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THE EVOLUTION OF GEOSYNTHETICS IN EROSION AND SEDIMENT CONTROL

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ABSTRACT

Much of the development of geosynthetics technology in environmental applications has been in response to government regulations. This is certainly true for geosynthetics used in erosion and sediment control. Geosynthetics continue to replace traditional materials such as soil and stone in performing important engineering functions in erosion and sediment control applications while simultaneously introducing greater versatility and cost-effectiveness. Geosynthetics are widely used as a "carrier" for degradable materials to the enhancement of vegetative establishment; as nondegradable materials to extend the erosion control limits of vegetation or soil; as primary slope or channel linings; as components in silt fences and turbidity curtains; and as a component in an ever growing array of sediment retention devices.

Along with the introduction of geosynthetics into this wide range of applications has come the need for industry-wide initiatives to promote their correct use and new test methods to characterize them. All of which, are a "work in progress".

THE NEED FOR EROSION AND SEDIMENT CONTROLS

Much of the development of geosynthetics technology related to erosion and sediment control applications has been in response to government regulations. A progression of regulatory actions has brought a national focus on erosion and sediment control, including:

- Amendments to the Federal Water Pollution Control Act (1985) - eliminating discharge of any pollutant to navigable waters.
- The Clean Water Act (1987) - requiring National Pollution Discharge Elimination System (NPDES) Permits for large construction sites. More recently, NPDES regulation of construction activities on 1 or more disturbed acres of land became effective on February 16, 2012 . . . <u>though numeric turbidity limits have been stayed</u>!
- Intermodal Surface Transportation Efficiency Act (1991) - requiring erosion control guidelines for all federal-aid construction projects. This lead to AASHTO's "Erosion and Sediment Control in Highway Construction," in Volume III, Highway Drainage Guidelines (1992). This has subsequently been made a regulatory document.
- Coastal Zone Act Reauthorization Amendments (1990) - requiring measures to control non-point sources of pollution in coastal areas.

The centerpiece of regulatory action has been the NPDES permitting process, which is required for construction activities. Coverage under a state's general NPDES permit requires the submittal of 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.

Why Geosynthetics?

Geosynthetics have proven to be among the most versatile and cost-effective ground improvement materials. Their use provides the following advantages over traditional materials:

- *Lighter, Easier to Handle, More Durable* - Geosynthetics are comprised of plastic.
- *Verifiable Material Quality Control* - Geosynthetics are manufactured in controlled environments under standard operating conditions.
- *Easier Construction Quality Control* - Often the installation procedure for geosynthetics is as simple as rolling out and securing in place as opposed to concrete or rock being constructed in place and subject to variations caused by weather, handling and placement.
- *Real Cost Savings* - Geosynthetics are typically less costly to purchase, transport and install than are aggregates or subcontractor-dependent systems.
- *Technical Superiority* - Geosynthetics are engineered materials optimized for performance.
- *Easier Construction* - 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 Availability* - Numerous geosythetic suppliers and ease of shipping insure competitive pricing and availability of materials.

What do Geosynthetics do in Erosion and Sediment Control Applications?

Geosynthetics replace traditional materials such as soil and stone in performing important engineering functions, and thus can be selected via a “design-by-function" methodology as prescribed by Koerner (2012). While traditional applications of geosynthetics perform more common in-ground functions such as separation and filtration, geosynthetics used in erosion and sediment controls are used on the soil surface. As such, they introduce the following unique functions according to ASTM D5819:

- *Containment* - A geosynthetic provides containment when it encapsulates or surrounds materials such as sand, rocks, and fresh concrete.
- *Dynamic Filtration* . . . A geosynthetic performs the dynamic filtration function when the equilibrium geotextile-to-soil system allows for adequate liquid flow with limited soil loss across the plane of the geotextile over a service lifetime compatible with dynamic flows.
- *Screening* . . . A geosynthetic, placed across the path of a flowing fluid (ground water, surface water, wind) carrying particles in suspension, provides screening when it retains some or all soil fine particles while allowing the fluid to pass through. After some period of time, particles accumulate against the screen, which requires that the screen be able to withstand pressures generated by the accumulated particles and the increasing pressure from accumulated fluid.
- *Surface Stabilization* . . . A geosynthetic, placed on a soil surface, provides surface stabilization when it restricts movement and prevents dispersion of surface soil particles subjected to erosion actions (rain, wind), often while allowing or promoting vegetative growth.
- *Vegetative Reinforcement* . . . A geosynthetic provides vegetative reinforcement when it extends the erosion control limits and performance of vegetation.

EROSION AND SEDIMENT CONTROL MATERIALS

Geosynthetics, as well as natural materials, are used extensively in erosion and sediment control systems such as:

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

A large construction site may have several different erosion and sediment control materials depending on location (i.e., slopes vs. channels), flow conditions (i.e., sheet vs. concentrated), and regulatory requirements.

Erosion Control Systems

There are two categories of erosion control systems: The first is termed temporary or degradable and the second is termed long-term or nondegradable. There are numerous types of materials within these categories according to Zoghi, et al, (2000). Temporary degradable systems include conventional loose mulches, as well as, hydraulic mulch geofibers (HMG), erosion control netting (ECN), open weave meshes (ECM), erosion control blankets (ECB), and fiber roving systems (FRS). The long-term systems include conventional sod and riprap, as well as, turf reinforcement mats (TRM), fabric formed revetments (FFR), geocellular confinement systems (GCS), gabions (G), and articulating concrete blocks (ACB). ECNs, ECMs, ECBs, and TRMs commonly contain geosynthetic components and are classified as rolled erosion control products, or RECPs. Other geosynthetic systems include FFRs and GCSs.

The advantages and disadvantages of the various systems are detailed in Tables 1 and 2. The relative performance of permanent systems is presented in Table 3, and the relative installed costs of the various erosion control systems is presented in Table 4. Following are brief descriptions of each system.

Hydraulic Mulch Geofibers (HGM) – Hydraulic mulch is commonly used as an alternative to loose straw mulch. It consists of short organic fibers, such as paper, straw, wood, coconut, or cotton, mixed with water in a tank (usually with seed) and sprayed over the bare soil. As it dries it forms a thin mulch layer, yet it is still susceptible to the wash and wind-blown problems associated with loose fiber mulches. A more stable matrix can be created by incorporating a tackifier or adhesive in the mixture that, after drying, is stable when re-wetted by rainfall.

Erosion Control Netting (ECN) – Erosion control netting is typically polyolefin biaxially-oriented process (BOP) mesh. ECNs are used for anchoring loose fiber mulches. They are rolled out over the seeded and mulched area and stapled or staked in place.

Open Weave Meshes (ECM) – Open weave meshes are woven of organic “twines” of jute or coir or polyolefin yarns. Organic ECMs typically are 0.25 to 0.50 in. thick and have 1 inch or larger square uniform openings. Polyolefin meshes are considerably thinner with smaller openings. All meshes are very flexible, promoting intimate ground cover, though they do not provide full ground coverage. Organic meshes also absorb water, which can help maintain soil moisture.


Figure 1 – ECN Applied Over Straw


Figure 2 – ECM on Hillside

Erosion Control Blankets (ECB) – Erosion control blankets are organic fiber filled “blankets” consisting of straw, wood (excelsior), or coconut fibers sewn to or between synthetic (or organic) nettings. ECBs provide a thick (up to 0.5 in.) full coverage of mulch which better absorbs rainfall impact and retains moisture. The nettings add strength to help ECBs resist erosive forces. Their useful life is limited to durability of the organic fibers.


Figure 3 – ECBs Come in Many Varieties


Figure 4 – ECB (left) vs. HMG (right)

Fiber Roving Systems (FRS) – Fiber roving systems use fibrillated, or split, yarns that are fed off spools and continuously fed from the spools through a special air gun and uniformly applied over a seeded soil surface. A randomly laid mat of continuous strands results and provides a high percentage of ground cover. A tackifier is then sprayed on top of the FRS to firmly anchor it to the soil. FRS can conform to almost any geometry.

Turf Reinforcement Mats (TRM) – Turf reinforcement mats (TRMs) are thick structures composed of fused or stitched polymer nettings (often filled with polymeric fibers), randomly laid monofilaments, or more recently yarns woven or tufted into an open, dimensionally stable mat. The dimensional stability produces a somewhat stiffer, but much stronger mat. These flexible, synthetic 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 more than twice the erosion protection of plain grass alone.

Figure 5 – TRMs are Polymer Structures

Figure 6 – TRMs are Used in Channels

Fabric Formed Revetments (FFR) – Fabric formed revetments take advantage of low-cost, durable, synthetic fabrics to produce 3-dimensional forms for casting concrete slabs. By pumping a very fluid fine-aggregate grout into a fabric envelope consisting of 2 layers connected by tie-chords or by interweaving at points, a concrete mattress can be constructed in minutes. FFRs provide the durability of rigid linings, such as cast-in-place concrete or asphaltic concrete, and the flexibility and/or water permeability of protective rock systems such as riprap or gabions.

Geocellular Confinement Systems (GCS) – Geocellular confinement systems, often called geocells, are 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 that can be filled with soil, rock or concrete. Geocell thickness (depth) typically ranges from 2 in. to 12 in. A GCS is effective at assuring that surface soil is retained on a slope.

Figure 7 – FFR Installed in Wave Zone

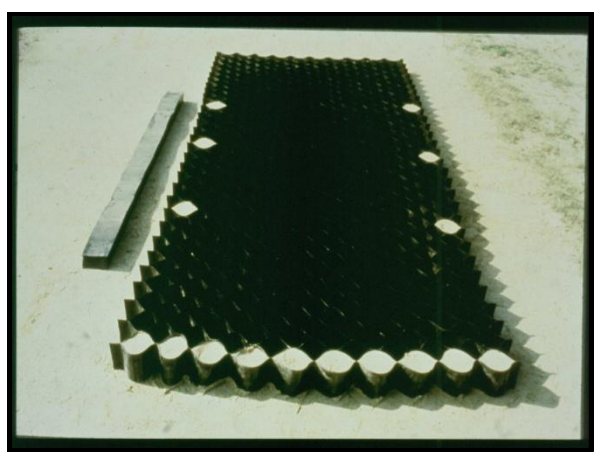

Figure 8 – GCS "Honeycomb" Structure

Gabions (G) – Gabions are compartmented rectangular containers made of galvanized steel hexagonal wire mesh and filled with hand-sized stone. In highly corrosive conditions a polyvinyl chloride coating is used over the galvanized wire. Gabions are more flexible, durable and permeable than rigid structures and more stable than loose rock.

Articulating Concrete Blocks (ACB) – Articulating concrete block (ACB) revetments are interlocking cellular concrete blocks, with varying amounts of open area within or between blocks, underlain by a filtration geotextile. The blocks can be assembled into mats either at the factory or on site with or without cables running through them. The blocks are held on the slope by anchors placed at the top of the slope and/or friction between the slope and the blocks. ACB revetments provide the porosity, flexibility, vegetation encouragement and habitat enhancement, and ease of installation of rolled RECPs and the nonerodibility, self-weight, and high shear resistance of rigid linings.

Table 1 – Some Potential Advantages and Disadvantages of
Temporary, Degradable Erosion Control Systems

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

**Commonly composed partially or completely of geosynthetics.*

Table 2 – Some Potential Advantages and Disadvantages of Long-term, Nondegradable Erosion Control Systems

SYSTEM	POTENTIAL ADVANTAGES	POTENTIAL DISADVANTAGES
Sod	Immediate vegetation and its associated benefits	May need irrigation Risk of dying before establishment High costs Limited to turf grasses
Turf Reinforcement Mats (TRM)*	Moderate costs Long-term (indefinite) Moderate to high flows Encourages infiltration Mod. To high vegetative density Extends the limits of vegetation Flexible over differential settlement	Low to moderate sediment yields during unvegetated stage Requires vegetative establishment for effective long-term performance
Riprap	Long-term (maintenance req'd) Moderate to high flows Encourages infiltration Low to moderate sediment yield (when underlain by a geotextile)	Moderate to high cost Possible negative aesthetic/safety impact Difficult to install on steep slopes Low vegetative density Often unstable, especially w/o geotextile
Other Hard Armor Systems**	Long-term (indefinite) Moderate to Very high flows Low to moderate waves Low to moderate sediment yields Range of fill materials Durable & Low maintenance	High to very high costs No to delayed vegetation establishment No to low vegetation density May prevent infiltration Special deployment/equipment req'ts

**Commonly composed partially or completely of geosynthetics; **Including: Fabric Formed Revetments, Geocellular Confinement Systems, Gabions, Articulating Concrete Blocks*

Table 3 - Typical Erosion Control System Performance Limits

BMP	**Limiting Shear (psf)**
Mechanically or Hydraulically Applied Seeding	< 0.5
Mechanically or Hydraulically Applied Mulching	< 0.5
Meshes and Nets	0.5-1.5
E.C. Blankets	1.5-3.0
Fiber Roving	1.0-2.0
Natural Vegetation	up to 2.0
Sod	0.4-3.7
Turf Reinforcement	2.0-11.0
Geocellular Confinement	10
Fabric Formed Revetments	2.2-24
Riprap (6" to 18" thick)	2.5-5.0
Gabions (6" to 18" deep)	35
Interlocking Block Mats	4.4-25

Geosynthetics in bold. Conversions: ft/s = m/s x 3.28; psf x 47.88 = Pa

Table 4 - Erosion Control Systems Costs

Erosion Control System*	**Approx. Cost per Square Yard – Installed*****
Dry-Blown and Hydraulic Mulching	$0.50 - $1.00
Meshes and Nets	**$0.50 - $1.00**
E.C. Blankets	**$1.00 - $1.50**
Fiber Roving	$1.50 - $3.00
Sod	$2.00 - $3.00
Turf Reinforcement	**$4.00 - $7.00**
Hard Systems**	$15.00 - $60.00

Geosynthetics 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.

Sediment Control Systems

In general, the benefits of geosynthetic sediment control systems over traditional structures, such as rock checks and sediment traps, include: minimal labor required to install; low cost; highly efficient in removing sediment; very durable and sometimes reusable. The performance of sediment control systems typically depends on the proper selection and deployment of sediment retention devices (SRDs). SRDs, such as silt fences, typically cause the following to happen:

- The SRD initially screens silt and sand particles from runoff.
- A soil filter is formed adjacent to the upstream face and reduces the ability of water to flow through the fence.
- This leads to upstream ponding, which serves as a "stilling" basin to collect suspended soils from runoff water.

To perform satisfactorily as an SRD, the geotextile component must have properly sized openings, which initiate the formation of a soil filter. Also the strength and storage capacity of the SRD must be adequate to contain the volume of water and sediment anticipated during a major storm. Hydraulic loading during a storm event is commonly the primary loading considered.

Other SRDs include turbidity curtains and fiber rolls. Turbidity curtains are reusable floating panels of geotextile or geomembrane 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 weights are attached to the lower edge of the curtain to keep it vertical in the water. Fiber rolls are three-dimensional rolls of organic fibers contained within a tubular netting or geotextile structure. They are commonly used as ditch checks or slope interrupters.

Figure 9 – Silt Fence

Figure 10 – Wattles in Channels

Figure 11 – SRD Protecting Inlet

Figure 12 – Turbidity Curtain

Emerging Erosion and Sediment Control Technologies

Biotechnology – Probably the hottest topic in erosion control today is "biotechnology", or the maximum use of vegetation. This technology appeals to environmentalists and engineers, alike, because it looks good and brings the many benefits of vegetation to bear on the problems of erosion and water quality. This is also why geosynthetic-containing RECPs are steadily gaining in popularity. RECPs nurture and support vegetation that, by itself, is often fragile, and costly and labor-intensive to construct.

Anchored Geotextiles and Geonets – An anchored geonet presents a good example of an emerging development in biotechnical stabilization, specifically for stabilization of sandy slopes and coastal landforms. The anchored geotextile or geonet is made of a fabric or net which is stretched over and pulled down tightly on the ground surface and is secured in place by means of anchors inserted through and fastened to the geotextile.

Geotextile Tubes and Containers – Very large geotextile containers filled with dredged material have re-gained popularity in the past decade because of their simple placement and construction, cost effectiveness and minimum impact on the environment. These containers are hydraulically or mechanically filled with a variety of dredged material types, including fine-grained materials. Containment of dredged material in geotextile tubes, bags or other large containers, filled in place or filled in large bottom dump hopper barges and dumped below water has helped solve several difficult construction problems. Dike construction using long, sometimes continuous, tubes in wetlands, subdivision and perimeter dikes in dredged material disposal areas, under water stability berms, containment of contaminated materials, island construction, barrier island breach repair and structural scour protection are examples of projects that could not have been completed without use of geotextile containment systems.

Figure 9 – Biotechnology for Shoreline

Figure 10 – Geotextile Tube / Groin

INDUSTRY EFFORTS

The first attempts to promote the erosion and sediment control industry were by the International Erosion Control Association (IECA) in the 1980s. The IECA even set up a committee (Committee C) to look into test methods to characterize the ever expanding products being introduced. Within a few years, the IECA determined that because of liability issues surrounding the setting up of standards, the standardization effort was better undertaken by ASTM. As a result, members of Committee C became some of the strongest initiators of efforts to energize and formalize meetings of manufacturers to develop, draft, and standardize test methods. These efforts fueled two industry-wide initiatives:

- The Erosion Control Technology Council (ECTC), an industry group driven by manufacturers, and
- ASTM D18.25 and D35.05, Subcommittees on Erosion and Sediment Control, where other interest groups (i.e. engineers, regulators, researchers) where other industry partners could contribute to the standardization effort.

In 1994, the Erosion Control Technology Council (ECTC), an organization of rolled erosion control product (RECP), hydraulically applied erosion control product (HECP), and sediment retention fiber roll (SRFR) manufacturers commissioned a program to identify and establish a common terminology and to develop standardized index and performance tests for the characterization of erosion control and sediment retention products containing natural materials.

In January 1997, a manual of common terminology and recommended index testing standards (*ECTC Technical Guidance Manual: TASC 00197*) was issued to the industry. Then, in the late 1990s, ECTC once again commissioned a new class of test – this time it was bench-scale performance test – that focused on testing an erosion control product along with a default soil system under carefully controlled "standard" conditions. The project included the development of bench-scale (i.e. small-scale) laboratory tests for slope erosion, channel erosion, vegetation enhancement, and biodegradability.

Subsequent to each of these development efforts, there have been coordinated efforts to work through the ASTM International to achieve consensus standardization of both erosion control and sediment retention test procedures. This work continues within ASTM Subcommittee D18.25, "Erosion and Sediment Control Technology" and Committee D35, "Geosynthetics." Over the past decade, ASTM has released several new standard test methods for turf reinforcement mats (TRMs) and erosion control blankets (ECBs) that have been eagerly adopted. New standard test methods for Sediment Retention Devices have also been released, though their adoption has been slower.

Though both ECTC and ASTM began their erosion control efforts with a primary focus on RECPs, the ASTM effort quickly evolved to include biotechnology, various hard armor systems, and sediment retention devices. The ECTC remained focused on RECPs until around 2006 when it, too, began addressing HECPs and then, more recently sediment retention fiber rolls (SRFRs).

ASTM has struggled to make significant progress in standardizing HECP test methods, though the effort continues. It appears proprietary interests make consensus building difficult.

Finally, it should be noted that the IECA has just in the last year re-initiated its effort to pursue erosion and sediment control standards. It has formed that Standards and Practices (S&P) Committee, including subcommittees focusing on terminology, sediment control testing, sediment control design, and turbidity testing. The IECA S&P Committee plans to funnel it's efforts into ASTM for eventual consensus standardization.

QUALITY CONTROL, QUALITY ASSURANCE AND PERFORMANCE TESTING

As noted in the previous section, the industry recognized early on that with so many new types of erosion control products (many incorporating geosynthetics), and their associated new applications, has come a need for new relevant tests to properly characterize them. Basic index tests are typically needed to assure manufacturing quality control. Not only are these tests useful for manufacturing quality control, but when used on the same materials deployed in bench-scale and large-scale performance tests, they serve to "bench-mark" the performance results to specific material properties. Not surprisingly, a variety of performance tests have been developed over the years to answer design questions regarding performance among different products and product categories.

Since 2003, the National Transportation Product Evaluation Program (NTPEP) has provided a program for independent testing of RECPs. The program has included both index tests and bench-scale “indexed performance” tests. The goal of the program is to minimize duplicative testing of erosion control products done by individual State Departments of Transportation (DOTs) by providing a process where manufacturers and suppliers submit their products to the NTPEP for independent index and bench-scale testing. The results of the testing are then shared with participating DOTs. The results of the testing may be used for assessing product conformance to material specifications. Further, the testing results provide quantitative material data necessary for placing specific products on, or removing specific products from a DOT’s qualified products list (QPL). The NTPEP program is intended to serve as a nationwide quality assurance (QA) program for the DOTs.

Additionally, in 2009, NTPEP began offering independently verified large-scale erosion control performance testing to complement on-going index and bench-scale testing. NTPEP (2011) describes the purpose and rationale for exclusive use of standardized test procedures in the programs.

While standardized tests for geotextiles – which are used in many SRDs – have been available for decades, new tests have been needed for RECPs. The following section details the tests that have developed and are generally used to characterize RECPs and SRDs.

Index Testing

Index tests are standard tests that may be used for manufacturing quality control and to compare the relative material properties of several different RECPs. Quality Control tests are index tests which are performed on a production basis to evaluate product integrity, quality, continuity, and the impact of changes in production methodology on product properties. Quality control test results can be reported with statistical relevance when they are run with sufficient frequency. Recently, ASTM D4354, “Standard Practice for Sampling of Geosynthetics for Testing”, has been revised to include appropriate sampling frequencies to achieve a 95% confidence level for RECP quality control, quality assurance, and conformance testing. Following are the index test methods used for RECPs:

- Mass per Unit Area**:** ASTM D 6475, “Standard Test Method for Measuring Mass per Unit Area of Erosion Control Blankets”**;**
- ASTM D 6566, “Standard Test Method for Measuring Mass per Unit Area of Turf Reinforcement Mats”**.**
- Thickness**:** ASTM D 6525, “Standard Test Method for Measuring Nominal Thickness of Permanent Rolled Erosion Control Products”**.**
- Tensile Strength**:** ASTM D 6818, “Standard Test Method for Ultimate Tensile Properties of Turf Reinforcement Mats”**.**
- Light Penetration: ASTM D 6567, “Standard Test Method for Measuring the Light Penetration of a Turf Reinforcement Mat (TRM)”.
- Water Absorption: ASTM D 1117 Section 5.4 and ECTC-TASC 00197, “Standard Guide for Evaluating Nonwoven Fabrics – Absorptive Capacity Test (for Larger Test Specimens)”.
- Specific Gravity: ASTM D 792, Method A, “Standard Test Methods for Density and Specific Gravity (Relative Density) of Plastics by Displacement”.

Following are index test methods used for SRDs:

- Mass per Unit Area: ASTM D 5261, "Standard Test Method for Measuring Mass per Unit Area of Geosynthetics";
- Thickness: ASTM D 5199, "Standard Test Method for Measuring Thickness of Geosynthetics". Note: Many SRDs are 3-dimensional products (i.e. wattles, bales, etc.), thus non-standard procedures are currently used to measure such things as density (or unit weight per length) and circumference.
- Tensile Strength: ASTM D 4595, "Standard Test Method for Measuring the Wide-width Tensile Strength of Geosynthetics";
- Permittivity: ASTM D 4491, "Standard Test Methods for Water Permeability of Geotextiles by Permittivity".
- Apparent Opening Size (AOS): ASTM D 4751, "Standard Test Method for Measuring the Apparent Opening Size of Geosynthetics".
- Percent Open Area (POA): Corps of Engineers protocol CW02215.
- Ultraviolet Stability: ASTM D 4355, "Standard Test Method for Deterioration of Geotextiles by Exposure to Light, Moisture and Heat in a Xenon Arc Type Apparatus". The exposed specimens are typically tested for retained strength in accordance with ASTM D 6818. Note: Since accelerated tests have not shown a consistent correlation to outdoor exposures, ASTM's D 5970, Standard Test Method for Deterioration of Geotextiles from Outdoor Exposure is also used.

Bench-Scale Testing

Bench-scale "indexed" performance tests are a class of tests that have been developed to focus on testing the RECP/soil system or SRD/water system under carefully controlled "standard" conditions. Bench-scale tests have been developed for slope erosion, channel erosion, and vegetation enhancement for RECPs and for filtration efficiency and flow for SRDs. Bench-scale tests do not reflect product installation techniques or site conditions to which these materials are typically subjected. Therefore the results of these tests may not be indicative of a RECP's or SRD's actual field performance. Following are the bench-scale test methods used for RECPs:

- Slope Erosion and Runoff Reduction**:** ASTM D 7101, "Standard Index Test Method for Determination of Unvegetated Rolled Erosion Control Product (RECP) Ability to Protect Soil from Rain Splash and Associated Runoff under Bench-Scale Conditions".
- Permissible Shear and Channel Erosion: ASTM D 7207, "Standard Test Method for Determination of Unvegetated Rolled Erosion Control Product (RECP) Ability to Protect Sand from Hydraulically-Induced Shear Stresses under Bench-Scale Conditions".
- Germination/Vegetation Growth: ASTM D 7322, "Standard Test Method for Determination of Rolled Erosion Control Product (RECP) Ability to Encourage Seed Germination and Plant Growth under Bench-Scale Conditions".

Following are the bench-scale test methods used for SRDs:

- Filtration Efficiency and Flow: ASTM D 5141, "Standard Test Method for Determining Filtering Efficiency and Flow Rate of the Filtration Component of a Sediment Retention Device Using Site-Specific Soil".
- Horizontal Permeability: Many SRDs are 3-dimensional, and therefore cannot be tested for clear water flow (a.k.a. permeability or flow rate) using standard procedures that have been developed for planar materials. To fill the gap, a "horizontal permeability" test has been developed that exposes the SRD to a constant head of clear water on one side.

Large-Scale Testing

Large-scale performance tests have been developed to simulate expected field conditions to report performance properties of "as installed" RECPs. Large-scale tests have been developed for slope erosion and channel erosion. The channel erosion test may be conducted un-vegetated or vegetated. Performance of RECPs relies not only on material properties but also on the installation techniques. Products are installed on the test slope or channel per manufacturer installation recommendations. The results of these tests are more indicative of actual field performance of RECPs and are acceptable for use in design calculations. Following are the large-scale test methods used for RECPs:

- Slope Erosion: ASTM D 6459, "Standard Test Method for Determination of Rolled Erosion Control Product (RECP) Performance in Protecting Hillslopes from Rainfall-Induced Erosion".
- Channel Erosion: ASTM D 6460, "Standard Test Method for Determination of Rolled Erosion Control Product (RECP) Performance in Protecting Earthen Channels from Stormwater-Induced Erosion".

The most unique thing about SRD's is that, typically, for them to be very effective in retaining sediment they must also impound most of the runoff. Conversely, for them to freely pass runoff, they have to be allowed to pass a significant amount of sediment. Neither of these extremes is usually preferred, so the user has to determine the proper balance of retaining sediment while permitting seepage. Following are the large-scale test methods used for SRDs that are used to quantify the "balance" of retention and flow provided under standard conditions:

- ASTM D 7351, "Standard Test Method for Determination of Sediment Retention Device Effectiveness in Sheet Flow Applications".
- D 7208, "Determination of Temporary Ditch Check Performance in Protecting Earthen Channels from Stormwater-Induced Erosion".
- ASTM's WK11340, is a derivation of ASTM D 6459, Large-scale Slope Erosion Testing, but permits a flatter slope and calls for a lighter rainfall.
- ASTM D 7351 can be modified to better simulate the runoff being more concentrated and potentially having a lower sediment load as may be applicable to inlet protection.
- Another modification to the D 7351 protocol that has been proposed is the Texas Transportation Institute's (TTI) Sediment Control Device (SCD) performance testing facility to focus on evaluation of roadside SCDs.

Some of the unique standardized tests are shown in the following figures.

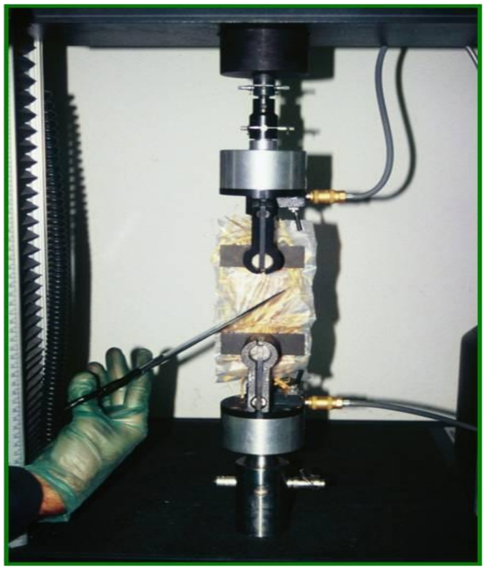

Figure 11 - ASTM D 6818, Tensile Testing

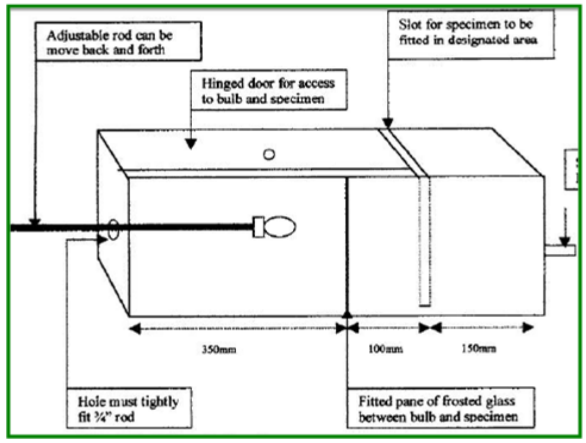

Figure 12 - ASTM D 6567, Light Box for % Light Penetration

Figure 13 - ASTM D 7101, Rainfall

Figure 14 - ASTM D 7207 Hydraulic Shear

Figure 15 - ASTM D 7322 Germination Testing

Figure 16 - ASTM D 5141

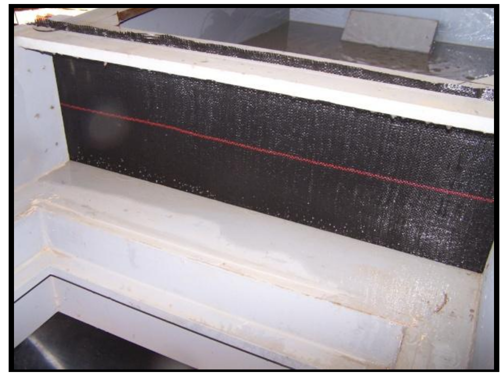

Figure 17 - ASTM D 5141 Test Close-up

Figure 18 - ASTM D 6459 Slope Testing

Figure 19 - ASTM D 7351 SRD Testing

Figure 20 - ASTM D 7351 with Silt Fence

Figure 21 - ASTM D 6460 Channel Testing

Figure 22 - ASTM D 7208 Check Testing

Figure 23 - ASTM D 7208 Close-up

EXISTING INDEPENDENT DATA AND MATERIAL SPECIFICATIONS

Independent RECP and SRD Data

While relatively little independent data on SRDs exists, the opposite is true for RECPs. Thanks largely to the NTPEP program mentioned earlier, much independent data on a wide range of products is available at the click of a mouse at www.ntpep.org. Sprague and Sprague (2013) have summarized the available NTPEP data and proposed associated specifications.

Generic RECP and SRD Specifications

The most widely circulated "generic" specifications for RECPs are the categorizations presented by the ECTC (2006) and the Federal Highway Administration's FP-03 (2003). These specifications include both temporary and permanent RECPs, and reflect different performance levels based on functional longevity, C-Factor, and Permissible Shear from large-scale testing. An update of the ECTC specification is expected in the coming months.

Unfortunately, there are no widely circulated "generic" specifications for SRDs. Thankfully, the IECA Committee on Standards and Practices is working toward developing specifications, but developing test methods is their initial focus.

CONCLUSIONS

Geosynthetics continue to replace traditional materials such as soil and stone in performing important engineering functions in erosion and sediment control applications while simultaneously introducing ever greater versatility and cost-effectiveness. Geosynthetics are commonly used along with temporary, degradable materials for the enhancement of vegetative establishment; as long-term, nondegradable materials to extend the erosion control limits of vegetation or soil; as primary slope or channel linings; and as components in silt fences and turbidity curtains and an ever growing array of sediment retention devices.

Industry-wide initiatives are well underway to promote the correct specification and use of geosynthetics in erosion and sediment control. This includes efforts to facilitate more comprehensive quality systems in manufacturing and better measurements of performance via new and better test methods. All of this is indeed a "work in progress".

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