Large-scale Performance Testing of Erosion Control Products

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ABSTRACT
Sediment is the number one pollutant of US water resources even though erosion control best management practices (BMPs) are now commonly used. 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.

To-date, available 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. Thus, there is keen interest in the use of standardized testing procedures for evaluating the performance of a broad range of ECPs in a variety of applications, as well as characterizing the relevant "index" material properties of these ECPs. The combination of both tests facilitates "apples-to-apples" performance comparisons and links the relevant material properties used for the quality control to the tested products. Using this approach, it is possible to characterize full-scale, installed performance of commonly used ECPs. Furthermore, tested material properties can be "bench-marked" to facilitate future validation of ECPs without having to repeat large-scale performance tests.

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 ASTM procedures or be clear, easily implemented, modifications of the ASTM 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.

Keywords: RECPs, HECPs, erosion control, NTPEP, performance testing

1.0 INTRODUCTION TO MANUFACTURED EROSION CONTROL PRODUCTS AND ASSOCIATED TESTING

1.1 Manufactured Erosion Control Product Types

While conventional erosion control materials ranging from loose straw to rock riprap continue to be used extensively, new developments in erosion control systems are being used, including the following types of rolled erosion control products (RECPs) and hydraulically-applied erosion control products (HECPs):

- Temporary RECPs - For applications where natural vegetation alone will provide sufficient permanent erosion protection.
    - Open Weave Textile (OWT). OWTs are a degradable product composed of processed natural or polymer yarns woven into a matrix,
    - Erosion Control Blanket (ECB). ECBs are composed of processed natural or polymer fibers mechanically, structurally or chemically bound together to form a continuous matrix.
- Permanent RECPs - For applications where natural vegetation alone will not sustain expected flow conditions and/or provide sufficient long-term erosion protection.
    - A turf reinforcement mat (TRM) is a permanent RECP composed of non-degradable synthetic fibers, filaments, nets, wire mesh and/or other elements, processed into a permanent, three-dimensional matrix of sufficient thickness.
- HECPs. HECPs are manufactured, temporary, degradable, pre-packaged fibrous material that is mixed with water and hydraulically applied.

1.2 Quality Control, Quality Assurance and Performance Testing of ECPs

Basic index tests are typically needed to assure manufacturing quality control of ECPs. Mass per unit area, thickness, and tensile strength are index tests used by manufacturers to monitor quality. Additionally, other index tests, including water absorption and light penetration tests are used as measurements of material characteristics that more closely relate to performance. Not only are these tests useful for manufacturer quality control, but when used on the same materials deployed in large-scale tests, they serve to “bench-mark” the large-scale results.

Since 2003, the National Transportation Product Evaluation Program (NTPEP) has provided a program for independent testing of ECPs. The program has included both index tests and bench-scale, indexed performance tests. The goal of the program was 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.

Still, index properties alone are not useful for answering designers’ and specifiers’ questions regarding performance among different products and product categories. Thus, 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 NTPEP began offering independently verified full-scale performance testing to complement on-going index testing. NTPEP’s program relies exclusively on standardized test procedures.

2. LARGE-SCALE TESTING OF EROSION CONTROL PRODUCTS ON SLOPES

2.1 Slope Erosion Testing

A slope is generally eroded by rainfall impact and sheet runoff forces. Therefore, 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 6459-07 describe other laboratory and field systems for testing of slope erosion. The ASTM standard test method will be described in the following section.

2.2 Standard Full-Scale Testing: ASTM D 6459 - Standard Test Method for Determination of Rolled Erosion Control Product (RECP) Performance in Protecting Hillslopes from Rainfall-Induced Erosion.

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 RECP-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 thru 5 show this type of test setup.

Figure 1. ASTM D 6459 Slope Testing Facility
(bare soil test shown)

Figure 2. Testing of Rolled Erosion Control Products
(RECPs)

Figure 3. Eroded Surface after RECP Removed

Figure 4. Testing of HECPs

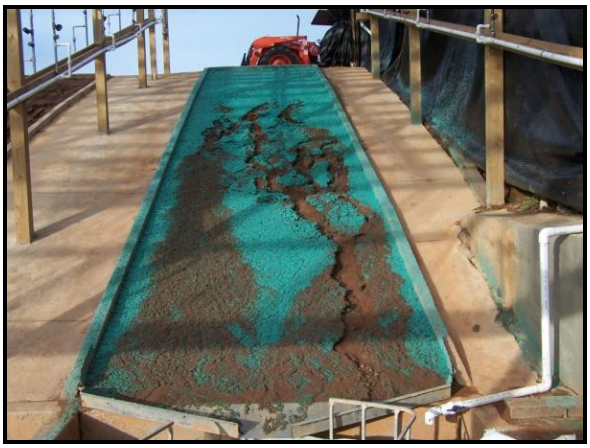

Figure 5. Testing Shows that Different Products and
Installations Perform Differently

2.3 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 in-situ 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.

3. LARGE-SCALE TESTING OF EROSION CONTROL PRODUCTS IN CHANNELS

3.1 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 m^2 (10 ft^2) 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 an 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 done. 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 6460-07 describe large-scale field channel erosion testing facilities and associated procedures. The ASTM standard test will be described in the following section.

3.2 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.

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 RECP without excessive erosion. Not only does a RECP material need to retain its integrity under the expected flow conditions, but it also needs to prevent the erosion of underlying soils. 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. 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.

Figures 6 thru 9 show this type of test setup.

Figure 6. Channels Tested in Triplicate

Figure 8. ECPs of All Types are Tested

Figure 7. Long-term Flows are Facilitated by Pumped Recirculation

Figure 9. Vegetated Turf Reinforcement Mats (TRMs) Can Be Tested

4. NTPEP TESTING TO-DATE.

As noted earlier, the NTPEP's nationwide quality assurance program for RECPs began in 2003 and uses three bench-scale "indexed" performance tests; as well as several index tests, including: mass per unit area, thickness, tensile strength, percent cover, and water absorption to provide member DOTs with independent data on the ECPs entered into the program. Sprague and Nelson (2009) reported on the testing and how it is useful in identifying a hierarchy of product types for each performance measurement. Additionally the data can be used by the individual states to identify products that are excessively outside the expected average for a particular product class.

4.1 NTPEP Large-scale Testing To-Date

Not available until recently, full-scale performance testing information has now been added to the voluminous amount of index and bench-scale data found at www.ntpep.org to better characterize and differentiate between various ECP types. Tables 1 and 2 show the results of independent large-scale slope and channel testing done under the NTPEP program. Average test results are further summarized in Figures 10 and 11.

Table 1. ASTM D 6459 Slope Tests for NTPEP 2010-2011

Product Type	Index Mass/Area (g/m^2)	Tensile Strength (kN/m)		Tensile Elongation (%)		Thickness (mm)	% Cover	Absorption OR Specific Gravity	Coverage Rate (kg/hectare) OR Anchorage Rate (staples/m^2)	C-Factor
		MD	XD	MD	XD					
HECP	364	0.14		3.2		7.3	98.5	527	3366	0.290
HECP	457	0.68		4.8		7.4	99.2	695	3927	0.003
1NS	261	1.80	0.68	36.1	28.3	12.6	90.4	344	1.8	0.053
2NS	274	1.98	1.33	34.8	31.6	10.4	77.5	399	1.8	0.012
2NC	374	3.36	2.15	11.6	14.5	8.3	88.3	232	2.1	0.006
HECP	441			n/a		5.0	98.7	n/a	3927	0.003
HECP	439			n/a		5.5	99.3	n/a	3927	0.001
2NS	211	2.08	1.33	33.2	37.5	8.4	63.6	218	1.4	0.024
2NS	261	2.51	1.75	15.9	11.9	9.8	88.6	301	2.2	0.005
2NC	237	4.27	2.15	26.5	38.5	5.9	73.7	205	1.3	0.010
1NX	287	1.17	0.40	28.5	22.9	9.9	55.1	189	1.3	0.039
Jute	405	16.05	13.40	14.4	20.4	4.7	55.1	425	1.8	0.085
HECP	365	1.73		4.4		5.0	99.0	395	3590	0.002
HECP	326	0.07		5.1		3.9	100.0	49	3366	0.005
HECP	208	0.05		1.2		2.9	98.0	265	2244	0.015
HECP	351	0.25		4.8		4.6	100.0	382	3927	0.003
2NC	387	5.20	3.57	24.1	26.5	6.4	88.0	270	2.0	0.004
HECP	201			n/a		3.5	94.9	n/a	2244	0.049

Product Type Key:
HECP = hydraulically-applied erosion control product;
1NS = single net straw blanket;
2NS = double net straw blanket;
1NX = single net excelsior blanket;
2NC = double net coconut blanket

Table 2. ASTM D 6460 Unvegetated Channel Tests for NTPEP 2010-2011

Product Type	Index Mass/Area (g/m^2)	Tensile Strength (kN/m)		Tensile Elongation (%)		Thickness (mm)	% Cover	Absorption OR Specific Gravity	Anchorage Rate ($staples/m^2$)	Perm. Shear, N/m^2
		MD	XD	MD	XD					
1NS	261	1.80	0.68	36.1	28.3	12.6	90.4	344	3.6	86.7
2NS	274	1.98	1.33	34.8	31.6	10.4	77.5	399	3.6	92.9
2NC	351	3.80	2.86	20.0	19.6	6.6	83.7	308	4.5	170.0
2NFF	353	7.25	4.36	24.9	18.4	7.3	79.8	0.92	5.4	119.7
3NFF	623	17.99	18.54	27.7	20.3	8.8	83.8	0.91	5.4	158.0
3NFF	656	16.07	13.19	31.2	24.7	14.9	84.4	0.92	2.7	119.7
3NFF+Panel	689	18.40	14.68	26.3	20.4	14.6	89.5	0.92	2.7	411.7
	13127	6.71	11.65	251.4	489.8	20.4	79.3	1.63	10.8	
2NS	259	2.37	1.38	31.0	32.3	9.5	72.4	260	4.5	99.6
1NS+2D Grid	339	1.65	0.84	30.1	27.7	9.2	97.5	493	3.9	103.9
	317	30.31	23.48	11.2	18.4	8.3	37.0	1.29		
2NSC	253	2.91	2.37	30.8	28.3	7.3	87.7	295	4.5	96.7
2NX	330	1.98	0.74	29.1	21.9	11.0	61.2	189	4.5	107.7
2NX	253	1.73	0.74	36.2	28.2	10.2	50.1	181	4.5	100.5
2NC	319	5.94	4.05	25.2	30.4	6.4	80.1	356	4.5	109.2
3NSC	473	10.91	11.58	33.3	22.1	15.7	95.5	0.92	4.5	144.6
3NC	514	14.35	10.60	29.3	18.8	14.8	93.8	0.92	4.5	153.2
2NFF	389	7.20	3.14	29.1	27.3	9.8	74.5	0.92	4.5	134.1

Product Type Key:
1NS = single net straw blanket;
2NS = double net straw blanket;
2NSC = double net straw-coconut blanket;
3NSC = triple net straw-coconut blanket;
2NX = double net excelsior blanket;
2NC = double net coconut blanket;
3NC = triple net coconut blanket;
2NFF = double net polyfiber matting;
3NFF = triple net polyfiber matting;
2D Grid = 2-dimensional geogrid;
Panel = scour resistant panel

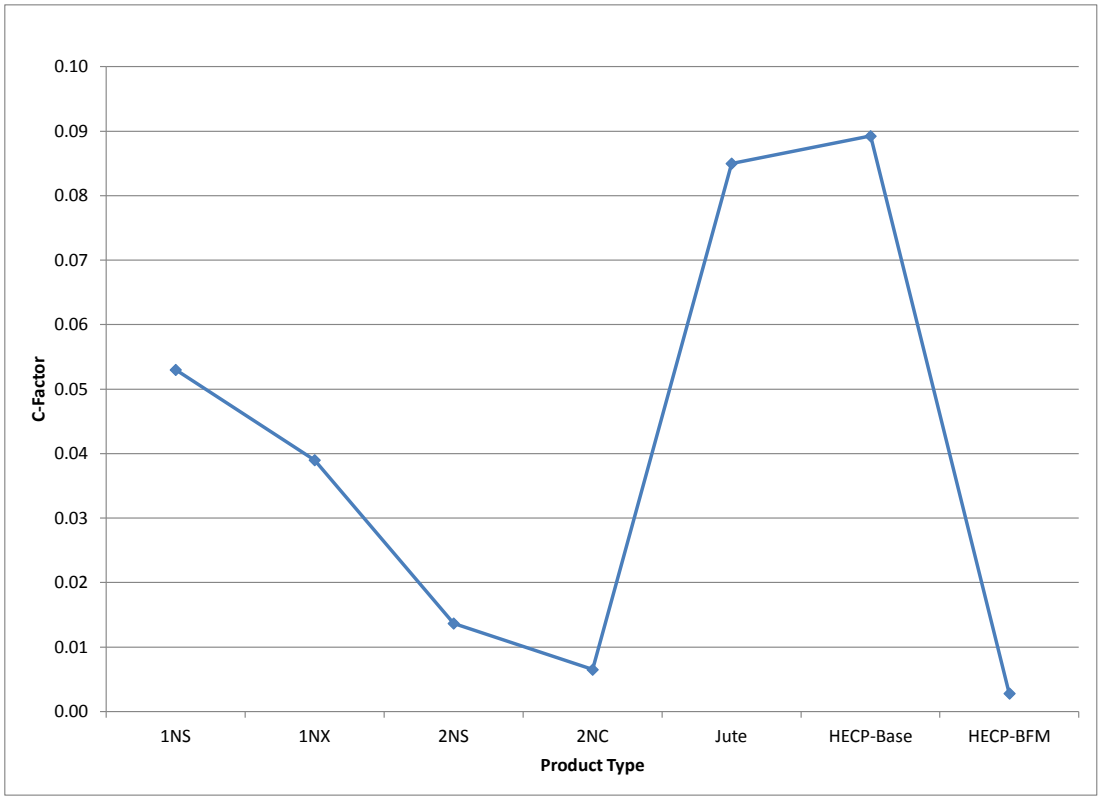

Figure 10. Slope Testing Summary – Product Type vs. C-Factor

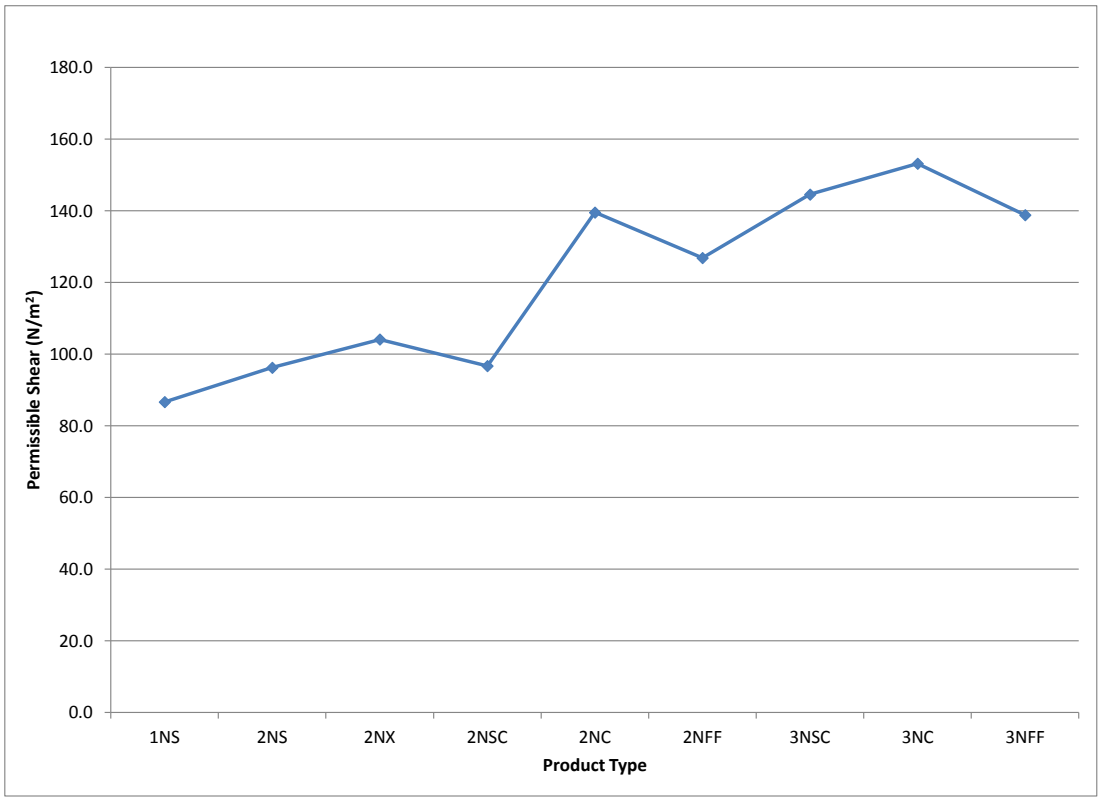

Figure 11. Channel Testing Summary – Product Type vs. Permissible Shear

4.2 Large-scale Testing Observations

A review of Figures 10 and 11 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 RECPs 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 mattings. 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. For example, as detailed in Table 1, three different single net straw blankets were tested for slope erosion protection using ASTM D 6459. The manufacturer recommended pinning frequency ranged from 1.43 to 2.15 staples/m^2 (1.2 to 1.8 staples/sy) and had corresponding C-Factors ranging from 0.024 to 0.005, clearly demonstrating the importance of knowing both the product type and the associated anchorage details to properly assess product-specific performance.

It should also be recognized that there may be considerable variation in components 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. For example, as detailed in Table 1, the three single net straw blankets discussed previously had a significant variation in mass/area. The tested products ranged from 210 to 275 g/m^2 (6.2 to 8.1 oz/sy) suggesting that both the product type and the minimum component properties are relevant to product-specific performance.

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) 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

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