a soil mass to complement the soil's compressive strength and to improve the mechanical properties of the soil mass.

Engineered Soil Fill

Beginning in the early 1970's, experimentation using geotextiles as soil reinforcement was conducted in Europe and the United States. The U.S. Forest Service constructed full-scale wrapped-face walls using geotextiles in 1974 and 1975 and the U.S. Army Corps of Engineers began using geosynthetics in reinforcement applications in 1978. Under FHWA sponsorship, highway departments in New York, Colorado, and Oregon constructed geotextile reinforced walls in the early 1980's. These successes attracted other candidate forms of plastic inclusions such as geogrids manufactured of polyethylene and coated polyester.





Geosynthetic Reinforcement

These and other reinforced soil systems have become known as mechanically stabilized earth (MSE) and their use has significantly increased. The primary types of MSE systems which have emerged include: mechanically stabilized earth walls (MSEW); reinforced soil slopes (RSS); reinforced embankments over soft foundations (RESF). MSEW and RSS have become especially important in highway construction as their use reduces the required width of new right-of-way and facilitates construction within existing limited right-of-way. RESF are recognized as a cost-effective alternative to traditional techniques for constructing earthen embankments over low strength foundations.

Facing

Geosynthetic reinforced soil systems include:

- Engineered soil fill
- Geosynthetic reinforcement
- Facing or slope protection system

EMBANKMENT OVER SOFT SOILS

Introduction to the Problem

Historically, construction of embankments is costly and environmentally sensitive when very soft soils, especially in wetlands, are encountered. The primary problem with these soft soils results from their low shear strength and excessive consolidation settlements requiring special construction practices and leading to high construction costs.

Soft foundation soils pose real construction challenges

Typical Solutions

Several methods of treatment are available to reduce the problems associated with soft foundations. These methods include:

- Removal and replacement of soft soil.
- Displacement of compressible material by end-loading.
- Staged construction - placing fill at controlled rates to allow for consolidation and strength gains.
- Installation of drains to facilitate consolidation.
- Pre-loading the site to reduce settlements of the structure and provide higher strength.
- Soft soil modification using admixtures (e.g. soil, cement, lime) or injections
- Reinforcement of the soil matrix using a structural element.

Geosynthetic Solutions

Geosynthetic solutions include geotextiles, geogrids and combinations of geotextiles and geogrids. While a wide variety of site improvement methods have been used during the past decade, soil reinforcement has emerged as an efficient, economical and effective solution to the problem of constructing embankments over soft soils.

Reinforced Embankment Concept

Geotextiles

For many years very strong fabrics have been employed in constructing embankments over soft ground. Very strong fabrics, with tensile strengths ranging from 1000 lb/in to 4500 lb/in, are placed over a prepared ground surface and earthen embankments are erected using a system of controlled height lifts to maintain uniform pressure on the subgrade.

Geogrids

Smaller embankments may also be designed and constructed using single or multiple layers of high strength, high modulus reinforcing geogrids at the base. The geogrid(s) reduce lateral displacement and improve the overall stability of the soil embankment.

Combination systems

Geogrids are limited in ultimate strength by structure and polymer properties. In a combined system, a geogrid or a geotextile can be employed to facilitate the development of a working platform which is subsequently covered with the very strong geotextile. The embankment is then constructed on the geotextile.

Large factory-fabricated panels are deployed on the jobsite.

As the backfill is placed, the soft foundation soils begin to "mud wave".

Factory-fabricated panels must still be field sewn into continuous sheets of reinforcement.

The fill thickness tapers toward the embankment toe reducing the reinforcement requirements and allowing a lighter-weight geotextile to be used under the embankment slopes.

The connected panels are then positioned to assure that the reinforcement is oriented to maintain embankment stability.

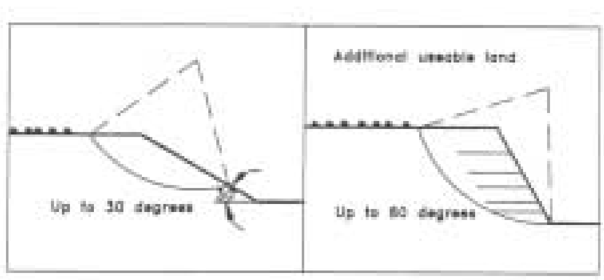
The completed embankment is taller and has steeper side slopes than would be possible without reinforcement or alternative stabilization.

REINFORCED STEEPENED SLOPE (RSS)

Advantages Of RSS Systems

Slopes are common geographic features and can be found everywhere with steepness ranging from gentle swales to ultra steep mountain sides. The full range of these terrain features is commonly found adjacent to transportation rights of way and building sites. The economics associated with a particular highway alignment or with the development of a parcel of land may be determined by the ability to create sufficient flat, or level, land to satisfy space, safety, or access requirements. On highway and building projects relatively flat areas are preferred. These areas must be constructed by excavation or filling in the existing terrain, often leaving significant grade changes at the edges of the excavation.

Reinforced steepened slopes provide a cost-effective means to achieve more efficient grade changes than are possible with conventional unreinforced slopes.



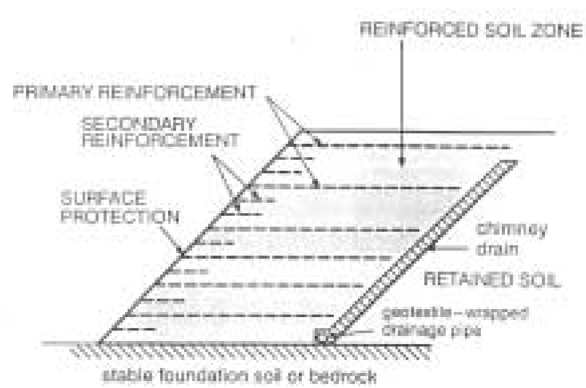
Conventional vs. Steepened Slopes

Geosynthetic reinforced steepened slopes are soil structures constructed with a slope face angle up to as high as 80 degrees from the horizontal. Typical unreinforced soil slopes are limited to a slope face angle of approximately 30 degrees, or less, depending on the angle of repose of the slope soil.

Details of RSS Systems

Like conventional soil slopes, reinforced slopes are constructed by compacting soil in layers while stepping the face of the slope back at an angle. Subsequently, the face is protected from erosion by vegetation or other protective systems ranging from concrete slabs to geocell walls and including a wide variety of systems. Additional geosynthetic elements are incorporated into reinforced steepened slopes to facilitate drainage, minimize ground water seepage and to assure the stability of the steepened slope and the erosion resistance of the facing. Following are the detailed components of a geosynthetic reinforced steepened slope system:

- Foundation - Stable soil or bedrock upon which the slope is constructed. Stability in the foundation is assumed.
- Retained Soil - The soil which remains in place beyond the limits of the excavation.
- Subsurface Drainage - Geosynthetic drainage medium installed at the limits of the reinforced soil zone to control and collect ground water seepage.
- Reinforced Soil - The soil which is placed in lifts adjacent to the retained soil and incorporates horizontal layers of reinforcing to create the sloped structure.
- Reinforcement - Geosynthetic, either geogrid or geotextile with sufficient strength and soil compatible modulus, placed horizontally within the slope to provide tensile forces to resist instability.
- Surface Protection - The erosion resistant covering of the finished slope surface.



Components of a
Reinforced Steepened Slope System


An RSS is used to raise this site out of the flood plain.

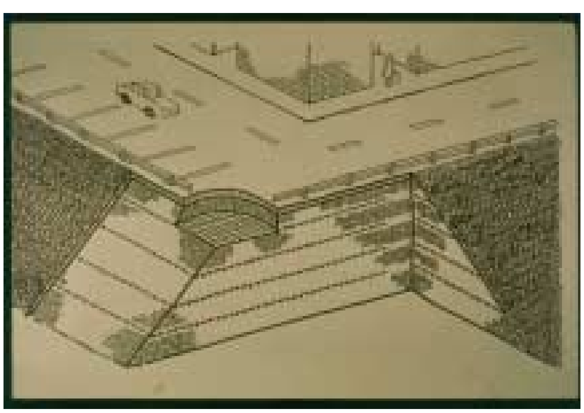

A slope repair that must support a roadway.


Alternating layers of geosynthetic and compacted soil.


An RSS is constructed using conventional equipment.


The steepened face must be protected from erosion.


The RSS with protected face and toe.

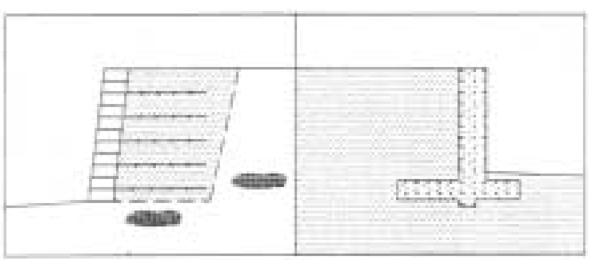

The finished project includes important structures.


The RSS supports a public roadway.

MECHANICALLY STABILIZED EARTH (MSE) WALLS

Advantages of MSE Wall Systems

The economics associated with a particular highway alignment or with the development of a parcel of land may be determined by the ability to create sufficient flat, or level, land to satisfy space, safety, or access requirements. Retaining walls are a common structural feature located adjacent to highways and building sites in many areas of the country. Retaining walls are popular because their vertical or near vertical faces increase the width of the relatively flat areas which are preferred for both highways and building sites. These areas must be excavated out of the existing terrain often requiring significant grade changes at the edges of the excavation. Though there are many types of retaining walls, geosynthetic reinforced (MSE) soil walls provide vertical grade changes at significantly less cost than conventional retaining walls.



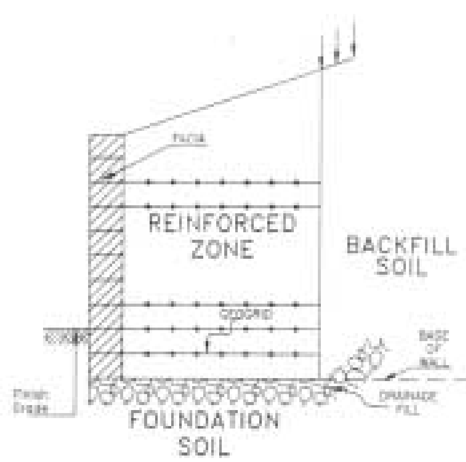
Reinforced Soil vs. Conventional Walls

Geosynthetic reinforced soil walls are soil structures constructed with the face at an angle of close to 90 degrees from the horizontal. Conventional retaining walls are gravity structures which must be massive enough to resist the destabilizing forces of the retained fill. Reinforced soil walls create gravity retaining structures out of the fill itself by incorporating geosynthetic reinforcement into the design.

Details of an MSE Wall System

Unlike conventional retaining walls, reinforced soil walls are constructed by compacting fill soil in layers between intermittent horizontal geogrid layers. These geosynthetic elements are incorporated into fill soil to assure the stability of the entire soil/facing system. Following are the detailed components of a geosynthetic reinforced soil wall system:

- Foundation - Stable soil or bedrock upon which the slope is constructed. Stability in the foundation is assumed.
- Retained/Backfill Soil - The soil which remains in place beyond the limits of the excavation or is placed behind the reinforced zone.
- Subsurface Drainage - Geosynthetic drainage medium installed at the base and back of the reinforced soil zone to control and collect ground water seepage.
- Reinforced Soil - The soil which is placed in lifts between the facia and the retained soil and which incorporates horizontal layers of reinforcing to create the gravity wall structure.
- Reinforcement - A geogrid or geotextile with sufficient strength and soil compatible modulus, placed horizontally within the soil to provide tensile forces to resist instability.
- Facia - The nearly vertical covering, or face, of the reinforced zone which provides the desired appearance and retains near surface soils. A sufficient connection must be provided between the facia and the geosynthetic reinforcement.




The first MSE walls used "wrap-around" techniques.


Backfill placed over reinforcement layer.


The wrapped face was protected with shot-crete


One of numerous, attractive block facing options.

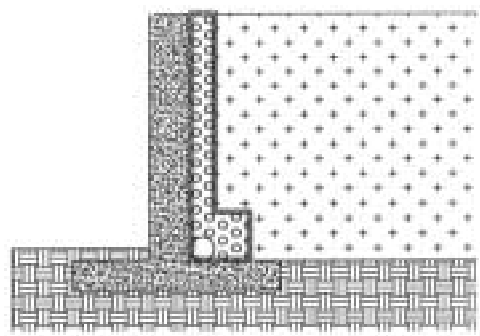

More recent walls commonly use masonry block units.

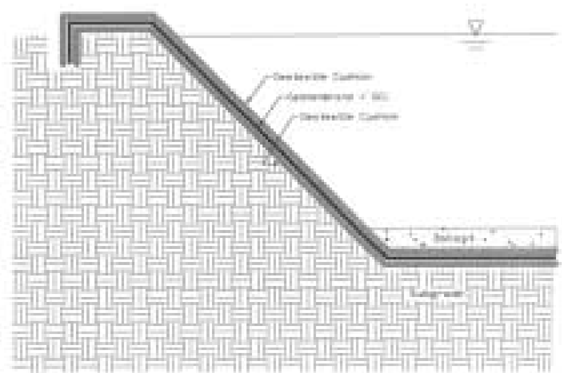

Geocellular confinement system faced MSE wall.


MSE walls have geosynthetic reinforcement layers.

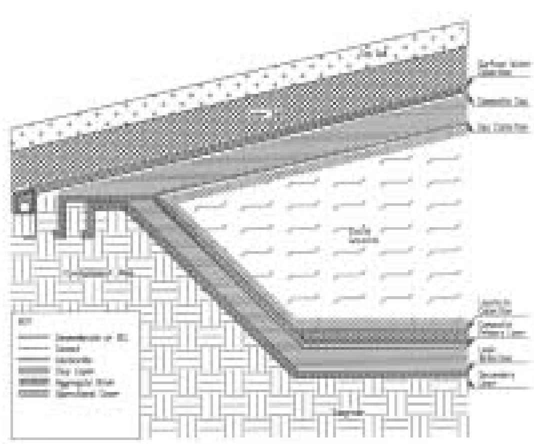

MSE wall with timber facing.

GEOSYNTHETICS IN SEEPAGE CONTROL SYSTEMS: Structure Waterproofing, Water Supply Preservation, Environmental Protection





SURFACE IMPOUNDMENT



OVERVIEW

Geosynthetics have been utilized in numerous civil and environmental engineering applications worldwide for more than 20 years to prevent seepage of liquids. Such seepage control applications as water containment and conveyance, structure waterproofing, and environmental protection make extensive use of geomembranes and geosynthetic clay liners (GCLs) along with other geosynthetics.

The materials used for seepage control may be exposed, as with pond linings, or buried, as with landfill linings. They may be subject to significant stresses, as with a pond cover, or exposed to very aggressive environments, as with a chemical tank lining.

The wide variety of potential exposure conditions is why there is such a wide variety of geosynthetic barrier materials. Material selection and installation details are, therefore, project specific.


Tank Lining


Spray-applied lining


Lined Architectural Pond


Pond Cover


Landfill Lining


Landfill Cap

STRUCTURE WATERPROOFING

Introduction to the Problem

The protection of structures (even soil and rock structures) from the effects of seeping water is a common need. As noted in Chapter 3, this need is typically addressed with a drainage layer, often accompanied by a waterproofing layer.

Typical Solutions

Conventional soil barrier layers silts and clays attempt to minimize liquid migration. Where readily available, clay can be compacted in multiple layers to achieve a durable, low permeability barrier, although placement against a vertical structure can be difficult, costly or impossible. Additionally, the integrity of clay barriers is adversely effected by:

- variations in texture (i.e. presence of clods),
- fluctuating moisture content and compaction effort,
- extreme temperature exposure, and
- exposure to certain chemicals.

Gravel and sand layers, if locally available, can be cost-effectively engineered into systems to collect and remove liquids and gasses. Assuring proper gradations, facilitating vertical placement on slopes, and obtaining uniform layer thickness often requires large construction tolerances and numerous duplicate inspections.

The Geosynthetic Solution

Since geomembranes and GCLs can be easily deployed in horizontal, vertical or even overhead configurations, they are especially useful for waterproofing tunnel linings as well as foundation and basement walls and other wall structures such as bridge abutments.

Taking advantage of their "sheet-like" nature, geomembranes and GCLs can be used to isolate or encapsulate water-sensitive roadway soils and subgrades in order to maintain the soils at their desired water content. They are also quickly and easily deployed as protective covers over material stockpiles to prevent wetting and erosion.

Geosynthetics, specifically geomembranes and GCLs, can offer a more economical, less installation-intensive alternative to clay barriers. In areas where naturally occurring clays and silts are scarce, GCLs can provide the impermeability required to protect structures. In addition, it is not always possible to place and compact natural clay in non-planar forms as in a tunnel lining or wall. GCLs also take up less space and are somewhat resistant to freeze/thaw and wet/dry cycles.

Geomembranes can be effectively incorporated into the construction of earthen and earth/rock dams which require an impervious core. These structures are traditionally constructed with silts and clays. In addition, concrete dams must be protected from seepage into the structure. Geomembranes are often used to cover the upstream sides of these dams.

Effective waterproofing includes drainage.

Tunnels require sophisticated waterproofing and drainage systems – made easier with geosynthetics

WATER SUPPLY PRESERVATION

Introduction to the Problem

Water Containment Systems

The containment and protection of important water supplies is a challenge to public works agencies as well as to industry. Effective lining of potable water reservoirs can conserve millions of gallons of water by preventing seepage losses. Additionally, covers can prevent contamination, control evaporation and prevent chlorine loss. Similar containment and protection is needed in waste water treatment facilities, though the purpose is to prevent leakage of untreated liquids and to collect biodegradation gases such as methane.

Water Conveyance Systems

The prevention of seepage from lined and relined canals is critical in arid regions.

Similarly, storm water retention and detention facilities are lined with a geomembrane or GCL to prevent excess wetness or instability of surrounding property resulting from seepage of contained runoff.

Typical Solutions

Most water reservoirs, because of their magnitude, are lined with low permeability soil and left uncovered. This often results in high water treatment costs and potentially serious contamination.

Clay or concrete linings have commonly been used for water and wastewater conveyance.

The Geosynthetic Solution

Geomembranes serve as effective protection against evaporation and contamination and can prevent seepage losses when used as liners and floating covers. Though generally used in more “highly engineered” installations, their low cost, wide spread availability, and relative ease of installation make geomembranes and GCLs more and more popular for lining architectural ponds, recreational ponds, and fire fighting ponds as well as for facing dams.

Geomembrane and GCL barrier systems provide flexibility and ease of installation which is especially beneficial when lining and relining is done over existing rigid linings of clay, asphalt, or concrete.

Installation of Cushion Geotextile

Geomembrane Placed Over Cushion

Pond Complete with Geosynthetic Lining

ENVIRONMENTAL PROTECTION SYSTEMS

Introduction to the Problem

The increase in environmental sensitivity of the last two decades has led to important regulations requiring "de minimus" leakage of contamination to the environment from landfills and other waste deposits. Additionally, as soon as a landfill reaches capacity, it must be capped to minimize future leachate generation

Typical Solutions

Conventional Systems. To minimize liquid migration, conventional capping and lining systems often include:

1. very low permeability soil barrier layers such as thick layers of silts and clays,
2. drainage layers of coarse uniformly graded sands or gravels, and
3. specially graded sand filters.

Where readily available, clay can be compacted in multiple layers to achieve a durable, very low permeability barrier. Yet, the integrity of clay barriers is adversely effected by:

- variations in texture (i.e. presence of clods),
- fluctuating moisture content and compaction effort,
- extreme temperature exposure, and
- exposure to certain chemicals.

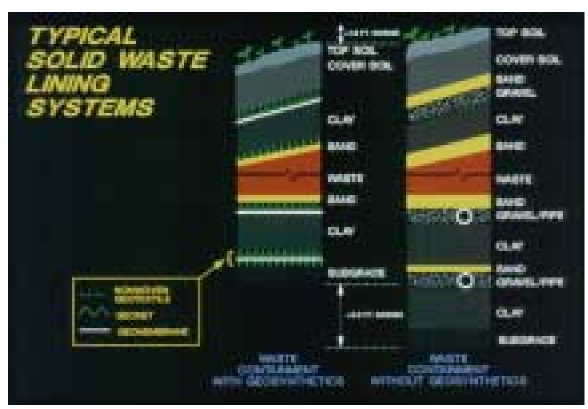
Gravel and sand layers, if locally available, can be cost-effectively engineered into systems to collect and remove liquids and gasses. Yet, assuring proper gradations, facilitating placement on slopes, and obtaining uniform layer thickness often requires large construction tolerances and numerous inspections.

The Geosynthetic Solution

The chemical resistance and flexibility of geomembranes and GCLs makes them technically superior to any other alternative for providing a positive barrier to the movement of fluids and gases. In the case of environmental protection, that movement usually includes containment of contaminated liquids and gases while keeping clean water, in the form of rain or runoff, from becoming contaminated.

There are many ways that geomembranes and GCLs have been incorporated into environmental protection barrier systems, including:

- final covers over waste materials,
- liners for solid, hazardous and monofill waste landfills,
- liners for lagoons and other surface impoundments such as geothermal, aquaculture, solar, or specific chemical ponds,
- secondary containment for underground storage tanks,
- vertical barriers to contain subsurface contaminant plumes,
- horizontal and vertical barriers to radon and methane emissions,
- pit liners for the collection and recycling of leached solutions from ore piles or even manure piles.



Typical Geosynthetic vs. Conventional Lining Systems

Landfill lining projects use many geosynthetics.

Composite liners include both clay and geomembrane.

Geonet composite drains for leachate collection.

Geonet and geotextile are sometimes placed separately.

Sand operational cover layer protects liner system.

The leachate collection system drains to a lined sump.

Geosynthetic installation proceeds in muliple layers.

Clay (and then a geomembrane) is placed over a leak detection system in a double composite liner system.

GEOSYNTHETIC SUPPORT SYSTEMS: Prefabricated Systems, On-site Fabrication, Testing and Specifying

OVERVIEW

Innovation is a tradition in the geosynthetics industry. In partnership with contractors, engineers are constantly developing cost-effective installation techniques, advanced new products and specially fabricated systems. Such innovations include prefabricated soil containment systems and preassembled fences and specially developed installation equipment and techniques for on-site fabrication. Additionally, the industry has developed an extensive array of tests for establishing the quality of geosynthetics and facilitating their specification.


Specialty Installation Equipment

PREFABRICATED SYSTEMS

Factory fabrication is an effective way of minimizing field operations. Fabricated geosynthetic products lead to faster, easier and more accurate installation, plus significant cost savings. Many geosynthetic suppliers offer factory fabrication capabilities including seaming of extra wide panels, joining multiple rolls and re-rolling them onto pipe cores, or specialty folding and bundling to facilitate field installation. Common prefabricated systems include:

- Geotextile socks for perforated pipe
- Reinforced selveges and grommets for silt (turbidity) curtains and geomembrane covers.
- Special widths, lengths or shapes of geosynthetic panels for installation in curves, on slopes or in other irregular configurations.

Some prefabricated "systems" mentioned earlier in this handbook include:

- Dredged Soil Containment System
- Barge-Placed Soil Containment System
- Sandbags
- Silt Fences and Turbidity Curtains
- Safety Fences

Dredged Soil Containment System
Geotextiles fabricated into a tube shape are used to contain various soil materials. The tube's diameter and length is determined by project requirements. The tube is filled by a hydraulic piping system conveying dredged material. Designed with appropriately sized openings, the geotextile tube retains fill material while allowing water to permeate out through the tube wall. Geotextile tubes permanently trap granular material in both dry and underwater construction. Additionally, tubes can be used to contain and dewater sludges.


Dredged Soil Containment System

Barge-Placed Soil Containment System
Geotextile containers are constructed of woven geotextiles using special seaming techniques to contain available granular fill material. Sunk accurately into position by barge, geotextile containers are designed to provide a desirable alternative to loose soil placement. Geotextile containers can be used for preventing erosion around piers and revetments, protecting and ballasting pipelines, and constructing groins, breakwaters, embankment cores and breach repairs.

Barge-Placed Soil Containment System

Sand Containers - Pre-Fabricated

Geotextile sandbags provide incomparable convenience to contractors needing fast, easy access to sand-filled bags. Geotextile sandbags are perfect for weighing down sign bases, anchoring plastic sheets or redirecting storm runoff.

Sandbags

Sand Containers – Custom Fabricated

Sandbags can also be custom engineered. Facing storm-induced erosion, large bags offer a flexible, stable armoring system that can be quickly installed to protect against storm induced erosive forces. Multiple bags can be stacked as required to create larger erosion protection structures.

Large sandbags can be fabricated to the size and material specifications of each customer. Bags are positioned and filled by hand. Ends are closed using a hand-held sewing machine.

Sand Containers – Custom Fabricated

Turbidity Curtains

Turbidity curtains are reusable floating geotextile or reinforced geomembrane panels that prevent water-polluting sediment from shore-side construction or off-shore filling and dredging operations from moving off-site. The top edge of each curtain contains floats and a cable or chain. Weights are attached to the lower edge of the curtain to keep it vertical in the water. Posts, piling, or anchors hold the curtains in place.

Typical Turbidity Curtain

ON-SITE FABRICATED SYSTEMS

Installation of a geosynthetic is only a small part of many projects. But if there are installation delays, work schedules and budgets can be drastically effected. By subcontracting geosynthetic installation including field seaming, project delays and overruns are avoided. Experienced installers work closely with contractors assuring timely deliveries and proper installation.

When time and quality matter, an experienced fabricator/installer with specialty equipment and know-how makes the ideal partner on projects involving field seaming of geosynthetics.

Geomembrane Deployment

Geomembrane Seaming: Wedge & Extrusion Welding

GCL Deployment

GCL Seaming

High Strength Geotextile Seaming

High Strength Geotextile Deployment

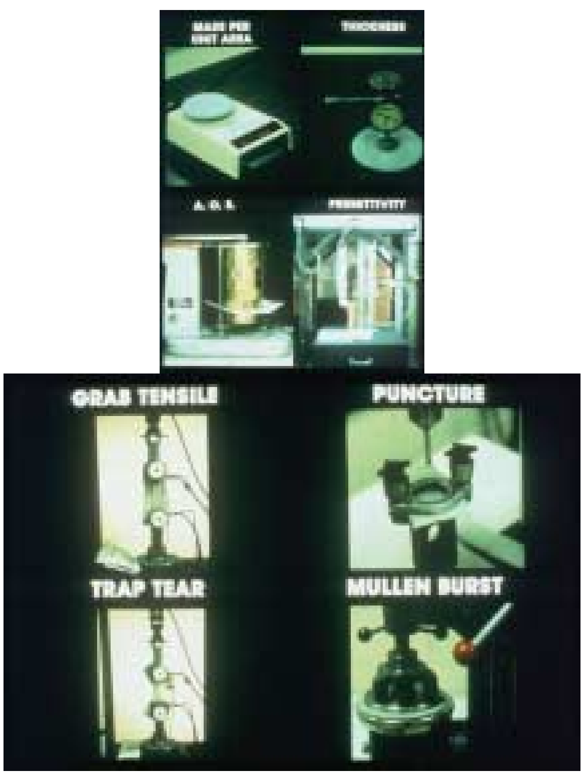
GEOSYNTHETIC TESTING AND SPECIFYING

Testing

Most specifiers and users of geosynthetics establish required physical property values for the geosynthetics to be utilized in their project based on standard tests. This practice is common for most engineering materials and is certainly recommended for geosynthetics. National standards bodies, such as the American Society for Testing and Materials (ASTM) have established standard tests for geosynthetics. These standard tests can be used to compare specific properties of different geosynthetics.

Geosynthetics test procedures can generally be placed in two categories: index tests and design tests. These two categories tend to overlap at times, and this distinction is not always clear.

Index tests are those tests a specifier or user can use to compare different geosynthetics. They do not, generally, provide a designer with "hard numbers" to use in his design, but they do allow for a quantitative comparison of physical property data. Most standard geosynthetics testing methods fall into this category.



Typical QC Index Tests

Index tests are further divided by geosynthetics manufacturers into quality control tests and performance tests. Quality control tests are run routinely by the manufacturer in their labs and are used as a means of insuring product quality. Performance index tests are run at regular intervals (sometimes by an independent lab) in order to provide necessary test results for the manufacturer's products.

Design tests, as the term implies, provide a designer with additional performance values usable in design calculations. An index test may be converted to a design test by changing boundary conditions, soil types, etc. The basic premise of a design test is that the test set-up accurately models field conditions.

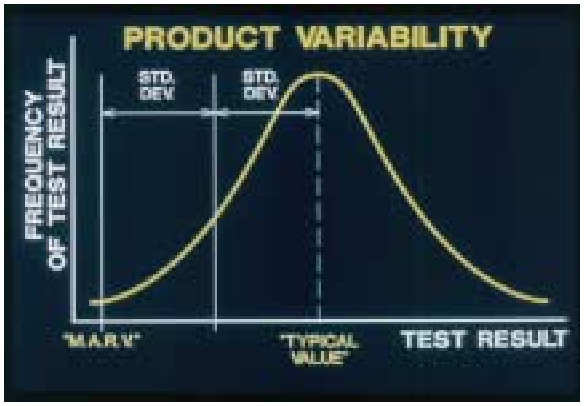
Typical Performance Index Tests

Specifying Geosynthetics

For all applications, four selection criteria should be considered.

<u>Quality Control</u> - Geosynthetics must be tested to insure they meet the specification. Most manufacturers test their geosynthetics and will supply certificates of compliance to the specification. However, on critical applications, additional testing should be performed by the user or an independent lab to guarantee that the geosynthetic complies with the specification.

Geosynthetics are commonly specified using Minimum Average Roll Values which statistically assures the contractor that the material purchased will consistently meet specs.

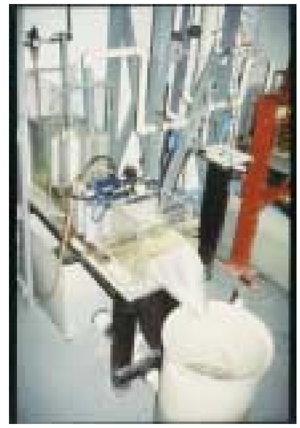


Minimum Average Roll Values (MARVs) assure that nearly all material exceeds specification requirements

Survivability - Geosynthetics must be able to withstand installation stresses. Often these stresses are significantly more severe than application stresses.

Installation damage testing determines how much the tensile strength of a product should be reduced to account for damage during construction

Long-term Design - Geosynthetics must be able to function as designed over the life of the project. Most specifications include properties related to long-term performance.



Transmissivity and Creep Testing are examples of commonly run design tests.

Durability - Geosynthetics must be able to function in the application's environment over the design life of the project. Durability considerations are particularly critical for waste facilities and chemical storage areas, but should be examined whenever acidic or alkaline soils are present or unusual geosynthetic design conditions are known, (e.g. prolonged exposure to sunlight. etc.)

Environmental Stress Crack Resistance testing is a common durability test run on geomembranes

Specifications

Appendix 1 presents representative generic material specifications for common geotextile applications. The specification of other geosynthetic applications will generally require the input of a qualified engineering professional.


GEOTEXTILE DESIGN
CRITERIA
• CONSTRUCTION
SURVIVEABILITY
• IN-SERVICE
PERFORMANCE