Large-scale Performance Testing of Erosion Control Products

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ABSTRACT

Sediment is the number one pollutant of water resources even though erosion control best management practices (BMPs) are now commonly used in many parts of the world. While a large amount of information on types of storm water BMPs, including Erosion Control Products (ECP), exists, quantitative information on performance effectiveness is difficult to find and not well documented. In order to help protect water quality as it relates to sediments, regulatory agencies and site designers are increasingly responsible for determining how well specific BMPs will perform, quantitatively, relative to alternatives.

Standardized test methods provide testing labs with clear protocols so that future testing of ECPs can be easily reproduced and compared to the results of existing tests. Thus, it is desirable that all testing conform to existing standardized procedures, or be clear, easily implemented applications of those procedures.

This paper will present commonly used large-scale standardized performance tests and review the results of independent large-scale tests performed on a range of rolled erosion control products (RECPs) and hydraulically-applied erosion control products (HECPs). These large-scale tests were performed under the auspices of the National Transportation Product Evaluation Program (NTPEP). Additionally, recommendations will be made on the appropriate use of large-scale tests in specifications for erosion control products.

1. GEOSYNTHETIC FUNCTIONS IN EROSION CONTROL

Traditional applications of geosynthetics perform more common in-ground functions such as separation and filtration. In contrast, geosynthetics used in erosion controls are used on the soil surface. As such, they introduce the following unique functions according to ASTM D5819 (Standard Guide for Selecting Test Methods for Experimental Evaluation of Geosynthetic Durability):

- Containment - A geosynthetic provides containment when it encapsulates or surrounds materials such as sand, rocks, straw, brush, and fresh concrete.
- 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.

In all of these functions, the geosythetic is acting to control the dislodgement of soil, called erosion control.

2. ADVANTAGES AND TYPES OF GEOSYNTHETIC EROSION CONTROL PRODUCTS

The benefits of geosynthetic-enhanced erosion control products (ECPs) and sediment retention devices (SRDs) over traditional or natural systems, include:

- Material Quality Control: Geosynthetics undergo manufacturing quality control to minimize material variation.
- Construction Quality Control: Geosynthetics can be easily and efficiently deployed.
- Cost Savings: Geosynthetics are generally less costly to purchase, transport and install than alternative systems.
- Technical Superiority: Geosynthetics are engineered for optimal performance based on the unique scenario in which use is anticipated.
- Construction Timing: Geosynthetics can be installed quickly.
- Material Availability: Geosynthetics are easily shipped, competitively priced and readily available to any location.

Conventional, natural mulches, such as loose straw, brush, soil, or compost provide only a few weeks or months of protection to the bare soil seed bed making reapplication necessary if arid conditions prevail during initial periods of seed germination. Thus, a diverse offering of erosion control products, such as erosion control blankets and turf reinforcement mats, have emerged which provide greater strength, enhanced performance, and greater longevity. These geosynthetic-enhanced systems dependably meet the two principal objectives: reducing seed and soil loss due to erosive forces and expediting site revegetation.

In more demanding erosion control applications, rock, or riprap, is often engineered into systems to resist erosion by lateral concentrations of water flows, swift currents, or high energy waves. Yet, assuring proper gradations and stone quality, facilitating placement on slopes, and obtaining uniform and stable layers often requires large construction tolerances and repeated inspections. In these cases, geotextile filters placed under the rock rip-rap to protect the underlying subgrade, and geosynthetic-enhanced armor systems, such as fabric-formed revetments and geocellular confinement systems, have proven to be more dependable engineered systems.

While global consensus-based standard terminology is still being developed for geosynthetic erosion control products, there are several product description and terms that are useful to be aware of. There are generally two categories of erosion control products. The first is termed temporary or degradable and the second is termed long term or nondegradable.

2.1 Temporary/Degradable ECPs:

Conventional: various natural fiber mulches and fiber roving systems.
Geosynthetic-enhanced: erosion control netting (ECN), geoblanket (GBL), open weave meshes (ECM), erosion control blankets (ECB).

2.2 Long-term/Nondegradable ECPs:

Geosynthetic-enhanced: geomats (GMA) and reinforced geomats (reinforced with stell mesh, yarns or other elements (GMA-R), prefilled geomats GMA-P, turf reinforcement mats (TRM), fabric formed revetments (FFR), and geocellular confinement systems (GCS). Also, it can't be overstated how important geotextiles (GTX) are as filters used beneath hard armor systems, such as riprap and articulating blocks.

3. LABORATORY TESTING OF EROSION CONTROL PRODUCTS

While geosynthetic erosion control product may be routinely characterized by a variety of index properties for manufacturing quality control and production verification, index properties alone are not useful for answering designers' and specifiers' questions regarding performance among different products and product categories. An effective erosdion control product is one which absorbs the kinetic energy of rain, slows runoff, promotes water infiltration, and provides the microclimate needed for the germination of seeds and the subsequent establishment of a self-sustaining vegetative mat to provide permanent erosion protection. It may additionally be proposed that when channel flow, currents or waves predominate, the ability to provide long term armoring is requisite.

To accomplish these functions, a well designed geosynthetic erosion control product (ECP) requires that:

- When used on slopes, the primary consideration of ECP systems is their ability to reduce soil loss caused by rain and immediate runoff.
- In channel lining applications, flowing water imposes shear stress on the sides and bottom of the channel. Thus, the lining must provide acceptable hydraulic shear resistance.
- When used to provide short-term mulching, along with erosion protection there is a need to nurture initial seed germination and vegetation growth.
- Additionally, to provide extended mulching in arid regions, permanent turf reinforcement, or extended armoring it must be shown that the ECP has the appropriate longevity.
- As a dynamic filter, the ECP must have sufficient durability to survive installation and be selected to have compatible openings and permeability to assure clogging resistance.

A variety of performance tests have been developed over the years. To-date, standardized test procedures for measuring relevant performance of ECPs have too often been rejected in favor of unique protocols designed by individual researchers. Thus, it is often not possible to accurately compare much of the available ECP performance data developed on different ECPs at different testing organizations. To remedy this situation, in 2009 under the management of the American Association of State Highway and Transportation Officials (AASHTO), through it National Transportation Product Evaluation Program (NTPEP) began offering independently verified full-scale performance testing of erosion control products to complement on-going index testing. NTPEP's program relies exclusively on standardized test procedures.

The following are the standards used for full-scale evaluations of ECPs:

- ASTM D 6459, "Standard Test Method for Determination of Rolled Erosion Control Product (RECP) Performance in Protecting Hillslopes from Rainfall-Induced Erosion"

- ASTM D 6460, “Standard Test Method for Determination of Rolled Erosion Control Product (RECP) Performance in Protecting Earthen Channels from Stormwater-Induced Erosion”

3.1 Slope Erosion Testing

A slope is generally eroded by rainfall impact and sheet runoff forces. The current most commonly used model for predicting soil loss from water erosion on slopes is the Revised Universal Soil Loss Equation (RUSLE), developed by the U.S. Department of Agriculture in the 1960s and 1970s. RUSLE is expressed by the following formula:

$$A = R \cdot K \cdot LS \cdot C \cdot P \qquad [1]$$

where:

A	estimated average soil loss (Mg/hectare/year);
R	rainfall-runoff erosivity factor (MJ·mm/ha·hr·yr);
K	soil erodibility factor (ton·ha·hours/ha·MJ·mm);
L	slope length factor;
S	slope steepness factor;
C	cover-management factor (for example a geosynthetic erosion control product);
P	support practice factor.

The RUSLE equation can be used to predict the amount of soil that may be eroded, for example, from construction sites. Specifically, it enables the most critical source areas to be identified and allows predictions of the benefits of erosion control measures.

The evaluation of an ECP's ability to protect a soil surface from rainfall is appropriate for slope protection applications. Most test procedures provide for the measurement of the amount of soil loss caused by simulated rainfall. Additionally, increased rainfall infiltration or runoff reduction can be measured. Soil type, slope, rainfall rate, and rainfall duration can be controlled. In one such procedure, plots measuring 0.6 m x 6.0 m (2 ft x 20 ft) are used to compare the effects of rain on an ECP protected slope versus an unprotected, or control, slope. The tested slopes can be left bare or allowed to establish vegetation prior to testing. Wind can also be applied to the slope. Erosion, plant germination, and plant growth time can be measured and compared to a control. Rain is applied to the plots until significant rilling has occurred. Runoff is collected and measured, then dried completely to obtain a final dry weight of sediment. The effectiveness of the RECP is based on the weight of dried sediment produced from runoff. Cabalka, et al (1998), Sutherland and Ziegler (1996), Rustom and Weggel (1993a,b), Godfrey and Landphair (1991), and perhaps most importantly ASTM D 6459-describe other laboratory and field systems for testing of slope erosion. The ASTM standard test method will be described in the following section.

Standard Full-Scale Slope Testing: ASTM D6459

This procedure has been developed for the measurement of the amount of soil loss caused by rainfall generated by a rainfall simulator. Total runoff is also measured. Soil type, slope, rainfall rate, and rainfall duration are controlled. Rain is applied to the plots and sediment-laden runoff is collected and measured, then dried completely to obtain a final dry weight of sediment. The most common application of the standard protocol includes simulated rainfall on 3:1 slopes with bare and ECP-protected soil, including:

- Rainfall Intensities = 50, 100, 150 mm/hr @ 20 minutes each;
- 1 control + 3 replicate slopes;
- Inclined (3:1) slopes, 12.2 m (40 ft) long and 2.4 m (8 ft) wide;
- Minimum 30 cm (12 in) compacted soil veneer;
- Simulated rain system with 4.3 m (14 ft) drop height & up to 150+ mm/hr capacity.

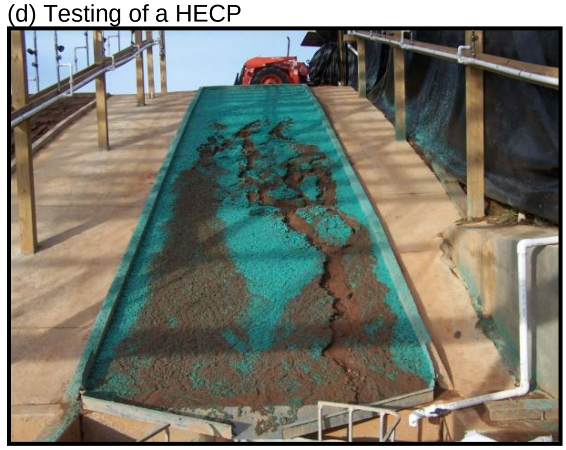
Figures 1 a through e show s this type of test setup.

(a)ASTM D6459 Slope Testing facility (bare soils test shown)

(b)Testing of a geomat (GMA) or rolled erosion control product (RECP)

(c.)Eroded surface after ECP removed - post test

(d) Testing of a HECP

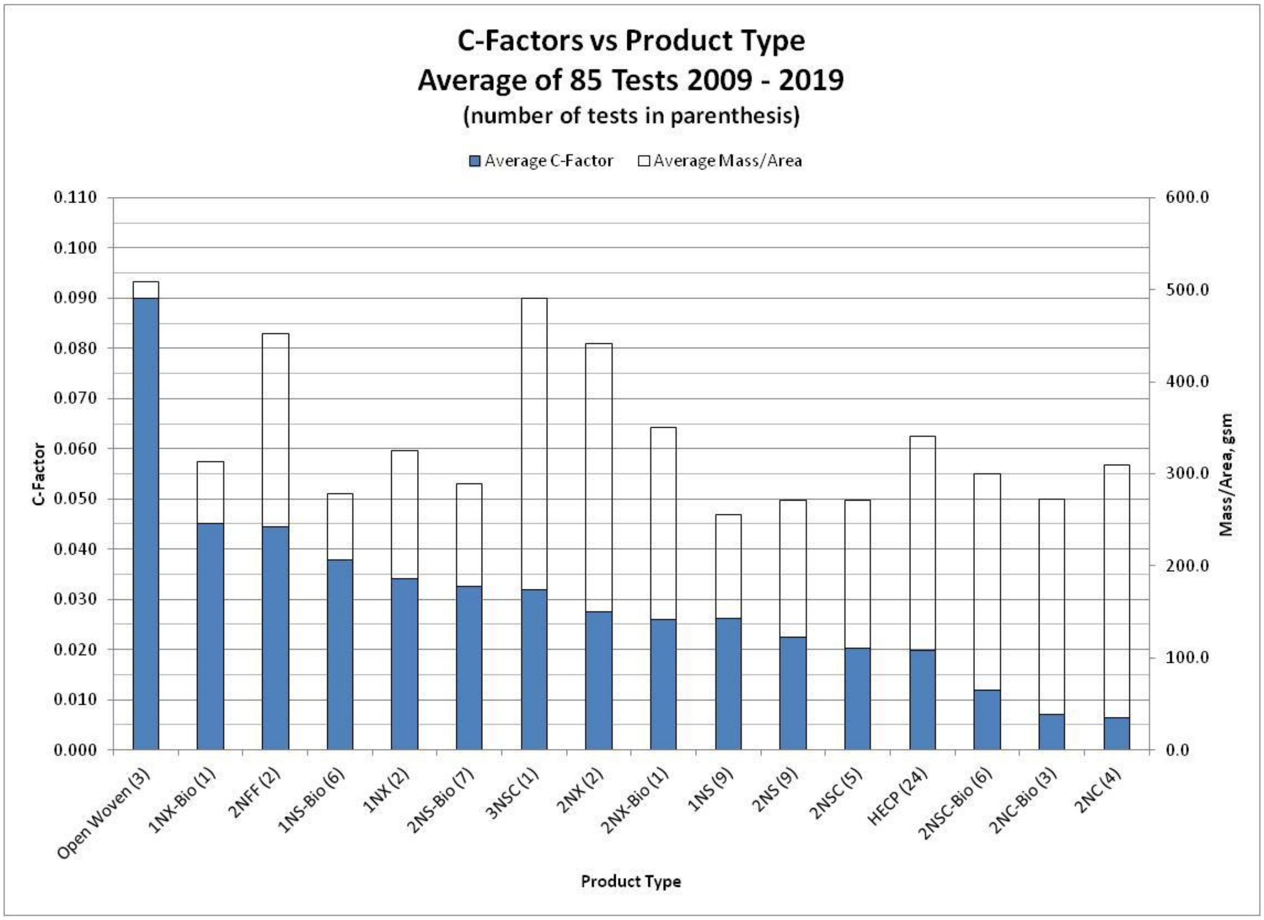


(e)Testing shows that different products and installations perform differently

Figure 1: Independent large-scale slope testing facility at TRI laboratories.

Correlation of Large-scale Test Results to Field Performance

Large-scale slope erosion testing is important for assessing the relative performance of various erosion control materials. Yet, currently used testing protocols vary widely. Sprague (2008) used the Revised Universal Soil Loss Equation (RUSLE) to show that there are significant differences in the erosivity (R), erodibility (K), and topographic (LS) factors associated with the indoor and outdoor (ASTM) testing protocols examined. Additionally, a parametric stability analysis identified the critical parameters related to stability as the following: test soil unit weight and strength, test soil / subsoil (or test bed) friction and drainage, slope steepness, and degree of test soil saturation. All of these parameters vary significantly between the testing protocols examined, suggesting that very different stability conditions exist between insitu and tilting bed protocols. Sprague also compared the calculated and actual soil loss test results to show that there is reasonable consistency between the ASTM protocol and RUSLE-based theoretical performance. Actual test results from other labs/protocols did not show a high correlation to expected field performance.



Product Type Key:
HECP = hydraulically-applied erosion control product;
X = wood fiber
FF = fiber fill
Bio = biodegradable
1NS = single net straw blanket;
2NS = double net straw blanket;
1NX = single net excelsior blanket;
2NC = double net coconut blanket
SC = straw and coconut

Figure 2: NTPEP ASTM D6459 slope testing results (average C factors shown)

Why is the ASTM D 6459 preferred for large-scale slope testing?

- ASTM D 6459 is the only international standard that simulates full-scale “real world” conditions.
- The protocol is public information and has been used to evaluate a wide variety of rolled and hydraulically-applied erosion control products.
- The protocol, standardized since 1999, provides detailed instructions for any lab’s use in setting up and performing the tests.
- Test setup permits an actual installation simulation, including anchor pattern, density, and depth, and joint overlaps to be examined.
- Test setup is large enough to address all relevant stability issues, including surface rilling and veneer stability, i.e. mass wasting.

- Test results have been correlated with "real world" performance and reported in, Slope Erosion Testing – Identifying "Critical" Parameters, the 2008 IECA Most Distinguished Technical Paper. The peer-reviewed paper presented an analysis of large-scale slope erosion testing protocols used by three different labs and demonstrated that at least one protocol (ASTM D 6459) produces actual performance results that correlate with the theoretical results predicted by the Revised Universal Soil Loss Equation (RUSLE). Tilting bed protocols did not correlate well.
- Thanks to this correlation, it is known that the test provides relevant input to the Revised Universal Soil Loss Equation.
- Numerous, comprehensive test reports of products independently tested in accordance with the standard are publically available at www.NTPEP.org.

Its important to note here that slope dimensions and their impact on measured test results have been studied and reported on at ASTM. The "apparent" erodibility of the soil increases as the slope dimensions decrease as shown in the graph below of testing performed at TRI. This would appear to make the testing on shorter slopes non-conservative as it would lead to a higher denominator when calculating the C-Factor.

Other currently used slope testing protocols employ tilting beds that allow for the soil layer to drain from below. This prevents the soil layer from becoming saturated under heavy rainfall simulations. This also creates a soil condition that cannot exist in the real world. Clearly, there are times when the primary indicator of differences in the treatments is whether mass wasting occurs or not. Thus, it would not be appropriate to have drained beds when testing these products.

The tilting bed slope test configuration has been used to isolate surface dynamics from full-depth slope stability issues, and thus has been shown in this limited context to segregate between surface-treatment technologies. However, global erosion phenomenon, including infiltration and associated hydraulic loading, warrant the use of large – real world slope tests, such as ASTM D 6459, for field performance investigations. For example, it has been documented that erosion control products that resist surface erosion dynamics by preferentially encouraging infiltration may also increase the risk of slope instability via mass wasting.

Other commonly used protocols use large, uniform sized raindrops rather than a range of drop sizes as found in nature. The rainfall is then reported in terms of a hypothetical amount of kinetic energy that has been applied. The argument for using large drop sizes has centered on the need to maximize the aggressiveness of the rain storm event in order to delineate between competing erosion control technologies, especially those that rely on a chemical agent to provide localized fiber-to-fiber bonding. While calculating the kinetic energy of single-sized spheres is quite straight forward, it is not at all clear how, or if, this can be accurately done for an actual rainfall distribution until the measurement of drop sizes and their proportional makeup of the rainfall can be more definitively measured.

Finally, many testing protocols use test slopes that are shorter (< 12 m) and narrower (< 2.4 m) limiting the extent to which natural erosion mechanisms can develop. Lal, 1994, notes that "experience has shown that 5 m is about the minimum slope length that will adequately represent a rill system in an up-and-down-hill plot." In the very next sentence Lal goes on to say, "A better length is at least 10 m." It seems clear that longer is better (i.e. less flawed).

3.2 Channel Erosion Testing

Shear strength, as used with ECPs, is the resistance to a force applied to the surface of the ECP by flowing water. The higher the shear strength the more stable the ECP will be under more severe flow conditions. One test procedure described by Urroz and Israelsen (1994) provides for the measurement of shear stress caused by flowing water and visual inspection of the specimen in a laboratory flume. In one such procedure, the mat is fastened to a 0.9 m2 (10 ft2) test section. Water is then released into the flume at velocities that increase incrementally to about 6 m/s (20 ft/s). Velocity is measured upstream and downstream of the test section and shear is measured directly from the test section using a load cell. Three replications are averaged.

Not only does an ECP material need to retain its integrity under the expected flow conditions, it also needs to prevent erosion of underlying soils. Large scale flume testing or field trials have been used to measure this performance property. Most large-scale test procedures provide for the measurement of the amount of soil loss caused by flowing water and visual inspection of the specimen in a relatively flat laboratory flume. In one such procedure, the mat is fastened to a 46 cm (18 in) bed of compacted soil in a 1.2 m (4 ft) wide flume. Water is then released into the flume at velocities which increase incrementally to about 6 m/s (20 ft/s), or higher. Average cross sectional velocities and flow depths are measured at stations along the flume. Shear stress can be calculated from these measurements and related to soil loss. Two replications are commonly performed. Israelsen (1994) and Sanders, et.al. (1990) have proposed similar procedures. Northcutt and McFalls (1997), Clopper, et al (1998), and perhaps most importantly ASTM D 6460 describe large-scale field channel erosion testing facilities and associated procedures. The ASTM standard test will be described in the following section.

Standard ASTM D6460 Full-Scale Channel Testing

Permissible shear, as used with channel flow, refers to the shear force caused by flowing water that can be resisted by the surface of the soil or ECP without excessive erosion. Not only does a ECP material need to retain its integrity under the expected flow conditions, but it also needs to prevent the erosion of underlying soils. The hydraulic shear stress applied by the channel water flow is:

$$\tau = \gamma_w \cdot D \cdot S \qquad [2]$$

where:
- τ tractive shear stress (kPa);
- γ_w unit weight of water (kN/m3);
- D maximum depth of flow (m);
- S average bed slope (-).

This standard protocol uses a large-scale flume to measure the amount of soil loss caused by flowing water. Average cross sectional velocities and flow depths are measured at stations along the flume. Shear stress can be calculated from these measurements and related to soil loss as follows. A common application of the standard protocol includes:

- 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.

Figure 3, a through d, shows this type of test set-up.

(a)Channel tested in triplicate

(c.) ECPs of all types are tested

(b)Long-term flows facilitated by pumped recirculation

(d) Vegeated turf reinforcement mats can be tested

Figure 3: Independent large-scale channel testing facility at TRI laboratories.

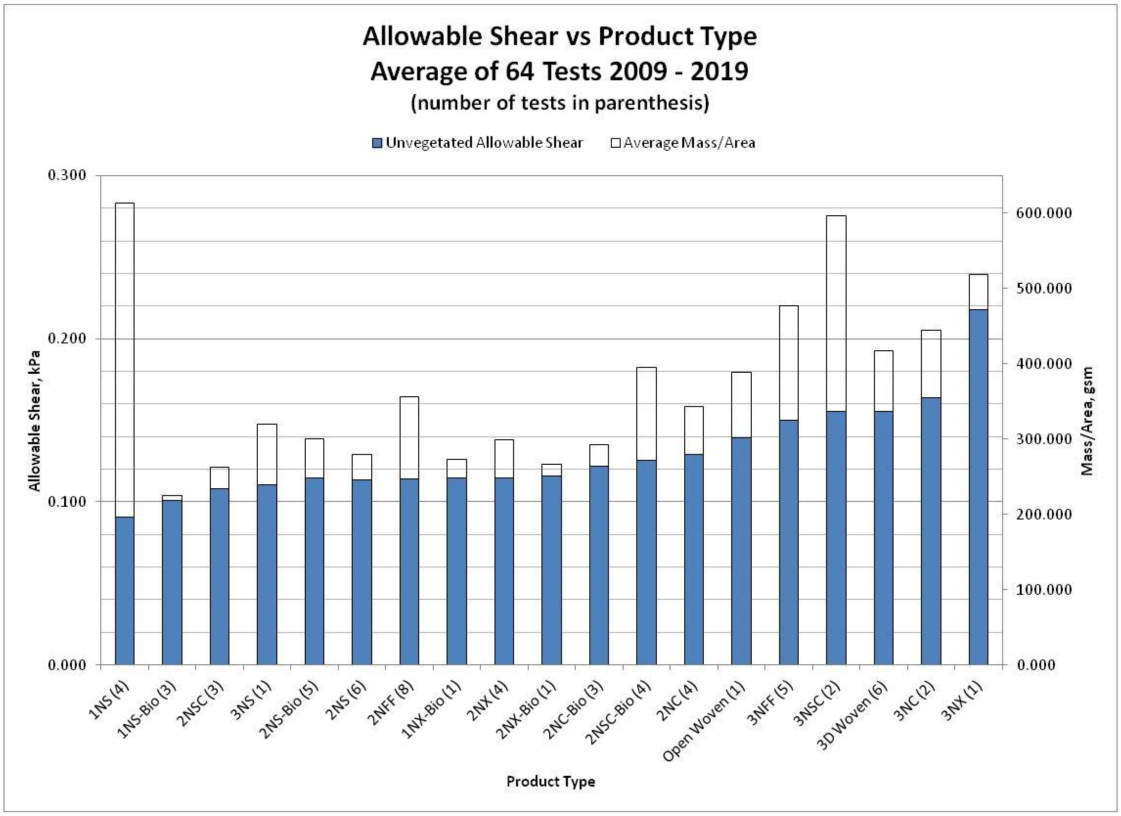


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Figure 4: NTPEP Channel testing results (average permissible or "allowable" shear stress values)

4. LARGE SCALE TEST OBSERVATIONS

A review of Figures 2 and 4 suggests that, based on averages, there is a unique performance related to a unique product type. For example, according to Figure 10, a single net straw blanket, a jute mesh, or a hydraulically-applied base mulch is considerably less protective (has a higher C-Factor) under rainfall impact and sheet flow runoff than a double net coconut blanket or a hydraulically-applied bonded fiber matrix (BFM). The plotted values in Figure 10 do not include variation that would be expected to result from different anchorage (pinning) patterns for geomats or coverage rates for HECPs but do provide some general guidance related to the relative performance of different products.

Similarly, according to Figure 11, a single or double net straw blanket is considerably less protective (has a lower permissible shear stress) under concentrated runoff (i.e. channel flow) than does a double net coconut blanket or a range of triple net geomats. Also, as with the slope results in Figure 10, the plotted values in Figure 11 do not include variation that would be expected to result from different anchorage (pinning) patterns but do provide some general guidance related to the relative performance of different products.

Caution should be used when attempting to make specification decisions based on averages that include a range of "manufacturer recommended" installation details that may vary from product to product for the same product type.

It should also be recognized that there may be considerable variation in component properties from product to product, such as mass per unit area or tensile strength. This variation is somewhat hidden in the averages represented in Figures 10 and 11 but may produce very different product-specific results if individual product results are considered.

Thankfully, the supporting installation details and component properties are available for each product tested by referring to the product-specific test reports required by the ASTM test procedures. The reports for the product tests discussed in this paper are posted at www.ntpep.org.

It should be noted that there is no cost information associated with the products included in this review, so there is no way to assess the “value” of each product type. Product cost is influenced by many factors, including product availability, raw material costs, specifier preferences, and installation requirements. Thus, a “value” assessment would have to be done on a project-specific basis.

5. CONCLUSIONS

Commonly used large-scale standardized performance tests have been discussed along with a review of results from independent large-scale tests performed on a range of rolled erosion control products (RECPs) or geomats (GMA) and hydraulically-applied erosion control products (HECPs) under the auspices of the National Transportation Product Evaluation Program (NTPEP).

The results to-date, demonstrate general trends associated with the relative ability of specific product types to protect against both rainfall-induced erosion and erosion associated with concentrated flows. While the trends provide general guidance, specifiers must consider the product-specific test results to assess the importance of component properties and the “manufacturer’s recommended” installation details to achieving the measured level of performance.

Still, when product-specific performance data is combined with project-specific cost information, a complete assessment of “best value” or “best management practice” is possible. On-going independent performance testing of erosion control products will be posted at www.ntpep.org

6. ACKNOWLEDGEMENTS

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