GEOSYNTHETICS IN STORMWATER CONTROLS AND HYDRAULIC ENGINEERING

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Short Course Breakdown

Part 1

Construction Site E&SC

Part 2

Erosion-Resistant Hydraulic Structures

Part 1

- The basics of . . .
  - Sediment and Erosion Control
  - Sediment Controls
  - Rainfall/Runoff Erosion Controls

GEOSYNTHETICS IN CONSTRUCTION SITE SEDIMENT AND EROSION CONTROL

INTRODUCTION TO THE PROBLEM
- Erosion, Sediment, & Sedimentation . . . The Effects of Sediment in Water Bodies
- Stopping Erosion, Prevents Sedimentation....Some Erosion Basics
- Accelerated (man-made) Erosion . . . The Construction Site

GEOSYNTHETICS IN CONSTRUCTION SITE SEDIMENT CONTROL
- Sediment Retention Devices (SRDs) – Good – Better Management Practices
- SRDs – Retention vs. Flow: The Grand Trade-off
- Silt Fence – The Most Common SRD – Installation and Maintenance
- SRDs – Generic Specifications and Index Property Testing
- "Best Management Practices"? The Search Goes On! – Performance Testing and Design

GEOSYNTHETICS IN CONSTRUCTION SITE EROSION CONTROL
- "Best Management Practices – BMPs" . . . Good – Better – Best Management Practices
- Rolled Erosion Control Products (RECPs)
- RECPs– Performance Design and Testing / Specifications and Testing / Installation
- RECPs – Anchorage Options
- Riprap Systems – Geotextile Filters: Specifications and Installation

The Facts about Sediment

Sediment as the most common pollutant in rivers, streams, lakes and reservoirs.

Natural erosion produces nearly 30 percent of the total sediment in the United States

Accelerated erosion from human use of land accounts for the remaining 70 percent.

The most concentrated sediment releases come from construction activities.

Sediment pollution causes $16 billion in environmental damage annually.

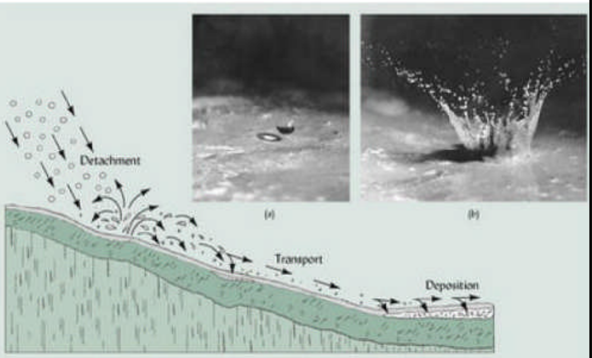
Erosion, Sediment, & Sedimentation

Erosion =
The displacement and movement of soil by wind or water

Sediment =
Eroded material suspended in water or soil.

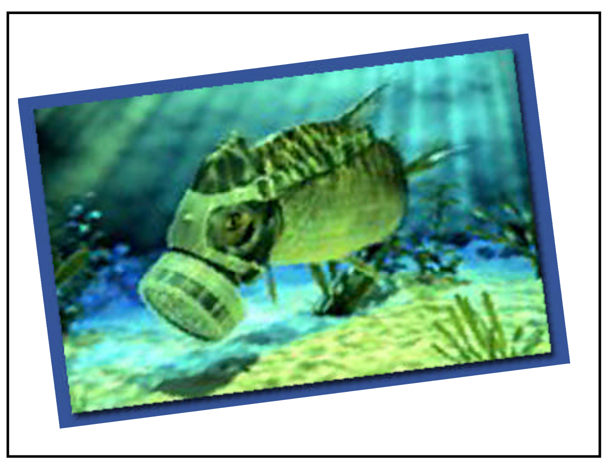
Sedimentation =
The deposition of eroded material.

Detachment and downslope soil transport by raindrops impact



The Effects of Sediment in Water Bodies

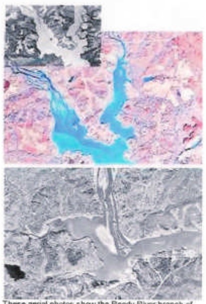
- Temperature Changes
- Wetland degradation/loss
- Increased algae growth (High P soils)
- Low DO (dead Algae, >temperature)
- Increased turbidity (Can't see food)
- Changes in habitat/species diversity
- Increased dredging
- Suffocates fish eggs and bottom-dwelling organisms
- Abrades gills



Upstate mud filling Lake Greenwood

Posted Sunday, August 24, 2003 - 12:03 am

By Jason Zacher
ENVIRONMENTAL WRITER
jzacher@greenvillenews.com



These aerial photos show the Reedy River branch of Lake Greenwood in 1954, inset, and 1999, color. At bottom, a 1999 aerial view shows the heavily silted Saluda arm of the lake.

The Problem: Sediment & Sedimentation

Saluda & Reedy River Branches of Lake Greenwood

- Downstream of Pickens and Greenville County.
- 60% filled with sediment.
- Primary source of Greenwood's drinking water.
- Areas where bottom has come up 8-10" in 10 years.

The Problem: Sediment & Sedimentation

Lake Greenwood (cont'd)

- 7.2 million cubic yards have filled the northern parts of lake.
- Equal to 1,000,000 dump trucks!
- Could fill Erickson stadium 6 times!
- Equivalent to 13.6 tons of sediment from every acre in the watershed!

Geosynthetics in Sediment Control Applications

- Silt fences and turbidity curtains;
- Components in sediment retention devices.

SRD Mechanisms

- Screening silt and sand particles from runoff . . .
- Until an upstream soil layer limits water flow through the fence. . .
- Causing ponding behind the device which then serves as a mini-sedimentation basin.
- Thus, hydraulic loading during a storm event is commonly the primary loading considered.
- Temporary check structures: slow and/or pond runoff to encourage sedimentation, thereby reducing soil particle transport downstream.

TRADITIONAL CONSTRUCTION SITE SEDIMENT CONTROL SOLUTIONS
(i.e. Good Management Practices)

Straw or hay bales staked to the ground around the area perimeter.

Sediment basin sized to hold the site runoff and associated sediment until sedimentation in the pond permits clear water release.

LIMITATIONS OF TRADITIONAL SEDIMENT CONTROL SYSTEMS

- Improper placement of the traditional barriers, such as straw bales, has allowed undercutting and end flow, which have actually resulted in additions to rather than removal of sediment from runoff waters.
- Inadequate maintenance and cleaning efforts have tended to greatly lower the effectiveness of barriers and basins.

Typical straw bale installation (failure)

Typical straw bale installation (failure)

Typical Unmaintained Basin

SEDIMENT CONTROL FUNDAMENTALS

First, the sediment is yours, keep it on your property.

Secondly, the heavy stuff will settle. The light stuff will stay suspended a long, long time.

Thirdly, there's a trade-off:

1. High seepage rate = Low filtration rate;
2. High filtration rate = Low seepage rate.

The SRD Trade-off. . .

Sediment Retention

Vs.

Seepage

Can a device both hold back all suspended sediments (and turbidity) and permit the runoff to efficiently seep through???

No! Not yet!

The SRD Trade-off . . .

Sediment Retention vs. Seepage

Currently, the designer/specifier has to decide which is more important!

Maximize retention

(risking excessive ponding)

OR

Maximize seepage

(risking excessive sediment release)

A Better Management Practice:

Overcoming traditional systems' limitations with the use of strong, tough, engineered geosynthetic or geosynthetic-enhanced systems!

To-date, relying on "experience-based", generic specifications that use general index properties.

Geosynthetic Sediment Retention Devices (SRDs)

- The performance of sediment control systems typically depends on the proper selection and deployment of sediment retention devices (SRDs). SRDs, include:
  - Silt fences,
  - Turbidity Curtains, and
  - Fiber Rolls (a.k.a. sediment retention fiber rolls, SRFRs)
  - Unique Inlet Protection Devices

Geosynthetic Sediment Retention Devices (SRDs)

Silt Fence

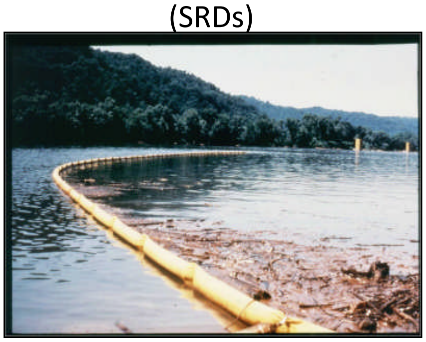
Wattles in Channels

Geosynthetic Sediment Retention Devices (SRDs)

SRD Protecting Inlet

Supported Silt Fence Inlet Protection

Geosynthetic Sediment Retention Devices (SRDs)



Turbidity Curtain

Geosynthetic Sediment Retention Devices (SRDs)

Geotube Turbidity Curtain

SILT FENCE

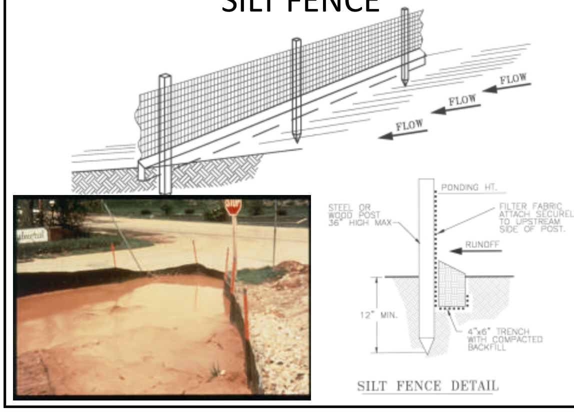
Sediment control barriers, such as silt fence, prevent construction-generated silt from being carried into nearby waterways or onto adjoining properties. These barriers serve:

1. to decrease the velocity of moving water, and
2. to trap suspended sediment.

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:

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

SILT FENCE



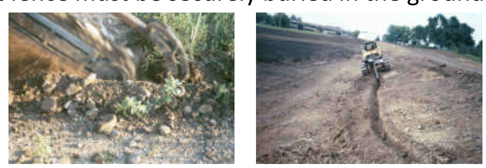
Silt Fence – The Benefits

Silt fence provides 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 Installation - Details

Silt fence must be securely buried in the ground . . .



Traditional Trenching Works, But Requires Careful Attention to Detail

Slicing is Quicker, Cheaper, and Less Prone to Undermining

Silt Fence Installation - Details

Silt fence trenched installations have more steps . . .

Once the (1) trench is dug, (2) place the fabric, (3) backfill, (4) compact,

(5) Install posts, (6) tie up fabric

Silt Fence Installation - Details

Silt fence sliced installations have fewer steps . . .

Once the (1) fabric is sliced into the soil, (2) compact,

(3) Install posts, (4) tie up fabric

Silt Fence Installation - 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

- 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.

Silt Fence Limits

It only works when put in correctly and maintained!

Silt Fence Limits

Since silt fence acts like a dam to sheet flow, even when put in correctly, it still has limits!

Existing National Specifications

- Sediment Retention Devices (Silt Fence)
  - AASHTO M288-18 Geotextile Specification
  - ASTM D6461 & D6462 Silt Fence Mat'ls & Installation
- Other SRDs
  - FP-14 Standard Specifications for Construction of Roads and Bridges on Federal Highway Projects (flh.fhwa.gov/resources/specs)

FP-14 Refers to . . .
M288 Temporary Silt Fence Spec

All numeric values except AOS represent MARV in the weaker principal direction.

	Test Methods	Units	Supported Silt Fence[a]	Requirements, Unsupported Silt Fence	
				Geotextile Elongation ≥50%[b]	Geotextile Elongation <50%[b]
Maximum post spacing			1.2 m	1.2 m	2 m
Grab strength	ASTM D4632	*N*			
Machine direction			400	550	550
X-Machine direction			400	450	450
Permittivity[c]	ASTM D4491	sec^{-1}	0.05	0.05	0.05
Apparent opening size	ASTM D4751	mm	0.60 max avg roll value	0.60 max avg roll value	0.60 max avg roll value
Ultraviolet stability (retained strength)	ASTM D4355	%	70% after 500 h of exposure	70% after 500 h of exposure	

a Silt fence support shall consist of 14-gage steel wire with a mesh spacing of 150 mm by 150 mm or prefabricated polymeric mesh of equivalent strength.

b As measured in accordance with ASTM D 4632.

c These default filtration property values are based on empirical evidence with a variety of sediments. For environmentally sensitive areas, a review of previous experience and/or site or regionally specific geotextile tests should be performed by the agency to confirm suitability of these requirements.

ASTM Silt Fence Specs

D6461

D6462

SRD

BEST MANAGEMENT PRACTICES!

TOO EARLY TO TELL???

STANDARDIZED PERFORMANCE TESTING IS NOW ABLE TO SHOW . . . GOOD vs. BETTER vs. BEST

SO THE SEARCH GOES ON!!!

FP-14 Other G-ECP & G-SRD Specs

Section 713. — ROADSIDE IMPROVEMENT MATERIAL

- 713.07 Cellular Confinement Systems 689
- 713.12 Fiber Rolls and Socks 691
- 713.13 Gravel Bags 692
- 713.14 Sandbags 692
- 713.16 Silt Fence 692
- 713.17 Temporary Rolled Erosion Control Products 693
- 713.18 Turf Reinforcement Mats 696
- 713.19 Sediment Filter Bags 697
- 713.20 Prefabricated Filter Insert 697
- 713.21 Floating Turbidity Curtains 697

FP-14 Standard Specifications for Construction of Roads and Bridges on Federal Highway Projects (flh.fhwa.dot.gov/resources/specs)

How Do I Design for Slope Sediment Control Using SRDs?

Soil Loss Computation

via

Revised Universal Soil Loss Equation (RUSLE)

SEDIMENT CONTROL ON SLOPES

THE REVISED UNIVERSAL SOIL LOSS EQUATION RUSLE

$$A = R \cdot K \cdot LS \cdot C \cdot P$$

where

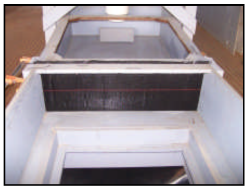
- **A = estimated average soil loss (tons per acre per year)**
- **R = rainfall-runoff erosivity factor (hundreds of foot·ton·inch/ acre·hour·year)**
- **K = soil erodibility factor (ton·acre·hours / hundred acre·foot·ton·inch)**
- **L = slope length factor**
- **S = slope steepness factor**
- **C = cover-management factor**
- **P = support practice factor ***

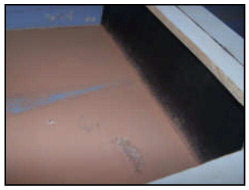
*** The P-Factor is the improvement provided by the SRD and is obtained from large-scale testing.**

TREATMENT		C-FACTOR	P-FACTOR
Bare Soil - Packed and smooth		1.00	1.00
Bare Soil - Freshly disked or rough, irregular surface		1.00	0.90
Sediment Containment Systems (a.k.a. Sediment Trap/Basin)		1.00	0.10-0.90
Bale or Sandbag Barriers		1.00	0.90
Rock (Diameter = 25-50 mm) Barriers at Sump Location		1.00	0.80
Silt-Fence Barrier		1.00	0.60
Contour Furrowed Surface - *Must be maintained throughout construction activities, otherwise P-factor = 1.00. Maximum length refers to downslope length.*			
Slope (%)	Max. Length (m)		
1 to 2	120	1.00	0.60
3 to 5	90	1.00	0.50
6 to 8	60	1.00	0.50
9 to 12	40	1.00	0.60
13 to 16	25	1.00	0.70
17 to 20	20	1.00	0.80
> 20	15	1.00	0.80
Terracing - *Must contain 2-year runoff volumes without overflowing, otherwise P-factor = 1.00*			
Slope (%)			
1 to 2		1.00	0.12
3 to 8		1.00	0.10
9 to 12		1.00	0.12
13 to 16		1.00	0.14
17 to 20		1.00	0.16
> 20		1.00	0.18
Grass Buffer Strips to Filter Sediment-Laden Sheet Flows - *Strips must be at least 15 m (50 ft.) wide and have a ground-cover value of 65% or greater, otherwise P-factor = 1.00.*			
Basin Slope			
0% to 10%		1.00	0.60
11% to 24%		1.00	0.80

Exerpted from Fifield 2001

Bench-scale SRD Testing





ASTM D 5141 has been revised to include a default sandy silt with more fines. VaDOT has adopted the new standard and is allowing suppliers to use private labs to support submittals.

SRD Performance Testing

ASTM D7351
Toe-of-Slope

ASTM D 7351 Test Setup

Runoff and Ponding During Test

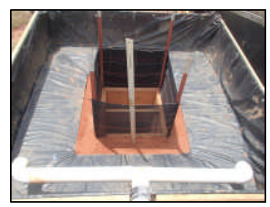
Fabric/Gravel Wattle Test

Silt Fence Seepage During Test

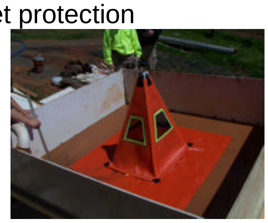
SRD Performance Tests

ASTM D7351
modified

EVALUATING
INLET PROTECTION
Concentrated Flow
Applications



All types of inlet protection



SEDIMENT PONDS

SEDIMENT PONDS & FLOATING SURFACE SKIMMERS

The purpose of a sediment pond is to detain runoff waters and trap sediment from erodible areas in order to protect properties and drainage ways below the installation from damage by excessive sedimentation and debris. The water is temporarily stored and the bulk of the sediment carried by the water drops out and is retained in the basin while the water is automatically released.

SEDIMENT PONDS & FLOATING SURFACE SKIMMERS

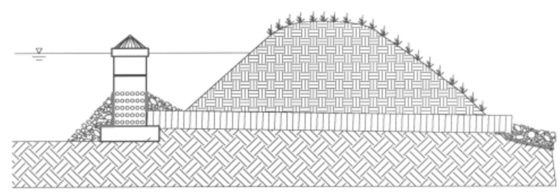
Retention time within the basin is an important factor in effective sediment retention. The method used to dewater the sediment basin may be selected from the following two methods:

- Perforated Riser Pipe
- Floating Surface Skimmer

SEDIMENT PONDS & FLOATING SURFACE SKIMMERS

- Perforated Riser Pipe – the conventional method for dewatering a sediment ponds. The lower half of the riser is perforated with 1/2-inch holes spaced approximately 3-inches apart. It is covered with two feet of 3 to 4 inch stone.
- Floating Surface Skimmer - The skimmer-type dewatering device operates at the surface of the ponded water and will not withdraw sediment from the submerged volume of the basin.

THE TRADITIONAL PERFORATED RISER



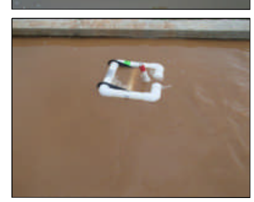
POND OUTLET

THE TRADITIONAL PERFORATED RISER *LIMITATIONS*

- Even with the gravel filter, the perforations in the lower elevations of the vertical riser allow discharge to pass which has a relatively high level of turbidity.
- Over time, the gravel filter surrounding the riser is coated with sediment that traps and detains water in the basin, reducing the storage capacity for incoming runoff.
- Sediment in the detained water is re-suspended with each new inflow.

FLOATING SURFACE SKIMMERS

- A floating surface skimmer "skims" water from the surface of sediment ponds at a controlled rate of flow where sediment concentrations are at a minimum in the water column instead of draining from the bottom where sediment concentrations are their highest.
- Floating surface skimmers serve two primary functions:
  - facilitate drainage of a sediment pond, basin, or trap, and
  - reduce turbidity and sediment concentration of the effluent discharge.



SEDIMENT PONDS & FLOATING SURFACE SKIMMERS

Skimmers

As compared to conventional perforated risers, skimmers discharge a 45 percent less mass of sediment. However, skimmers are mechanically more complex and will require frequent inspection and maintenance in order to operate as designed. (GSWCC)

Product-Specific Test Data: *B-Type*

Product-Specific Test Data: *E-Type*

Product-Specific Test Data: *F-Type*

Product-Specific Test Data: *I-Type*

Product-Specific Test Data: *S-Type*

D8107

ASTM D8107
Standard Practice for Measurement of Floating Pond Skimmer Flow Rate

Test Setup

- The skimmer to be tested was attached to the discharge pipe prior to pond filling using reducers/connectors depending on the size of the flexible coupling.
- The connection between the discharge pipe and the flexible coupling was watertight to ensure that the only outflow from the test basin was through the skimmer inlet.

ASTM D8107 – Skimmer Flow Rate Testing

Test Results

- Measurements of water surface elevation over time were the principle data used to determine the performance of the product tested.
- This data is converted into a curve that fits average flow rate, in gallons per minute, to a given depth, in feet.
- The data shows that each skimmer type exhibits a unique flow rate at various depths.

EROSION

Stopping Erosion,

Prevents Sedimentation

.

.

.

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Some Erosion Basics

EROSION MECHANISMS

Geologic (natural)

Vs.

Accelerated (man-made) Erosion

Geological Erosion

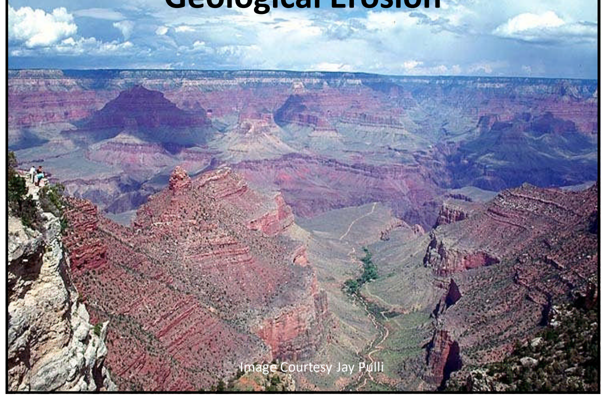

Image Courtesy Jay Pulli


Image Courtesy Jackie and Greg Tanner


Image Courtesy Nebraska History Organization


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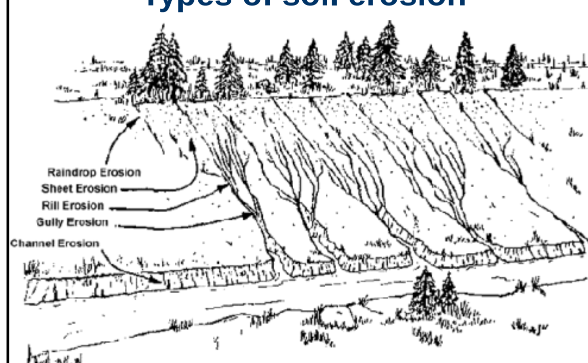
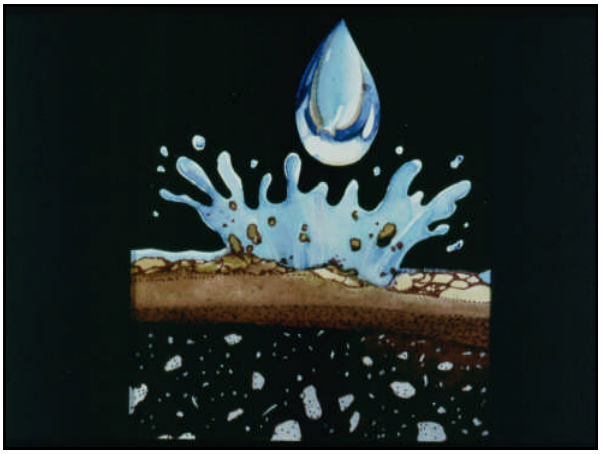
Accelerated Erosion

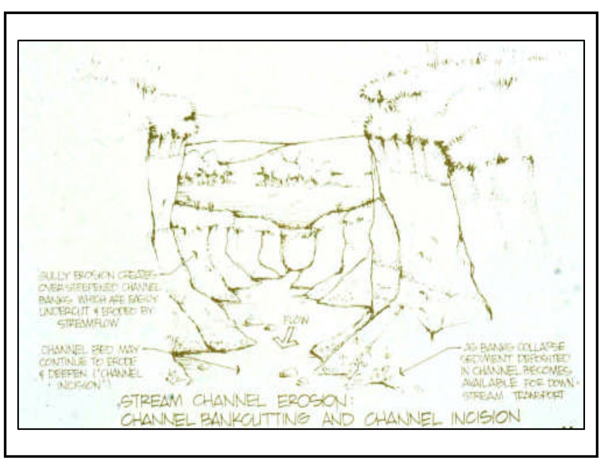
TYPES OF EROSION ASSOCIATED WITH WATER

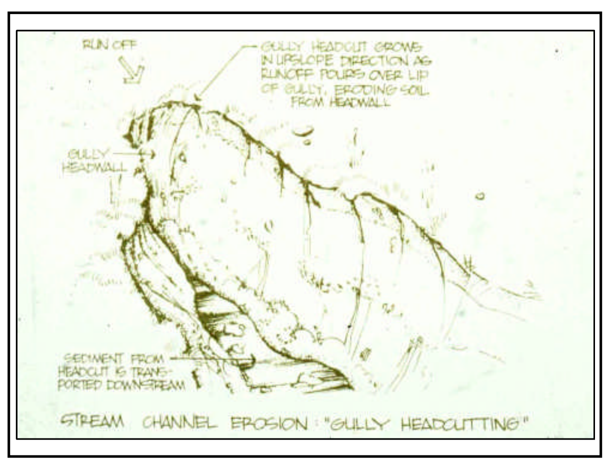
Splash
Sheet
Rill
Gully
Streambank
Shoreline
. . . as runoff concentrates,
it gets more destructive!

Types of soil erosion






GULLY EROSION CREATES OVERSTEEPENED CHANNEL BANKS, WHICH ARE EASILY UNDERCUT & ERODED BY STREAMFLOW
FLOW
CHANNEL BED MAY CONTINUE TO ERODE & DEEPEN ("CHANNEL INCISION")
AS BANKS COLLAPSE SEDIMENT DEPOSITED IN CHANNEL BECOMES AVAILABLE FOR DOWNSTREAM TRANSPORT
STREAM CHANNEL EROSION:
CHANNEL BANKCUTTING AND CHANNEL INCISION


RUN OFF
GULLY HEADCUT GROWS IN UPSLOPE DIRECTION AS RUNOFF POURS OVER LIP OF GULLY, ERODING SOIL FROM HEADWALL
GULLY HEADWALL
SEDIMENT FROM HEADCUT IS TRANSPORTED DOWNSTREAM
STREAM CHANNEL EROSION: "GULLY HEADCUTTING"

Erosion Control

"Best Management Practices – BMPs"

Regulatory Driven Growth

- The Clean Water Act's National Pollution Discharge Elimination System (NPDES) requires permits for construction sites.
- An NPDES permit requires a Storm Water Pollution Prevention Plan (SWPPP) that must include both the technical basis used to select the pollution control practices (a.k.a., best management practices or BMPs) to avoid increasing the historical amount of sediment in water and the maintenance of each sediment and erosion control measure.

"Best" Management Practices?

EROSION CONTROL FUNDAMENTALS

First, it is generally agreed that impacting raindrops dislodge particles and seal the soil surface, creating loose particles while reducing infiltration and increasing overland flow.

Secondly, maximizing infiltration and slowing down runoff, reduces the erosive power of the runoff.

Thirdly, vegetation, if left in place, can effectively reduce the momentum or energy of raindrops, prevent surface sealing, and slow down the runoff.

TRADITIONAL CONSTRUCTION SITE EROSION CONTROL SOLUTIONS

(i.e. Good Management Practices)

Straw or hay can be chopped and blown onto a preseeded soil bed. The straw or hay fragments are secured to the ground surface by crimping, punching, tacking, netting, or, in many cases, by nothing at all.

Alternatively, a cellulose-based fibrous mulch can be hydraulically spray-applied with the seed.

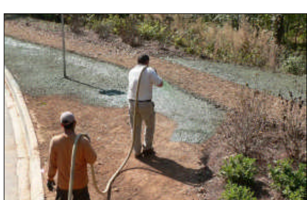
Rock, or riprap, can be used to resist erosion by splash, concentrated flow, swift currents, or wave action

Mulching

- Hay or Straw:
  - Crimped
  - Tackifier
- Hydraulic:
  - Recycled Paper
  - Wood Fiber
  - Other Fibrous Materials
  - Tackifier

Hand/Mechanically Applied Mulches

Hydraulically Applied Mulches



Soil Binders

- Acrylic Co-Polymers
- Plant Residues
- Polyvinyl Alcohol
- Asphalt Emulsions

Soil Fibers

- Rovings
- Individual Fibers
- Extended Roping

Riprap:
Angular Rock for Concentrated Flows

LIMITATIONS OF TRADITIONAL EROSION CONTROL SYSTEMS

The integrity of dry-blown or hydraulically-applied mulches can be severely effected by rain, wind, overland flow, and biological forces.

Assuring proper gradations and stone quality, facilitating placement on slopes, and obtaining uniform and stable layers often requires large construction tollerances and repeated inspections of riprap systems. Additionally, riprap is often installed without the necessary geotextile filter.

A Better Management Practice:
GREEN ENGINEERING

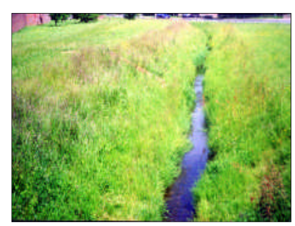
Overcoming traditional systems limitations with the maximum use of vegetation!

GREEN ENGINEERING

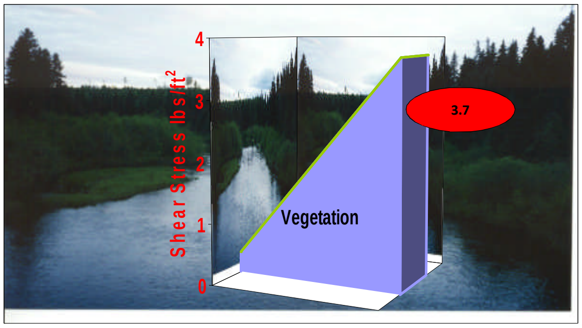
The maximum use of vegetation in erosion and sediment control that produces the following long-term benefits:

- Reduced flow velocities
- Self healing
- Hydrostatic pressure relief
- Resistance to heaving and differential settlement
- Greater safety for people and animals
- Proven Performance
- Aesthetics
- Pollutant Removal
- Reduced Thermal Heating
- Enhanced infiltration / groundwater recharge
- Wildlife Habitat
- Ease of installation
- Economical

Vegetation For Erosion Control



Performance Limits of Vegetation



For Example!

When Forces Exceed Capabilities of Vegetation

Devastation Can Be The Result

Historically Rock Riprap is Used

Historical Results From Riprap . . .

THE BEST MANAGEMENT PRACTICE!

DEPENDABLE GREEN ENGINEERING: THE MAXIMUM USE OF VEGETATION & GEOSYNTHETICS

What do Geosynthetics do in Erosion and Sediment Control Applications?

- **Traditional Geosynthetic Functions . . .** Separation, Filtration, Reinforcement, Planar Flow, Barrier
- **Geosynthetic Functions in Erosion & Sediment Control . . .**
  - Containment *(Erosion Control)*
  - Dynamic Filtration *(Erosion Control)*
  - Screening *(Sediment Control)*
  - Surface Stabilization *(Erosion Control)*
  - Vegetative Reinforcement *(Erosion Control)*

Geosynthetics in Erosion Control Applications

- Temporary, degradable materials for the enhancement of vegetative establishment;
- Long-term, nondegradable materials to extend the erosion control limits of vegetation or soil;
- Primary slope or channel linings;
- Shoreline and coastal defense systems;

ROLLED EROSION CONTROL PRODUCTS (RECPs)

RECPs have emerged which provide: greater strength, enhanced performance, and greater longevity thanks to geosynthetic components.

RECPs dependably meet the two principal objectives of mulches:

1) reducing soil loss, and

2) expediting/enhancing site revegetation

ROLLED EROSION CONTROL PRODUCTS ON SLOPES AND IN CHANNELS

- Rolled erosion control products (RECPs)
  - Temporary, Degradable RECPs for Slopes
  - Long-term, Nondegradable RECPs for Channel Lining

Rolled Erosion Control Products (RECPs)

Temporary degradable systems:

- erosion control netting (ECN)*: light-weight synthetic nets,
- open weave meshes (ECM): woven organic meshes,
- erosion control blankets (ECB)*: organic (straw, coconut, excelsior) fiber mats attached to organic or synthetic netting.

* These products may include primary geosynthetic components.

Temporary Rolled Erosion Control Products (RECPs)


ECN Applied Over Straw


ECM on Hillside

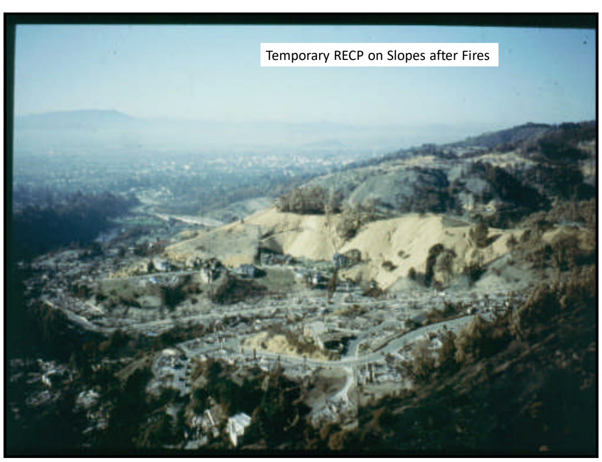
Temporary Rolled Erosion Control Products (RECPs)


ECBs Come in Many Varieties


ECB (left) vs. HMG (right)


Temporary RECP on Steep Slope


Temporary RECP on Steep Slope


Temporary RECP on Slopes after Fires


Temporary RECP on Steep Slope

Temporary, Degradable Erosion Control Systems

ADVANTAGES	DISADVANTAGES
Dry-Blown Mulches	
Lowest cost	Very temporary (< few weeks/months)
Well accepted	No concentrated flows
High installation rate	Dusty
Moderate sediment yield	Requires anchoring (i.e. crimping, tackifier)
Moderate vegetative density	May require certification (i.e. noxious weeds)
Hydraulic Mulches	
Low cost	Very temporary (< few weeks/months)
Well accepted	Very low or no concentrated flows
High installation rate	
Moderate sediment yield	
Moderate vegetative density	
Erosion Control Netting (ECN)	
More effective than tackifier (if properly anchored)	**Temporary (< 1 yr.), used with dry mulch**
	More costly than tackifier
	Netting may interfere with maintenance*
Open Weave Meshes (ECM)	
Low to moderate cost	**Temporary (1-2 yrs.)**
Moderate sediment yields	**Low flows only**
Moderate vegetative density	**Not complete ground cover**
Moderate moisture absorption	
Erosion Control Blankets (ECB)	
Low to moderate cost	**Temporary (1-3 yrs.)**
Easy to install	**Low to moderate flows**
Good moisture absorption	**Netting may interfere with maintenance***
Very low sediment yield	
Very good vegetative density	*** if improperly manufactured or inadequately anchored.**
Fiber Roving Systems (FRS)	
Low to moderate cost	Temporary (1-2 yrs.)
High subgrade conformance	Low to moderate flows only
Very low sediment yield	Special equipment required
Very good vegetative density	

Rolled Erosion Control Products (RECPs)

Long-term systems:

- turf reinforcement mats (TRM)*:
  - Synthetic fiber mats attached to or sandwiched between synthetic nets;
  - 2- and 3-dimensional welded or woven synthetic filament mat structures.

* These products always include primary geosynthetic components.

Long-term Rolled Erosion Control Products (RECPs)

TRMs have primarily polymer structures

TRMs are commonly used in Channels

TRMs: Nurturing Germination/Growth (short-term) and Reinforcing Vegetation (long-term)

Long-term, Nondegradable Erosion Control Systems

ADVANTAGES	DISADVANTAGES
Sod	
Immediate Vegetation and its associated benefits	High costs
	Risk of dying before establishment
	May need irrigation
	Limited to turf grasses (not native species)
Turf Reinforcement Mats (TRM)	
Moderate costs	**Low to moderate sediment yields (Unvegetated)**
Long-term (indefinite)	**Requires vegetative establishment for effective long-term performance**
Moderate to high flows	
Encourages infiltration	
Mod. to high vegetative density	
Extends the performance limits of vegetation	
Flexible – conforms to differential settlement	
Riprap	
Long-term (requires maintenance)	Moderate to Very high cost
Moderate to high flows	Unattractive, Unsafe
Encourages infiltration	Difficult to install correctly
Low sediment yield (when underlain by a geotextile)	Low vegetative density
	Often unstable, especially w/o geotextile
Other "Hard" Systems	
Incl. Geocellular Confinement Systems (GCS); Fabric Formed Revetments (FFR); Gabions (G); Articulating Concrete Blocks (ACB)	
Long-term (indefinite)	High to very high cost
Moderate to very high flows	No to delayed vegetation establishment
Low to moderate waves	No to low vegetative density
May encourage infiltration	May prevent infiltration
Low to moderate sediment yield	Low vegetative density
Can accommodate various fill materials	Special deployment/equipment req'ts
Durable and relatively maintenance free	

Erosion Control Systems Costs

BMP*per Square Yard – Installed***	Approx. Cost
Dry-Blown and Hydraulic Mulching	$0.50 - $1.00
Meshes and Nets	**$0.50 - $1.00**
E.C. Blankets	**$0.75 - $1.50**
Fiber Roving	$1.50 - $3.00
Sod	$2.00 - $4.00
Turf Reinforcement	**$5.00 - $8.00**
Hard Systems**	$15.00 - $60.00

RECPs in bold. * Excludes subgrade preparation, soil amendments and seeding operations.

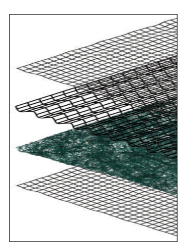
** Includes Geocellular Confinement, Fabric Formed Revetments, Riprap, Gabions, Interlocking Block Mats.

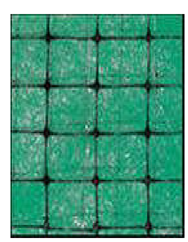
*** Cost is very sensitive to freight and labor rates.

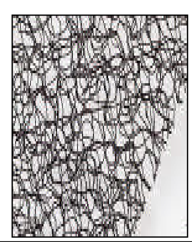
A Closer Look at TRMs?

Turf Reinforcement Mat (TRM) – A rolled erosion control product composed of non-degradable synthetic fibers, filaments, nets, wire mesh and/or other elements, processed into a permanent, three-dimensional matrix of sufficient thickness. TRMs, which may be supplemented with degradable components, are designed to impart immediate erosion protection, enhance vegetation establishment and provide long term functionality by permanently reinforcing vegetation during and after maturation.

TRM Examples

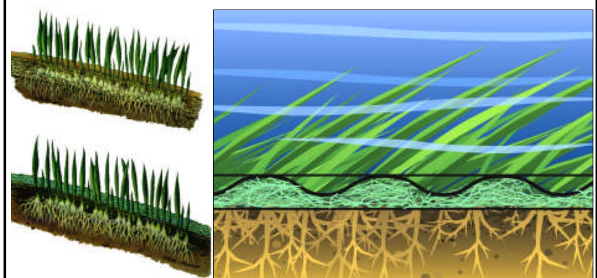






HPTRM Examples

Function of TRMs: Permanent Root & Stem Reinforcement



Areas Where Water Is Concentrated

Extremely Steep Slopes

Shorelines Where Soils Can Be Exposed to Constant Erosive Conditions

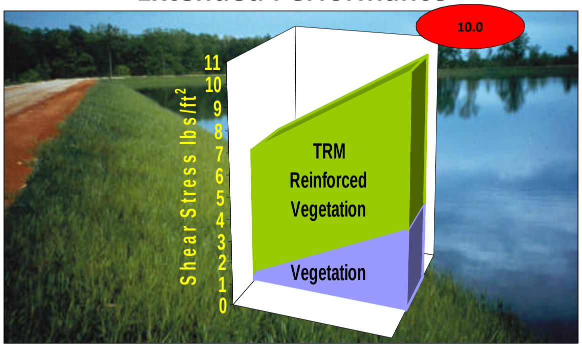
THE BENEFITS OF REINFORCED VEGETATION

The same as with plain vegetation . . . but more!

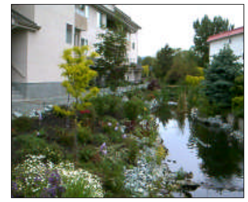
- Reduced flow velocities
- Self healing
- Hydrostatic pressure relief
- Resistance to heaving and differential settlement
- Greater safety for people and animals

- Extended Performance
- Aesthetics
- Pollutant Removal
- Reduced Thermal Heating
- Enhanced infiltration / groundwater recharge
- Wildlife Habitat
- Ease of installation
- Economical

Benefits of Reinforced Vegetation: Extended Performance



Benefits of Reinforced Vegetation: Aesthetics



Benefits of Reinforced Vegetation: Pollutant Removal

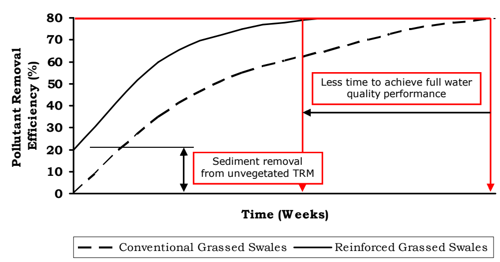
- EPA sponsored studies have shown that grassed swales are most effective at removing particulate pollutants
- A conservative estimate is 25-50% removal, but 70-95% has been achieved on most sites

TABLE 1 EFFECTIVENESS OF DESIGN SWALES

Pollutant	Median % Removal
Total Suspended Solids	81
Oxygen Demanding Substances	67
Nitrate	38
Total Phosphorus	9
Hydrocarbons	62
Cadmium	42
Copper	51
Lead	67
Zinc	71

Weiser & Austin, 2003

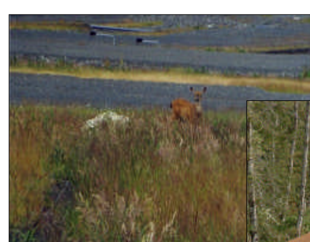
Benefits of Reinforced Vegetation: Achieve Water Quality Performance Faster

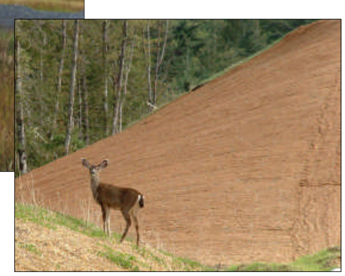


Weiser & Austin, 2003

Benefits of Reinforced Vegetation:

Benefits of Reinforced Vegetation: Offers Beneficial Wildlife Habitat.



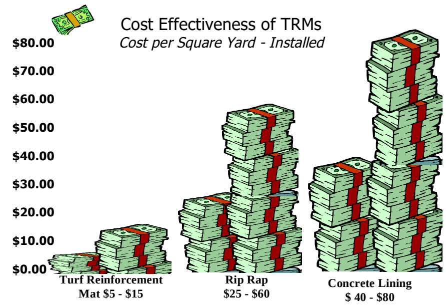


Benefits of Reinforced Vegetation:

TRMs Are Easily Installed Without the Need for Heavy Equipment

Benefits of Reinforced Vegetation:

Economical when Compared with other Erosion Control Methods



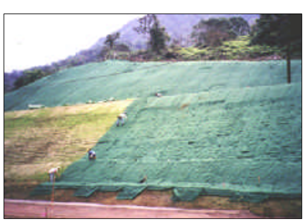
All values are provided by the ECTC for approximate installation costs in U.S. Dollars.

RECPs ON SLOPES AND IN CHANNELS
Design, Specification and Testing

RECP Performance Criteria

- On slopes, the ECP reduces soil loss caused by rain and immediate runoff.
- In channel linings, the ECP protects against the flowing water imposed shear stress on the sides and bottom of the channel.
- For short-term mulching, the ECP must nurture initial seed germination and vegetation growth.
- For extended mulching in arid regions or permanent armoring the ECP must have functional longevity.

How Do I Design for Slope Erosion Control Using RECPs?



Soil Loss Computation
via
Revised Universal Soil Loss Equation (RUSLE)

EROSION CONTROL ON SLOPES

THE REVISED UNIVERSAL SOIL LOSS EQUATION RUSLE

$$A = R \cdot K \cdot LS \cdot C \cdot P$$

where

- A = estimated average soil loss (tons per acre per year)
- R = rainfall-runoff erosivity factor (hundreds of foot·ton·inch/ acre·hour·year)
- K = soil erodibility factor (ton·acre·hours / hundred acre·foot·ton·inch)
- L = slope length factor
- S = slope steepness factor
- C = cover-management factor *
- P = support practice factor

* The C-Factor is the improvement provided by the RECP and is obtained from large-scale testing.

Typical C-Factors For Various Slope Treatments

(After Smith And Ports, 1976 & IECA, 1996)

Treatment	Dry Mulch Rate kg/m²	Slope %	C-Factor For Growing Period**			
			< 6 Wks	1.5-6 Mos.	6-12 Mos.	Annualized *
No mulching or seeding	all	-	1.00	1.00	1.00	1.00
Seeded grasses	none	all	.70	.10	.05	.15
	0.22	< 10	0.20	.07	.03	.07
	0.34	< 10	.12	.05	.02	.05
	0.45	< 10	.06	.05	.02	.04
	0.45	11-15	0.07	.05	.02	.04
	0.45	16-20	.11	.05	.02	.04
	0.45	21-25	.14	.05	.02	.05
	0.45	26-33	.17	.05	.02	.05
	0.45	34-50	.20	.05	.02	.05
Second Year Grass	-	all	.01	.01	.01	.01
Organic & Synthetic Blankets	-	all	.07	.01	.005	.02
Composite Mats	-	all	.07	.01	.005	.02
Synthetic Mats	-	all	.14	.02	.005	.03
Fully Vegetated Mats	-	all	.005	.005	.005	.005

* annualized C-Factor = (<6 wks value x 6/52) + (1.5-6 mos. value x 20/52) + (6-12 mos value x 26/52);
** approximate time periods for humid climates; Conversion: kg/m² x 4.46 = ton/acre

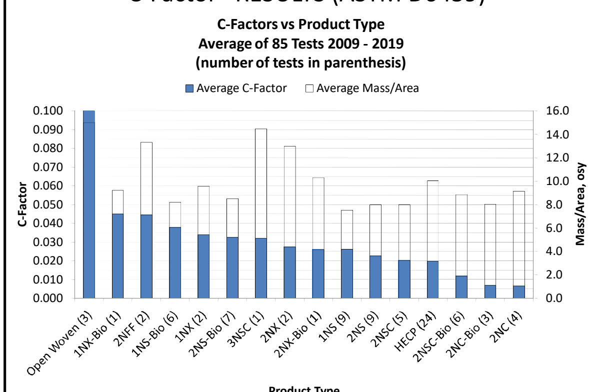
Large-scale Slope Protection Testing

Large-scale Testing of ECPs on Slopes

ASTM D 6459 Slope Testing Facility (bare soil test shown)

Testing of Rolled Erosion Control Products (RECPs)

"C-Factor" RESULTS (ASTM D6459)



How Do I Design for Channel Erosion Control Using RECPs?

Flow-induced Shear Stress

vs.

Channel Lining Permissible Shear Stress

Shear Stress at Maximum Flow Depth

$$\tau = \gamma \times D \times S_f$$

where:

τ = Shear stress at maximum flow depth: Pascal (Pa) / (lbs/ft²)

γ = Unit weight of water: 9810 N/m² / (62.4 lbs/ft³)

D = Flow depth: m (ft)

S_f = Friction slope or bed slope of channel: m/m (ft/ft)

$\tau_{permissible}$ >>> τ_{actual}

The allowable shear stress, $\tau_{permissible}$, is determined from large-scale testing of the candidate channel lining and compared to the actual flow-induced shear stress, τ_{actual}.

Permissible Shear Stress for Temporary Degradable RECPs

Category	Product Type	Permissible Shear Stress – Unvegetated
Low Velocity	Erosion Control Net	0.1 – 0.2 psf
	Erosion Control Mesh	0.4 – 3.0 psf
	Erosion Control Blanket – Single Net	1.55 – 2.0 psf
High Velocity	Erosion Control Blanket – Double Net	1.65 – 3.0 psf

Adapted from Gray, D.H. and Sotir, R.B. (1996) & Austin, D.N. and Ward, L.E. (1996).

Permissible shear stress for long-term nondegradable RECPs

Units	TRM Veg Phase	HEC 15[1]	Gray & Sotir[2]	CIRIA[3]	TTI[4]	GA DOT[5]	NAG[6]	SI[7]	ECTC Recommended Design Values
Maximum Velocity (fps)	Unveg.	n/a	n/a	n/a	n/a	n/a	9.5	7.9–20	Unveg. = 8 – 10 fps
	Partial Veg.	n/a	n/a	n/a	n/a	n/a	14 -16[8]	n/a	Partly Veg. = 10 – 16 fps
	Fully Veg.	n/a	n/a	19.7	32.8	n/a	18	14 – 25	Fully Veg. = 14 – 20 fps
Maximum Shear Stress (psf)	Unveg.	2	3	n/a	n/a	2.8-5.1	3.2	2 – 8	Unveg. = 2 – 4 psf
	Partial Veg.	n/a	4 – 6	n/a	n/a	n/a	4 - 6[8]	n/a	Partly Veg. = 4 – 6 psf
	Fully Veg.	n/a	8 – 10	n/a	8	n/a	8	5 - 10	Fully Veg. = 5 – 10 psf

1. Chen, Y.H. and Cotton, B.A. (1988),
2. Gray, D.H. and Sotir, R.B. (1996),
3. Hewlett, H.W., et al (1987),
4. Northcutt, P.J. and McFalls, J. (1997),
5. Keller, E.J. and Middlebrooks, P. (1989),
6. North American Green, Inc. (1993),
7. Austin, D.N. and Ward, L.E. (1996),
8. Values interpolated from unvegetated and fully vegetated TRM results.

LARGE-SCALE TESTING OF EROSION CONTROL PRODUCTS IN CHANNELS

Standard Full-Scale Testing:
ASTM D 6460 - *Standard Test Method for Determination of Rolled Erosion Control Product (RECP) Performance in Protecting Earthen Channels from Stormwater-Induced Erosion.*

- Rectangular (flume) with 10% (unvegetated) or 20% (vegetated) slope;
- Rectangular cross-section at least 0.6 m (2 ft) width and 0.6 m (2 ft) high side walls;
- 3 replicate test sections;
- Minimum 30 cm (12-inch) compacted soil veneer;
- Increasing Shear Levels @ 30 minutes (unvegetated) or 1 hour (vegetated) each;
- ½-inch average soil loss failure criteria.

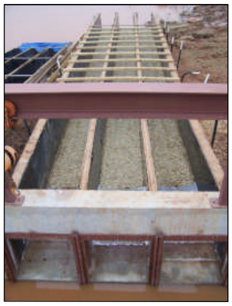
Large-scale Channel Lining Testing

Large-scale Testing of ECPs in Channels

Channels Tested in Triplicate

Long-term Flows are Facilitated by Pumped Recirculation

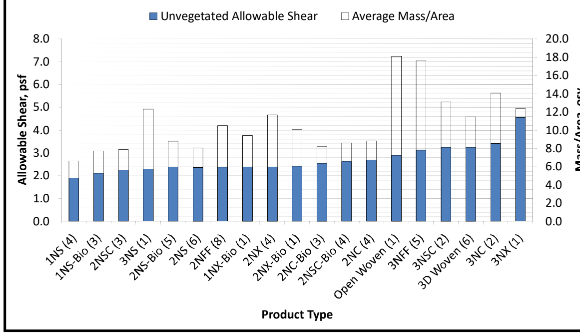
LARGE-SCALE TESTING OF EROSION CONTROL PRODUCTS IN CHANNELS



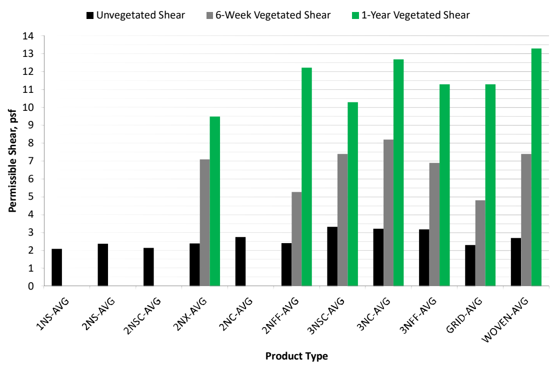
RECPs of All Types are Tested

Vegetated Turf Reinforcement Mats (TRMs) Can Be Tested

"Permissible Shear" RESULTS



"Permissible Shear" RESULTS



Specifying Rolled Erosion Control Products (RECPs)

How to Specify????

- Generic or Proprietary?
- Based on data from standard test methods?
- Can be sampled at the site and subject to conformance testing?
- Independent performance evaluated?

Simplified Generic Specifications For Routine Applications

Specification Criteria:

- **Construction Survivability**
- **In-Service Performance**

FHWA FP-14 / AASHTO M288 / ASTM D????

https://flh.fhwa.dot.gov/resources/specs/

(FP-14 will be described here because it is the most recognized in the US for erosion and sediment control products.)

Existing National Specifications

- Erosion Control Products (RECPs)
  - ECTC Erosion Control Technology Council (www.ectc.org)
  - FP-14 Standard Specifications for Construction of Roads and Bridges on Federal Highway Projects (flh.fhwa.dot.gov/resources/specs)
- Erosion Control Products (Geotextiles)
  - AASHTO M288-17 Geotextile Specification
- Sediment Retention Devices (Silt Fence)
  - AASHTO M288-17 Geotextile Specification
  - ASTM D6461 & D6462 Silt Fence Mat'ls & Installation
- Other SRDs
  - FP-14 Standard Specifications for Construction of Roads and Bridges on Federal Highway Projects (flh.fhwa.dot.gov/resources/specs)

FP-14, Table 713-4: Temp. RECP Spec

Property	Test Method	1.A[1]	1.B	1.C	1.D	2.A[1]	2.B	2.C	2.D	3.A[1]	3.B	4
Typical functional longevity[2] (months)	N/A	3	3	3	3	12	12	12	12	24	24	36
Minimum tensile strength	ASTM D6818	5 lb/ft (0.73 kN/m)	5 lb/ft (0.73 kN/m)	50 lb/ft (0.73 kN/m)	75 lb/ft (0.73 kN/m)	5 lb/ft (0.73 kN/m)	5 lb/ft (0.73 kN/m)	50 lb/ft (0.73 kN/m)	75 lb/ft (1.09 kN/m)	25 lb/ft (0.36 kN/m)	100 lb/ft (1.45 kN/m)	125 lb/ft (1.82 kN/m)
Maximum "C" factor at maximum gradient for slope applications[3]	ASTM D6459 or other qualified independent test[6]	0.10 at 1V:5H	0.10 at 1V:4H	0.15 at 1V:3H	0.20 at 1V:2H	0.10 at 1V:5H	0.10 at 1V:4H	0.15 at 1V:3H	0.20 at 1V:2H	0.10 at 1V:5H	0.25 at 1V:1½H	0.25 at 1V:1H
Minimum shear stress for channel applications[4][5]	ASTM D7207 or other qualified independent test[6]	0.25 lb/ft^2 (12 Pa)	0.50 lb/ft^2 (24 Pa)	1.50 lb/ft^2 (72 Pa)	1.75 lb/ft^2 (84 Pa)	0.25 lb/ft^2 (12 Pa)	0.50 lb/ft^2 (24 Pa)	1.50 lb/ft^2 (72 Pa)	1.75 lb/ft^2 (84 Pa)	0.25 lb/ft^2 (12 Pa)	2.00 lb/ft^2 (96 Pa)	2.25 lb/ft^2 (108 Pa)

Categories of Temporary RECPs :
1.A, 2.A, 3.A = mulch control nets; 1.B, 2.B = netless ECBs; 1.C, 2.C = single net ECBs and Open Weave Textiles; 1.D, 2.D = double net ECBs; 3.B, 4 = ECBs & Open Weave Textiles

FP-14, Table 713-4: TRM Spec

Properties[1]	Test Method	Rolled Erosion Control Product Type		
		5.A	5.B	5.C
Minimum tensile strength[2][3]	ASTM D4595	125 lb/ft (1.82 kN/m)	150 lb/ft (2.19 kN/m)	175 lb/ft (2.55 kN/m)
UV stability (minimum % tensile retention)	ASTM D4355 (500-hour exposure)	80	80	80
Minimum thickness[2]	ASTM D6525	¼ in (6.35 mm)	¼ in (6.35 mm)	¼ in (6.35 mm)
Maximum gradient for slope applications	–	2V:1H	2V:1H	2V:1H
Minimum shear stress for channel applications	ASTM D6460*	6.0 lb/ft^2 (288 Pa)	8.0 lb/ft^2 (384 Pa)	10.0 lb/ft^2 (480 Pa)

*or other qualified large-scale independent test.

FP-14 Other G-ECP

Section 713. — ROADSIDE IMPROVEMENT MATERIAL

FP-14 Standard Specifications for Construction of Roads and Bridges on Federal Highway Projects (flh.fhwa.dot.gov/resources/specs)

How do I install RECPs Properly?

- Slopes
- Channels

Installation of RECPs

Installation Techniques and Considerations

- Subgrade
- Other Layers
- Seeding
- Positioning and Anchorage
- Temperature and Moisture Extremes
- Wind

Installation of RECPs

Subgrade Preparation

- Till / Disc
- Use Standard Horticultural Practices for Soil Amendments

Installation of RECPs

Seeding and Backfilling

- RECPs which are installed prior to seeding must be subsequently seeded and, when directed, backfilled with soil;
- Seeding. For most RECPs, the recommended seed mixture shall be seeded onto the prepared soil surface. Every effort should be taken to obtain a uniform distribution over the seeded area;
- It should be noted that seeding during winter months may have to be repeated when temperatures reise unless the dormant seed is protected from being washed away.

VEGETATION SELECTION INFORMATION

Typical Seeding Schedule (Moderate/Humid Climate)

Temporary or Permanent	Mowed or Not Mowed	Dates of Planting	Seed	Seed Rate (lb/ac)	Lime Rate (lb/ac)	Fert. Rate (lb/ac)	Mulch Rate (lb/ac)
Temporary	Not Mowed	2/1-4/30	Rye Lespedeza	@ 50 @ 25	-	500	500*
Temporary	Not Mowed	5/1-8/15	Sudan Wpg. Love	@ 50 @ 10	-	500	500*
Temporary	Not Mowed	8/16-11/30	Rye	@ 45	-	500	500*
Permanent	Not Mowed	3/15-6/30	Lespedeza Bermuda	@ 50 @ 10	4000	800	500*
Permanent	Not Mowed	8/1 -2/28	Lespedeza Fescue Millet	@ 70 @ 30 @ 20	4000	800	500*
Permanent	Mowed	2/15-4/15; 8/15-10/31	Fescue	@ 50	4000	800	3000**
Permanent	Mowed	4/15-6/30	Bermuda	@ 20	4000	800	3000**

* Hydraulic Seeding; ** Spray with emulsion @ 300 gal/acre

VEGETATION SELECTION INFORMATION

Typical Seeding Schedule (Arid/Semi-Arid Climate)

Temporary or Permanent	Mowed or Not Mowed	Dates of Planting	Seed	Seed Rate (lb/ac)	Lime Rate (lb/ac)	Fert. Rate (lb/ac)	Mulch Rate (lb/ac)
Temporary	Not Mowed	2/1-11/30	Mix of Quick Germinating Grasses (4)	10 - 20	May need to neutralize (2)	0 - 250	2000 (3)
Permanent	Not Mowed or Mowed	2/15-10/31	Mix of Cool & Warm Season Grasses (1)	20 - 40	May need to neutralize (2)	250+	2000 to 4000 (3)

(1) Seed selection is very site-specific. Target 30-40 seeds/ft^2. Special attention to use of native grasses and targeted use of aggressive non-native grasses.
(2) Some arid soils may be very alkaline and require additives to reduce pH levels.
(3) Mulches include straw @ 2 Tons/acre, Hay @ 1.5 Tons/acre, Hydraulic mulching @ 1Tons/acre with 100 lb/acre tack.
(4) Ryes and crested wheatgrass.

Installation of RECPs

Seeding and Backfilling (continued)

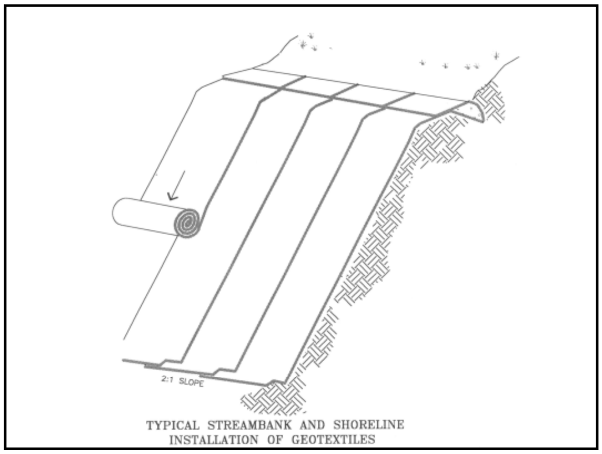
- *Backfilling of TRMs*. A thin layer of fine soil should be spread on top of the TRM and lightly raked/brushed into the mat apertures to completely fill the mat thickness.
- *Erosion of Backfill*. To prevent erosion of a filled RECP when frequent and/or heavy precipitation is expected during the germination and early vegetation growth periods, a traditional mulch or, preferably, an ECB can be deployed above the RECPs.
- *Maintenance of Seeded Areas*. Proper care of seeded areas is especially important during the period of vegetation establishment. Temporary irrigation may be necessary.

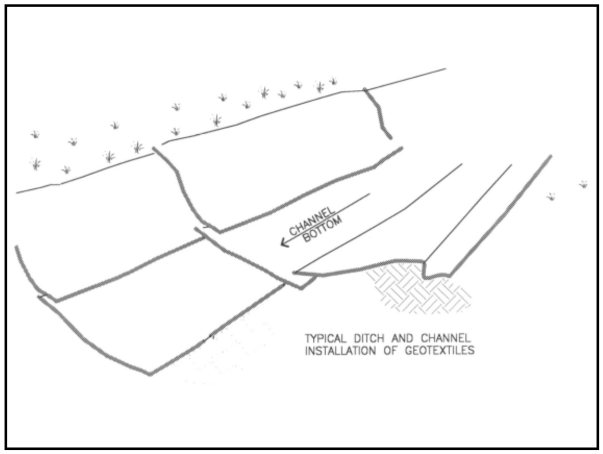
Installation of RECPs

Field Joining and Anchoring

Joining

- Overlapping or "shingling" in the direction of flow;
- Overlaps must be sufficient to accommodate a row of anchors.





Installation of RECPs – Critical Details

Field Joining and Anchoring

Proper anchoring includes:

- Terminal trenches (typically 6 in. wide x 12 in. deep) are made at the top and bottom (crest and toe) of all covered slopes and at the ends of all lined channels;
- Intermediate trenches, or "check slots", (typically 6 in. wide x 6 in. deep) or two closely spaced rows of anchors may be used transverse to flows at intermittent points down a slope or along a channel to prevent continuous flows beneath the RECP;
- Uniform anchoring is accomplished by "patterned" staking, pinning, or stapling of positioned RECPs. The pattern depends on the steepness of the slope or channel.
- Extra wide rolls are often used for installation efficiency and should be anchored in the same manner as individual rolls.

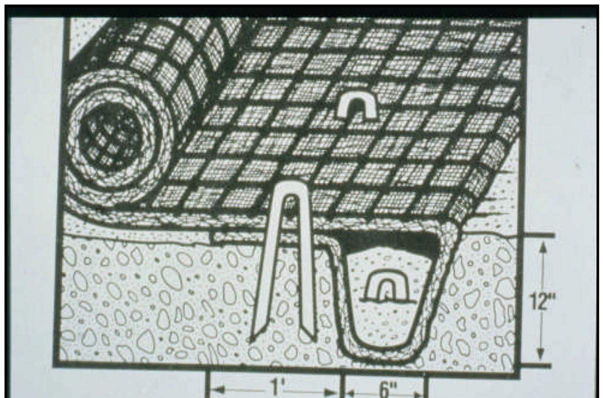


Figure 2: Initial Channel Anchor Trench

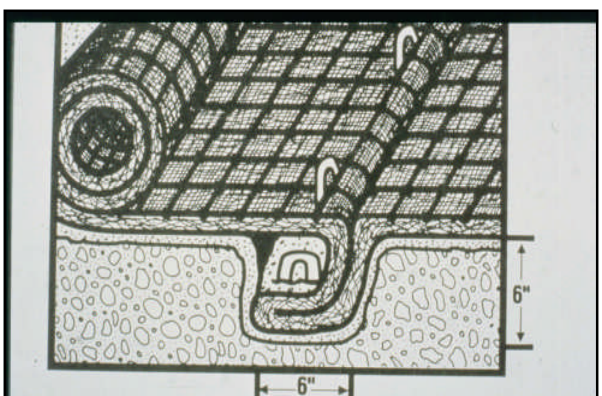


Figure 3: Intermittent Check Slot

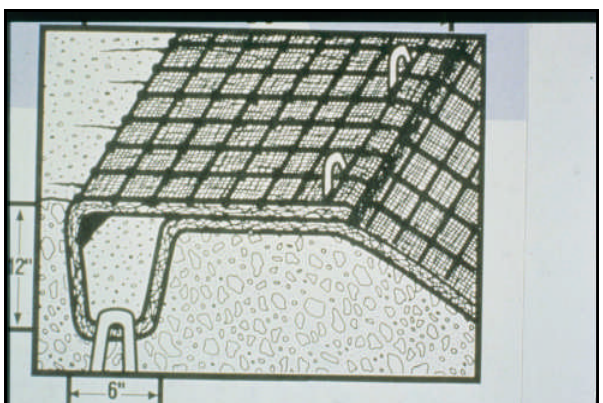


Figure 5: Terminal Slope and Channel Anchor Trench

Installation of RECPs – Critical Details

Field Joining and Anchoring (continued)

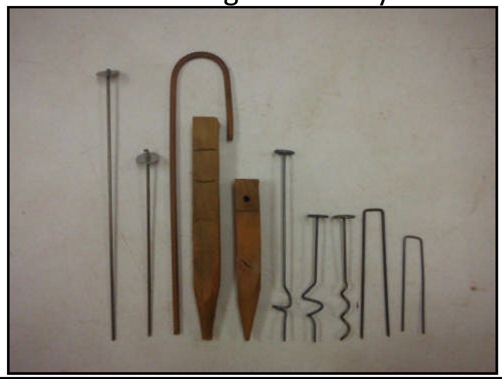
Penetrations

Provide additional anchorage because penetrations and structure interferences are notoriously prone to concentration of erosive forces.

Repairs

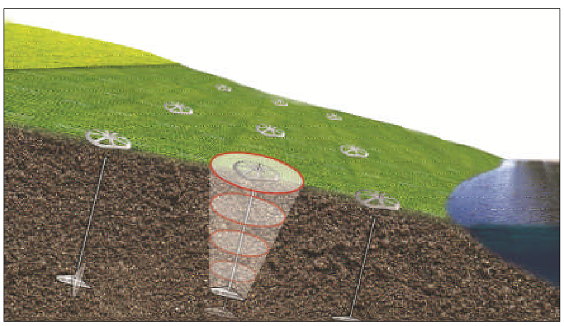
If a repair is required because the RECP has been accidentally damaged, a patch of the same base RECP type should be cut to fit over and sufficiently beyond the damaged area to permit joining to or anchoring through the parent RECP..

RECPs ON SLOPES AND IN CHANNELS
Anchorage is the Key

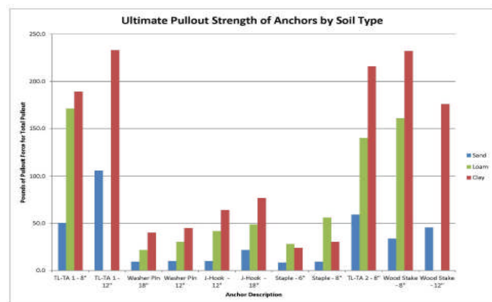


RECPs ON SLOPES AND IN CHANNELS
Anchorage is the Key

Percussion Driven Mechanical Anchors (PDMA)



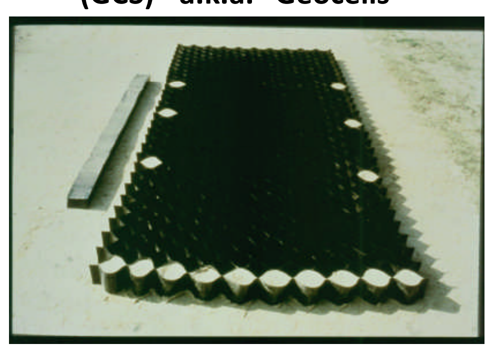
RECPs ON SLOPES AND IN CHANNELS
Anchorage is the Key



More Geosynthetics in Erosion Control Applications

- Long-term, nondegradable materials to extend the erosion control limits of vegetation or soil;
- Primary slope or channel linings;

GEOCELLULAR CONFINEMENT SYSTEMS (GCS) - a.k.a. "Geocells"



Geocells in Erosion Control

- Geocells are honeycomb products manufactured by joining polymeric strips or geotextile strips by welding, gluing or stitching.
- Geocells provide lateral confinment to the soil in-filled into the cells.
- The geocells by themselves cannot prevent soil erosion, since the soil surface is exposed to rain splash and runoff.
- Geocells can be used to establish a stable soil veneer of 100 - 300 mm on a steep slope.
- Then the top surface shall be protected against erosion by an ECP.
- Geocells can be used on arid slopes, when a thick topsoil layer is required for allowing vegetation growth.

Geocell – Infill Material

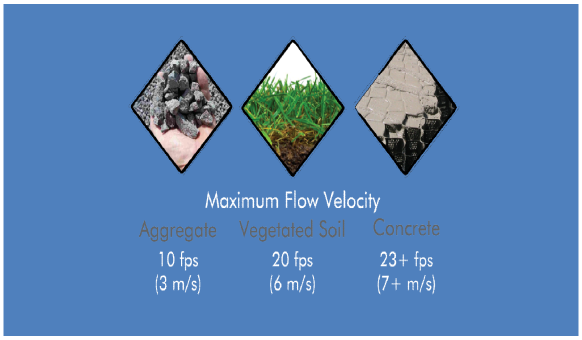
- Topsoil and Vegetation: Steep slopes, berms, levees, chutes, aprons and spillways.
- Structural/Growth Fill: Vegetated slopes that experience traffic loads
- Sand and Granular Fill: Suitable on gradual slopes.
- Aggregate: Channels, slopes, except for severe grades, moderate sheet flow.
- Concrete: Around bridges, severe slopes, high flow rate channels, spillways and chutes

Courtesy of Geo Products

Geocells for Channel Protection

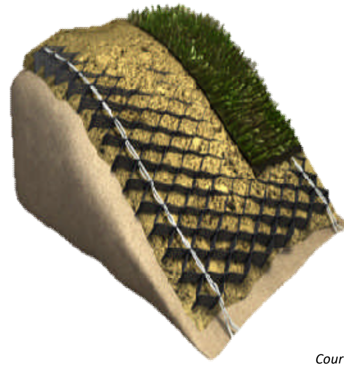
Courtesy of Geo Products

Geocell – Infill Recommendations For Channel Erosion Control



Courtesy of Geo Products

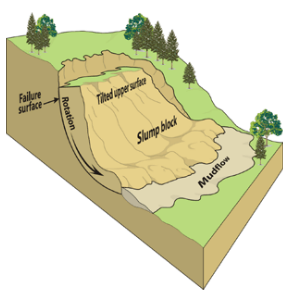
Slope Erosion Control



Courtesy of Geo Products

Geocells - Slopes

- Geocells protect the slope face against erosion or provide desired soil on face
- Slopes up to 70 degrees
- Proper anchoring is the key
  based on onsite parameters

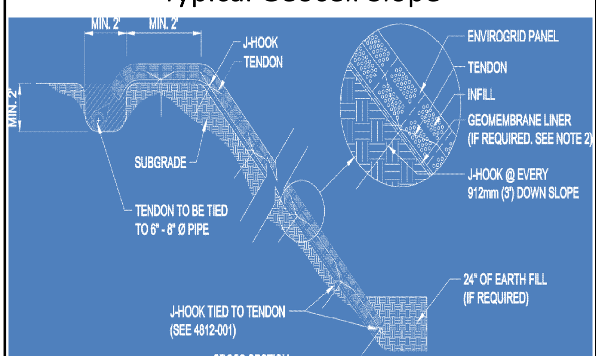


Courtesy of Geo Products

Courtesy of Geo Products

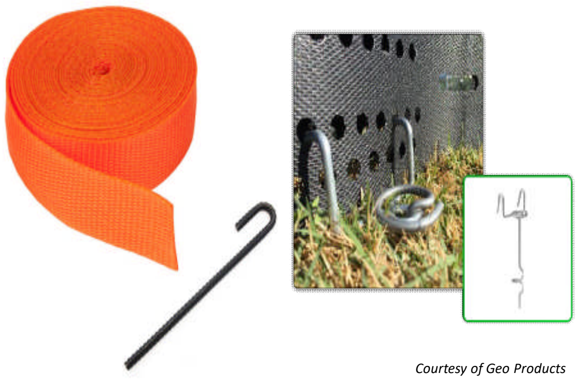
Courtesy of Geo

Typical Geocell Slope



Courtesy of Geo Products

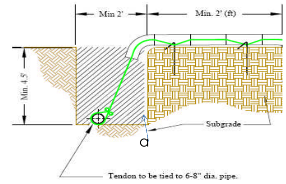
Tendons or Securing Device



Courtesy of Geo Products

Anchor Trench Design

- This method takes advantage of the weight of the soil on top of the buried cells.
  - Earth anchors
  - Dead man
  - Concrete trench



Courtesy of Geo Products

Unique Geocell Applications

Courtesy of Geo Products

Complements of Geo Products

Yanacocha Mine, Peru

Courtesy of Geo Products

Cellular Confinement Systems Spec.

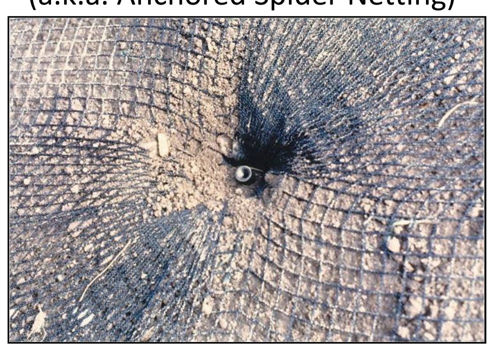
713.07 Cellular Confinement Systems. Furnish a flexible honeycomb three-dimensional structure fabricated from light stabilized polyethylene plastic. Conform to the following:

(a) Functional longevity - 120 months min.
(b) Cell area - 31.0 to 46.5 in^2 (200 to 300 cm^2)
(c) Sheet thickness, ASTM D751 - 48.8 to 49.6 mils (1.24 to 1.26 mm)
(d) Density, ASTM D792 - 0.549 to 0.555 oz/in^3 (0.941 to 0.960 g/cm^3)
(e) Carbon black content, ASTM D1603 1.5 to 2.5 percent
(f) Environmental stress-cracking, ASTM D1693 - 2000 hours min.
(g) Conform to Table 713-2 for the depth specified.

Table 713-2: Cellular Confinement Systems

Property	Requirements				
Nominal cell depth	2 in (50 mm)	3 in (75 mm)	4 in (100 mm)	6 in (150 mm)	8 in (200 mm)
Cell joint strength	110 lb min. (500 N min.)	160 lb min. (700 N min.)	225 lb min. (1000 N min.)	315 lb min. (1400 N min.)	450 lb min. (2000 N min.)

ANCHORED GEOTEXTILES
(a.k.a. Anchored Spider Netting)



ANCHORED GEOTEXTILES
(a.k.a. Anchored Spider Netting)

Anchored spider netting is a soil slope stabilization technique aimed at landslide problem areas.

It is an in situ technique in which a geosynthetic material (generally a geotextile) is placed on the un-stable or questionable slope and anchored to it with long steel rod nails.

These nails must be long enough to penetrate the actual or potential failure surface.

Upon being suitably deployed, anchored spider netting offers a number of advantages in arresting slope failures:

- the steel rods, in penetrating the failure surface, increase stability;
- the stress caused by the netting at the ground surface increases stability;
- the surface netting stress-mobilizes normal stress at the base of the failure surface, which increases stabil-ity; and
- the entire system causes soil densification, which increases the soil's shear strength parameters, increasing stability.

(Courtesy of Koerner, R.M., Designing with Geosynthetics)

ANCHORED GEOTEXTILES
(a.k.a. Anchored Spider Netting)

. . . Continued

Depending on the site conditions, the slope can be seeded either before or after the placement of the geotextile netting, although seeding before is generally pre-ferred. Growth of vegetation through the netting is considered to be an advan-tage in the long-term stabilization of the slope.

For long-term slope stabilization, particularly with high water-content cohesive soils (silts, clays, and their respective mixtures) it is necessary to return to the slope periodically to redrive the anchors. This is required because of the long-term consolidation characteristics of high water-content fine-grained soils, as de-scribed previously. This aspect of the system must be carefully tuned to the local conditions but will result in a greatly stabilized site.

(Courtesy of Koerner, R.M., Designing with Geosynthetics)

Real Spider Netting

Netting on Slope

Positioning Rods

Driving Rods

Rods Fully Deployed

GEOSYNTHETIC CEMENTITIOUS COMPOSITE MAT
GCCM

What is a GCCM?

GCCM is a geocomposite

- It combines the flexibility of geotextile fabrics with the durability of hardened concrete!

GCCM can be used:

- Where a hardened protective surface is required
- Where conventional concrete is difficult or impossible to install.
- As permanent hard armor alternative

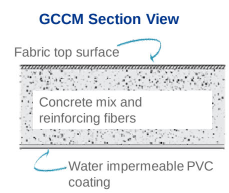
Courtesy of GeoTree

What is a GCCM?

A flexible cement-impregnated fabric that hardens when hydrated to form a thin, durable concrete layer.

GCCM consists of:

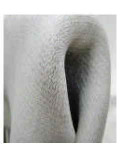
- Dry concrete mix
- Reinforcing fiber matrix
- Permeable top surface
- Impermeable bottom coating



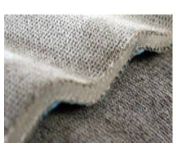
Courtesy of GeoTree

What is a GCCM?

ASTM D8058 defines GCCMs as *'a factory-assembled geosynthetic composite consisting of a cementitious layer contained within a layer or layers of geosynthetic materials that becomes hardened when hydrated'.*



Permeable Fabric Top Surface



3-Dimensional Substrate

PVC Bottom Surface

Courtesy of GeoTree

Typical GCCM varieties

Portable Batched Rolls

Bulk Roll

Courtesy of GeoTree

Typical Applications

Channel Lining

Slope Protection

Culvert Lining

Concrete Remediation

Advantages of GCCM

- ***Quick:*** Unroll, place and hydrate
- ***Simple:*** Cannot be over-hydrated
- ***Versatile:*** One material, many uses
- ***Durable:*** Wear-resistant concrete
- ***Robust:*** Fiber matrix reinforcement
- ***Portable:*** Easily transported and deployed without specialized equipment

Courtesy of GeoTree

GCCMs not a fix-all…but they are a tool…

If your location is:
- Remote, or
- Difficult to access with standard concrete equipment.

If you have limited time:
- Simple, installs quickly, and
- You don't have to go back to the site to remove forms.

If you have limited labor or equipment:
- A small crew can do the job, and
- You don't need specialized equipment.

If you cannot stop the water flow:
- It even cures under water.

Courtesy of GeoTree

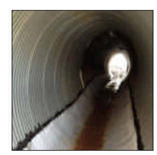
GCCMs are unique tools for your culvert toolbox…

If the culvert invert is in need of repair:
- The product provides a new wear surface for the invert, and
- Buys you a few years of additional life, letting you better prioritize your annual spend.

If your location is under a busy roadway:
- Limited footprint is required for installation, and
- The installation can be done without closing the road.

If you have limited funds for contractors:
- You can use your own labor.

If you cannot stop the water flow:
- It can be installed in running water.



Courtesy of GeoTree

GCCM Case Study: Kayenta Township, AZ

Project Details

Customer: Kayenta Township & Navajo County

Issue: The grades in the new drainage channel were as steep as 20% making their standard soil cement solution impractical. A GCCM was specified as an alternative.

Installation dimensions: 12,000 ft^2 of CC8

Installation Time: 2 Days

Courtesy of GeoTree

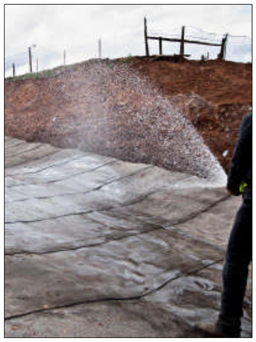
GCCM Case Study: Kayenta Township, AZ

A deep anchor trench was dug the full length of the channel and ground was properly graded for installation. Using a spreader bar chained to the backhoe bucket, bulk rolls of the GCCM were draped over the channel and secured.

Courtesy of GeoTree

GCCM Case Study: Kayenta Township, AZ

Anchor trench and hydration.



Courtesy of GeoTree

GCCM Case Study: Kayenta Township, AZ

Installation in progress.

Courtesy of GeoTree

GCCM Case Study: Kayenta Township, AZ

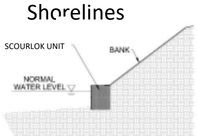
The completed project in operation – anchor trenches completed & compacted.

Courtesy of GeoTree

INNOVATIVE USE OF MULTIPLE GEOSYNTHETIC TECHNOLOGIES FOR BANK STABILIZATION

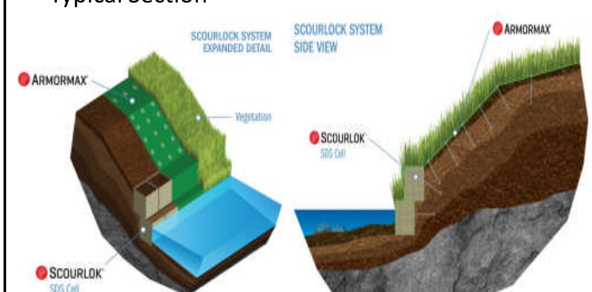
SCOURLOK™ Engineered Bank Stabilization System for vegetated and unvegetated erosion protection of:

- Banks
  - ✓Streams
  - ✓Lakes
  - ✓Ponds
- Shorelines



Courtesy of Propex Global

Engineered Bank Stabilization System
Typical Section



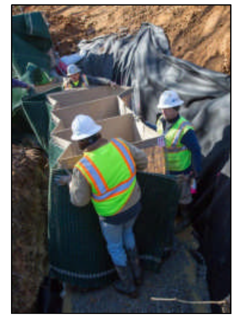
Courtesy of Propex Global

Engineered Bank Stabilization System
System Components

- Metal frame basket
  - ✓ Material - Galvanized/S.S.
  - ✓ 3-ft W x 3-ft D x 4-ft H
- Pre-assembled units
  - ✓ Internally lined w/ durable geotextile
  - ✓ Externally lined with PYRAMAT
- Each unit = 5 baskets = 15-ft long
- Outside pocket filled with mulch or other growth media for vegetation

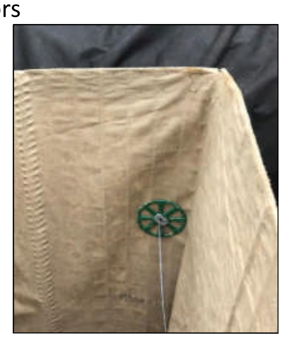
Courtesy of Propex Global

Engineered Bank Stabilization System
Simplified Installation



Courtesy of Propex Global

Engineered Bank Stabilization System
Engineered Earth Anchors



Courtesy of Propex Global

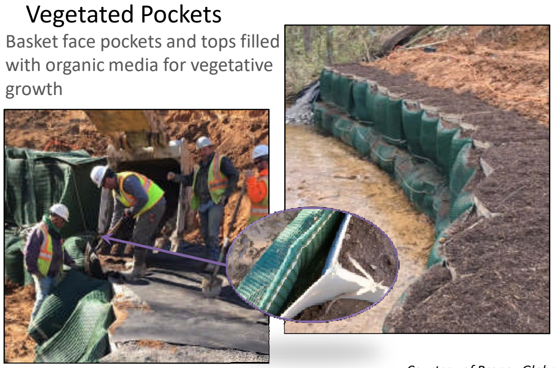
Engineered Bank Stabilization System
Fill Materials

- In-Situ Soils
  - up to 15% organic
- Gravel and rock
  - up to 3-inches
- Dredge (coastal)

Courtesy of Propex Global

Engineered Bank Stabilization System
Vegetated Pockets

Basket face pockets and tops filled with organic media for vegetative growth



Courtesy of Propex Global

<u>Case Study</u>: **Engineered Bank Stabilization System**
Flagler Estates Road and Water Control District

Application: Slope-Channel Stabilization

Owner: Flagler Estates Road and Water Control District (FERWCD)

Location: Hastings, FL

Designer: In-House/Propex

Installed: 2018

Product: SCOURLOK & ARMORMAX®

Scenario: Roadway Slope Failure / Channel Stabilization Limited ROW

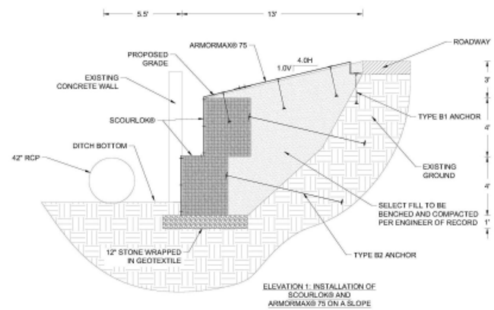
Courtesy of Propex Global

Case Study: **Engineered Bank Stabilization System**
Flagler Estates Road and Water Control District

Existing Conditions – Eroded Roadway Shoulder & Canal Banks

Courtesy of Propex Global

Case Study: **Engineered Bank Stabilization System**
Flagler Estates Road and Water Control District



Schematic of Design

Courtesy of Propex Global

Case Study: **Engineered Bank Stabilization System**
Flagler Estates Road and Water Control District

Foundation Excavation & Preparation

Courtesy of Propex Global

Case Study: **Engineered Bank Stabilization System**
Flagler Estates Road and Water Control District

Placement of SCOURLOK - First Tier

Courtesy of Propex Global

Case Study: **Engineered Bank Stabilization System**
Flagler Estates Road and Water Control District

Cell Fill with In-Situ Soils

Unit Backfill and Engineered Earth Anchors

Courtesy of Propex Global

Case Study: **Engineered Bank Stabilization System**
Flagler Estates Road and Water Control District

Cell Fill, Unit Backfill and Engineered Earth Anchors

Courtesy of Propex Global

Case Study: **Engineered Bank Stabilization System**
Flagler Estates Road and Water Control District

Aerial View – SCOURLOK First Tier Installation

Courtesy of Propex Global

Case Study: **Engineered Bank Stabilization System**
Flagler Estates Road and Water Control District

Filling of Vegetative Pockets with Soil to Support Wall Face Vegetation

Courtesy of Propex Global

Case Study: **Engineered Bank Stabilization System**
Flagler Estates Road and Water Control District

SCOURLOK Second Tier Installation & Backfill

Courtesy of Propex Global

Case Study: **Engineered Bank Stabilization System**
Flagler Estates Road and Water Control District

Reconstructing Roadway Shoulder Above SCOURLOK

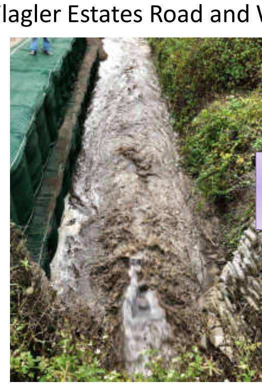
Courtesy of Propex Global

Case Study: **Engineered Bank Stabilization System**
Flagler Estates Road and Water Control District

SCOURLOK & Roadway Shoulder Completion.
Water Flow Restored to Canal.

Courtesy of Propex Global

Case Study: **Engineered Bank Stabilization System**
Flagler Estates Road and Water Control District



Water Flow Restored to the Canal

Courtesy of Propex Global

Case Study: **Engineered Bank Stabilization System**
Flagler Estates Road and Water Control District

Stabilized Roadway Shoulder with ARMORMAX.

Courtesy of Propex Global

Case Study: **Engineered Bank Stabilization System**
Flagler Estates Road and Water Control District

Topsoil, Seed & Erosion Control Blanket Placed on Top of ARMORMAX for Roadway Shoulder Vegetation Stabilization

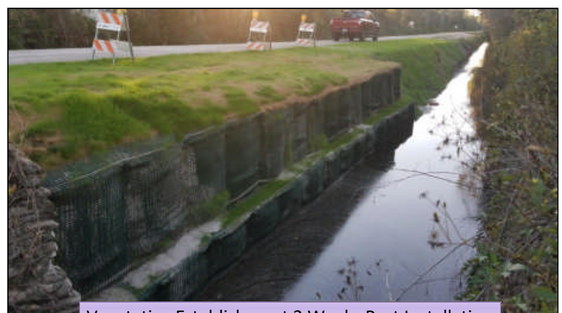
Courtesy of Propex Global

Case Study: **Engineered Bank Stabilization System**
Flagler Estates Road and Water Control District

Completed SCOURLOK & ARMORMAX Installation

Courtesy of Propex Global

Case Study: **Engineered Bank Stabilization System**
Flagler Estates Road and Water Control District



Vegetative Establishment 2 Weeks Post Installation

Courtesy of Propex Global

Case Study: **Engineered Bank Stabilization System**
Flagler Estates Road and Water Control District

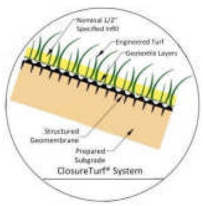
2 Weeks Post Installation

Courtesy of Propex Global

GEOSYNTHETIC
ENGINEERED TURF SYSTEMS
FOR
SLOPES AND CHANNELS

ClosureTurf® System Components

- ClosureTurf is a three-component system comprised of a structured geomembrane, an engineered turf, and a specified infill.




Structured Geomembrane


Engineered Turf


Infill (Sand or HydroBinder)

An Engineered Turf Final Cover is NOT an Exposed Geomembrane Cover, because the geomembrane is covered and protected by the engineered turf and infill.

Courtesy of Watershed Geo

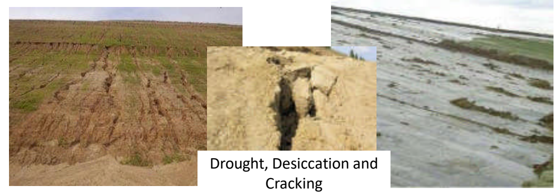
Why Engineered Turf as a Final Cover System?

Challenges with traditional soil covers:

- Soil erosion and sedimentation – soil quality, vegetation, and weather
- Final cover veneer stability – interface friction, drainage, and gas uplift
- Availability of soil
- Post-closure maintenance

Poor Vegetation and Soil Erosion

Veneer Slope Failure – Soil Cover

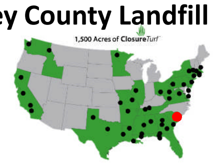


Drought, Desiccation and Cracking

Courtesy of Watershed Geo

Case Study - Berkeley County Landfill

Site: Berkeley County Landfill
Owner: Berkeley County
Location: Moncks Corner, SC
Completed: 2013
ClosureTurf Area: 12 acres



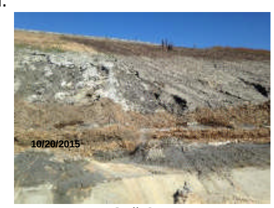

South Carolina's Catastrophic Floods Caused By One of the Most Prolific Rainfall Events in Modern U.S. History

Courtesy of Watershed Geo

Case Study - Berkeley County Landfill

- ClosureTurf survived around 26 inches of rain over a four-day period from October 1st to 5th, 2015 (1-in-1000 event).
- No maintenance was required post event: small amount of sand migration to the bottom of the slope. Because there was enough coverage of sand, the sand did not have to be redistributed or replaced.

ClosureTurf



Soil Cover

Courtesy of Watershed Geo

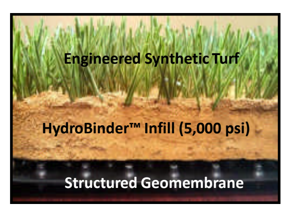
Case Study - Berkeley County Landfill

Perimeter Channels of ClosureTurf Versus Soil Cover
(Photos taken on Nov. 2018)

Courtesy of Watershed Geo

What is HydroTurf® Engineered Turf

- Innovative Revetment Technology
- Unique, Flexible Fiber-Reinforced Concrete Liner
- Protects Hydraulic Structures from Erosion
- Aesthetically Pleasing
- Appropriate Applications
  - Dam Spillways / Overtopping Protection
  - Embankment and Levee Protection
  - Channels
  - Basins / Impoundments
  - Shoreline Protection
  - Outfall Structures



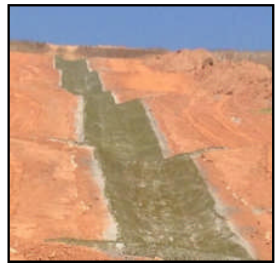
Courtesy of Watershed Geo

Benefits of HydroTurf ® Engineered Turf

- Exceptional Hydraulic Performance (>40 ft/s Velocity)
- Less Costly than Traditional Hard Armor
- Minimal Long-Term Maintenance
- 50+ year Functional Longevity
- Aesthetic Benefits of Vegetation without the Maintenance of Vegetation
- Rapid, Low Impact, and Scalable Installation

Courtesy of Watershed Geo

Engineered Turf in Landfill Downchutes

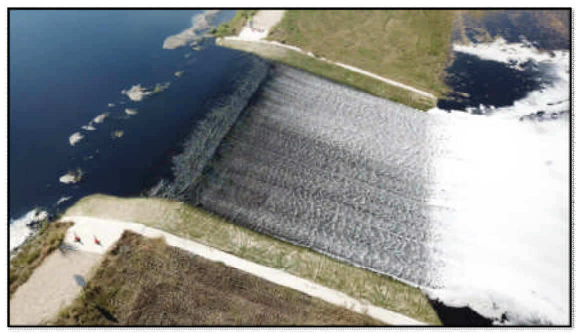


Courtesy of Watershed Geo

Village Creek WRF Overflow Spillway - TX

Courtesy of Watershed Geo

Village Creek WRF Overflow Spillway - TX



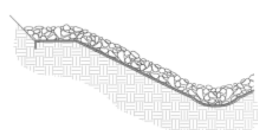
Courtesy of Watershed Geo

Geosynthetic-enhanced Riprap Armor Systems

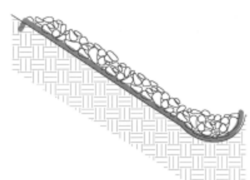
Riprap (angular rock) systems are commonly used to resist the erosive forces of concentrated flowing water at the end of culverts, at the toe of riverbanks, or even to line steep channels.

Used in this way, water can seep in and out of the supporting soil. 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 and *requires an appropriate filter*.

Geosynthetic-enhanced Riprap Armor Systems

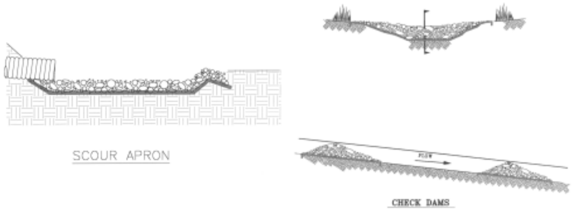


ARMOURED CHANNEL



ARMOURED SLOPE

Geosynthetic-enhanced Riprap Armor Systems



Traditional Filter Layers and Their Limitations

- A properly constructed armor system includes a filter layer 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 Geotextile Filter Solution

- Geotextiles 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 must include a Geotextile Filter

How to Specify????

- Generic or Proprietary?
- Based on data from standard test methods?
- Can be sampled at the site and subject to conformance testing?
- Independent performance evaluated?

Simplified Generic Specifications For Routine Applications

Specification Criteria:

- **Construction Survivability**
- **In-Service Performance**

FHWA FP-14 / AASHTO M288 / ASTM D????

https://flh.fhwa.dot.gov/resources/specs/

(M288 will be described here because it is the most recognized in the US for geosynthetics.)

Existing National Specifications

- Erosion Control Products (RECPs)
  - ECTC Erosion Control Technology Council (www.ectc.org)
  - FP-14 Standard Specifications for Construction of Roads and Bridges on Federal Highway Projects (flh.fhwa.dot.gov/resources/specs)
- Erosion Control Products (Geotextiles)
  - AASHTO M288-17 Geotextile Specification
  - FP-14 Standard Specifications for Construction of Roads and Bridges on Federal Highway Projects (flh.fhwa.dot.gov/resources/specs)
- Sediment Retention Devices (Silt Fence)
  - AASHTO M288-17 Geotextile Specification
  - ASTM D6461 & D6462 Silt Fence Mat'ls & Installation
- Other SRDs
  - FP-14 Standard Specifications for Construction of Roads and Bridges on Federal Highway Projects (flh.fhwa.dot.gov/resources/specs)

M288 Permanent Erosion Control Spec

			Geotextile Class[a,b]			
			Class 1		Class 2	
Property	ASTM Test Methods	Units	Elongation <50%[c]	Elongation ≥50%[c]	Elongation <50%[c]	Elongation ≥50%[c]
Grab strength	D4632	N	1400	900	1100	700
Sewn seam strength[d]	D4632	N	1260	810	990	630
Tear strength	D4533	N	500	350	400[e]	250
Puncture strength	D6241	N	2750	1925	2200	1375
Permittivity	ASTM D4491	sec^{-1}	Minimum property values for permittivity, AOS, and UV stability are based on geotextile application. Refer to Table 2 for subsurface drainage, Table 3 and Table 4 for separation, Table 5 for soil stabilization, and Table 6 for permanent erosion control.			
Apparent opening size	ASTM D4751	mm				
Ultraviolet stability (retained strength)	ASTM D4355	%				

[a]Required geotextile class is designated in Table 2, 3, 4, 5, or 6 for the indicated application. The severity of installation conditions for the application generally dictates the required geotextile class. Class 1 are specified for more severe or harsh installation conditions where there is a greater potential for geotextile damage, and Classes 2 and 3 are specified for less severe conditions.
[b]All numeric values represent MARV in the weaker principal direction. (See Section 8.1.2.)
[c]As measured in accordance with ASTM D4632/D4632M.
[d]When sewn seams are required. Refer to Appendix X1 for overlap seam requirements.
[ef]The required MARV tear strength for woven monofilament geotextiles is 250 N.

M288 Permanent Erosion Control Spec

All numeric values except AOS represent MARV in the weaker principal direction.

	Test Methods	Units	Requirements, Percent *In Situ* Soil Passing 0.075 mm[a]		
			<15	15 to 50	>50
Woven monofilament geotextiles All other geotextiles			Class 2 from Table 1[b] Class 1 from Table 1[b,c]		
Permittivity[a,d]	ASTM D4491	sec^{-1}	0.7	0.2	0.1
Apparent opening size[c,d]	ASTM D4751	mm	0.43 max avg roll value	0.25 max avg roll value	0.22[e] max avg roll value
Ultraviolet stability (retained strength)	ASTM D4355	%	50% after 500 hrs of exposure		

a. Based on grain size analysis of *in situ* soil in accordance with AASHTO T 88.
b. As a general guideline, the default geotextile selection is appropriate for conditions of equal or less severity than either of the following:
  1. Armor layer stone weights do not exceed 100 kg, stone drop height is less than 1 m, and no aggregate bedding layer is required.
  2. Armor layer stone weighs more than 100 kg, stone drop height is less than 1 m, and the geotextile is protected by a 150-mm thick aggregate bedding layer designed to be compatible with the armor layer. More severe applications require an assessment of geotextile survivability based on a field trial section and may require a geotextile with strength properties.
c. The engineer may specify a Class 2 geotextile from Table 1 based on one or more of the following:
  1. The engineer has found Class 2 geotextiles to have sufficient survivability based on field experience.
  2. The engineer has found Class 2 geotextiles to have sufficient survivability based on laboratory testing and visual inspection of a geotextile sample removed from a field test section constructed under anticipated field conditions.
  3. Armor layer stone weighs less than 100 kg, stone drop height is less than 1 m, and the geotextile is protected by a 150-mm thick aggregate bedding layer designed to be compatible with the armor layer.
  4. Armor layer stone weights do not exceed 100 kg, and stone is placed with a zero drop height.
d. These default filtration property values are based on the predominant particle sizes of *in situ* soil. In addition to the default permittivity value, the engineer may require geotextile permeability and/or performance testing based on engineering design for drainage systems in problematic soil environments.
e. See the following:
  1. Site specific geotextile design should be performed especially if one or more of the following problematic soil environments are encountered: unstable or highly erodible soils such as non-cohesive silts; gap graded soils; alternating sand/silt laminated soils; and /or rock flour.
  2. For cohesive soils with a plasticity index greater than seven, geotextile maximum average roll value for apparent opening size is 0.30 mm.

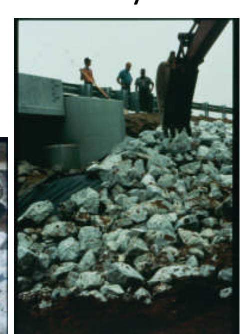
Placement Of The Armor Layer

Excessive Drop Height / Damage

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.

Placement Of The Armor Layer

Filter geotextiles must be designed for sufficient clogging resistance, permeability, and construction surviveability



Site Prep and Geotextile Deployment

- The slope or channel should be graded smoothly and compacted, if possible.
- 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 alignment 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.

- Questions?