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Correlation of Bench-scale and Large-scale Performance Testing of RECPs

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Abstract:

Large-scale laboratory and field tests have historically been used to evaluate the performance properties of rolled erosion control products (RECPs), using boundary conditions that simulate field conditions. More recently, a new class of test – the bench-scale performance test – that focuses on testing the RECP/soil system under carefully controlled "standard" conditions, but on a scale that facilitates lower cost and quicker testing has been developed. This series of bench-scale (i.e. small-scale) laboratory tests examine 1) slope erosion, 2) channel erosion, and 3) vegetation enhancement.

Since 2003, the National Transportation Product Evaluation Program (NTPEP) has used the bench-scale tests along with several index tests as an independent quality assurance program for the industry. Simultaneously, large-scale testing has been performed on some of the same products.

This paper will review the results of bench-scale tests performed to-date and provide correlations between the NTPEP bench-scale results and standardized large-scale tests that validate the use of the bench-scale tests for independent quality assurance.

Keywords: RECPs, erosion control, NTPEP, performance testing

1.0 Introduction to RECPs

While conventional erosion control materials ranging from loose straw to rock riprap continue to be used extensively, numerous different prefabricated erosion control systems are being used, including the following types of rolled erosion control products (RECPs):

- Light-weight synthetic nets or woven organic meshes;
- Organic (straw, coconut, excelsior) fiber mats attached to organic or synthetic netting;
- Synthetic fiber mats attached to or sandwiched between synthetic nets;
- 2- and 3-dimensional welded or woven synthetic filament mat structures;

2.0 Quality and Performance Characterization of RECPs

Just a few basic "index" tests are typically needed to assure manufacturing quality control of RECPs. Mass per unit area, thickness, and tensile strength are typically run by manufacturers to monitor quality, and these properties, therefore, can usually be certified by the manufacturer with statistical certainty. But simply being able to describe RECPs using index properties has not answered the designers' questions concerning how well different products will perform, thus performance tests are needed.

Performance tests are, as the name suggests, used to evaluate the performance of RECPs, typically using boundary conditions that simulate field conditions. Common performance evaluations focus on the RECP's ability to protect against soil loss and to enhance vegetation establishment. Because of the high cost and extended time periods required for full-scale performance testing, a new class of test – the bench-scale "indexed" performance test – has been developed that focuses on testing the RECP/soil system under carefully controlled "standard" conditions, but on a scale that facilitates lower cost and quicker testing. The bench-scale (i.e. small-scale) laboratory tests evaluate 1) slope erosion, 2) channel erosion, and 3) germination and initial vegetation enhancement and have been standardized by ASTM.

In 2003, the National Transportation Product Evaluation Program (NTPEP) established a program for testing RECPs using the bench-scale tests along with several index tests. The goal of the program was to minimize the amount of duplicative testing of erosion control products done by individual State Departments of Transportation (DOTs) by providing a process where manufacturers/suppliers submit their products to the NTPEP for independent testing. The results of the testing are then shared with participating DOTs. The results of the program may be used for assessing conformance to material specifications or for placing specific products on a DOT's qualified products list (QPL). The NTPEP program serves as a kind of nationwide quality assurance (QA) program for the DOTs.

There has been much interest in correlating the QA bench-scale test results with full-scale testing. In fact, the FHWA's National Cooperative Highway Research Program funded a study by Colorado State University (CSU) in 2004-2005 to attempt to obtain and correlate data supplied by RECP manufacturers. Unfortunately, the study was inconclusive though the investigators did find a likely correlation between shear testing methods.

Since the CSU study however, both bench-scale and large-scale test procedures have been standardized through the ASTM International standards development process, resulting in rigid procedures outlining specifics such as test specimen sizes, minimum measurement requirements and reporting protocols. This has afforded a more meaningful opportunity to compare bench-scale and large scale erosion testing results as all results are being produced the same way following the same procedures. In addition, a wealth of data using these standardized procedures has become available privately and through the NTPEP program inviting relevant comparisons.

3.0 Summary of Standardized Tests for Slope Erosion & Runoff Reduction

3.1 Bench-Scale. 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

This test method sets forth the procedures for evaluating the ability of RECPs to protect soils from rain splash and immediate runoff-induced erosion. The critical element of this protection is the ability of the RECP to absorb the impact force of raindrops, thereby reducing soil particle loosening through "splash" mechanisms. The test method utilizes containers of both bare and RECP-protected soil that are exposed to simulated rainfall and immediate runoff for 30 minutes in the apparatus shown in Figures 1 and 2, which includes a sloped table enclosed by a "shower" curtain. Rainfall is simulated using a laboratory drip-type simulator capable of creating uniform drops with a median diameter of 3.0 to 3.5 mm from a drop height of 2.0±0.1 m and producing rainfall intensities as high as 150 mm/hr. The amount of soil that splashes or is washed out of the containers is collected and weighed. From this data, an appropriate soil loss ratio or associated C-factor can be calculated by comparing the RECP-protected soil loss to the control for a given soil type and a project-specific slope and rainfall intensity.

Figure 1. Slope Erosion Apparatus

Figure 2. Runoff Collected from Control (above) and Protected (below)

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

A slope is generally eroded by rainfall impact and sheet runoff forces. This procedure has been developed for the measurement of the amount of soil loss caused by rainfall generated by a rainfall simulator. At the same time, the runoff is also measured. Soil type, slope, and rainfall rate and duration are controlled. Rain is applied to the plots and sediment-laden runoff is collected, measured, dried, and then the resulting sediments weighed. 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, 40-ft long and 8-ft wide;
- Minimum 12-inch compacted soil veneer;
- Simulated rain system with 14-ft drop height & up to 6+ inches/hr capacity.

Figures 3 and 4 show this type of test setup.

Figure 3. Prepared Slopes Ready for Testing (Control Slopes)

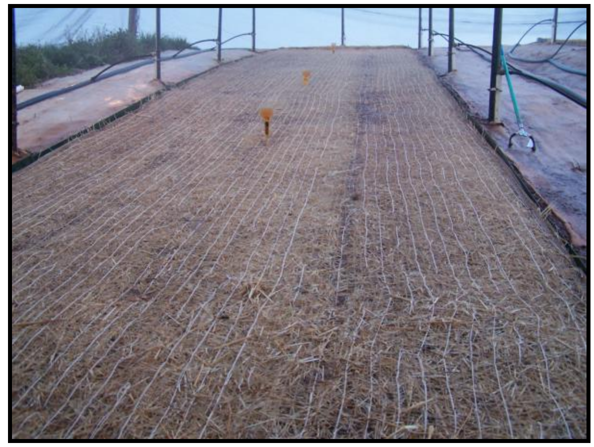

Figure 4. RECP Being Tested On Slope

4 Summary of Standardized Tests for Permissible Shear and Channel Erosion

4.1 Bench-Scale. 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

The test method sets forth the procedures for evaluating the ability of RECPs to protect soils from flow-induced erosion. The test method utilizes containers of RECP-protected soil that are immersed in water and subjected to shear stresses caused by the rotation of a three-blade impeller for 30 minutes in an apparatus such as the one shown in Figures 5 and 6. The amount of soil that erodes is found by weighing the containers under water both before and after testing. The shear stress test apparatus includes a tank, test well, motor, plastic lid, and impeller. The three-blade impeller is mounted in the cylindrical tank so that the lower edge of the blades is slightly above the floor of the tank. The sample test well is a recession in the floor of the tank that holds the pots of soil prepared for testing. When pots are placed in the well, the test surface is flush with the floor of the tank. Pots holding soil and test specimens are normally 200 mm diameter plastic pipe sections with height of 100 mm. The results of the testing include the amount of soil lost at various shear stresses. From this data, an appropriate permissible shear (τ_p) can be calculated by assuming a critical amount of soil loss (typically 13 mm).

Figure 5. Shear Erosion Apparatus

Figure 6. Inside the Shear Apparatus

4.2 Large-Scale. 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 5% or 10% slope;
- Rectangular cross-section at least 2-ft width and 2-ft high side walls;
- 3 replicate test sections;
- 12-inch compacted soil veneer;
- Increasing Shear Levels @ 30 minutes each;
- ½-inch average soil loss failure criteria.

Figures 7 and 8 show this type of test setup.

Figure 7. 10% Flume for Higher Shear Levels

Figure 8. RECP Secured to Soil in Flume and Ready for Testing

Figure 9. Germination Pots Grow Vegetation Inside Growth Chamber

5 Summary of Standardized Tests for Germination and Initial Vegetation Growth Enhancement

5.1 Bench-Scale. 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

The test method establishes procedures for evaluating the ability of RECPs to encourage seed germination. The results of the test can be used to compare RECPs and other erosion control methods to determine which are the most effective at encouraging the growth of vegetation in different climates. Testing is done within a growth chamber as shown in Figure 9. Containers of soil are sown with seeds and then covered with an RECP. Additional containers are left uncovered as controls. The light, water, and temperature are regulated and documented. The rate of germination is measured periodically throughout the test, and the weight of vegetation is calculated at the conclusion of the test. Test sets are designed to evaluate an RECP's ability to enhance the rate and quantity of germination. The testing results include the rate and total weight of germination after 21 days. From this data, a percent enhancement can be calculated by comparing results from the RECP covered soil to the control.

5.2 Large-Scale. There is no standardized large-scale test method for Germination and Initial Vegetation Growth Enhancement.

6.0 NTPEP Update.

As noted earlier, the NTPEP's nationwide quality assurance program for RECPs began in 2003 and uses the three bench-scale tests discussed above, along with some index tests, such as mass, thickness, and tensile strength, to provide member DOTs with independent data on RECPs entered into the program. Table 1 shows the number and types of RECPs that have been tested, and some statistics related to test results.

Table 1. Select Statistics for NTPEP Testing 2003-2007

Product Type	Number Tested	Mass		Bench Slope		Bench Shear		Bench Germ	
		Avg osy	Std Dev %	Avg C	Std Dev %	Avg psf	Std Dev %	Avg %	Std Dev %
Single and Double Net Type 1 Fiber	69	7.7	22	0.11	31	1.5	22	447	27
Single and Double Net Type 2 Fiber	20	11.3	31	0.12	38	2.4	21	497	20
Single and Double Net Type 3 Fiber	17	8.5	16	0.09	43	2.2	16	528	26
Single and Double Net Type 4 Fiber	15	9.2	27	0.07	44	2.7	20	436	30
Single and Double Net Type 5 Fiber	13	11.8	32	0.14	34	2.7	19	493	26
All Other Constructions	21	-	-	-	-	-	-	-	-

While detailed reports are available to participating DOTs, only generic classes and select statistics are presented in Table 1 to demonstrate that one of the primary challenges facing the manufacturing community is the large variability in the products, as demonstrated by the relatively high standard deviation in the mass results. Additionally, the comparable and sometimes higher variability found in the bench-scale test results indicates that the product variability, as well as, testing variability are indeed affecting test results, and the testing community may need to further refine testing protocols. Still, the data appears to be very 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.

7.0 Correlating Bench-scale to Large-scale Testing

A major difficulty to earlier efforts to make correlations between bench-scale and large-scale testing involved the fact that the testing was done at different times with different materials using nonstandard procedures. Recently, a relatively small data set of test results using the same material and standardized procedures for both bench-scale and large-scale tests was developed. The basis for the correlation and the graphical presentation of the promising results follows.

7.1 Slope Erosion Testing: ASTM D 7101 (bench-scale using sand) vs. ASTM D 6459 (large-scale using sandy loam)

Comparison of C-Factors determined at a comparable R-Factor: Soil loss is a function of rainfall exposure (intensity and duration) as well as soil erodibility, topography, and cover. The cover and, to some degree, the topography (slope steepness, not length) are common between test methods, thus, the primary concern is to compare performance at a common level of rainfall exposure for an appropriate area of soil surface. The appropriate area of rainfall impact and runoff for bench-scale testing is considered to be the total area of the runoff "ramp" associated with the tested pot of soil (i.e. 1ft x 3 ft = 3ft^2) because this entire area generates runoff that crosses the soil surface. Additionally, an R-Factor related to the associated total soil loss from bench-scale testing (i.e. sum of the soil losses at 3 rainfall intensities) was derived using RUSLE calculations. The "standard" bench-scale R-Factor was calculated to be 307 ft ton in / acre hr.

The soil loss associated with an R-Factor of 307 was then picked off the regression curve fitted to the large-scale test results for both protected and control testing. The ratio of the soil losses is the associated C-Factor to compare to bench-scale testing.

Example:
Bench-scale protected – 49.4 g total soil loss from 2, 4, 6 in/hr rain @ 30 mins. (R = 307) = 0.79 T/acre
Bench-scale unprotected – 450 g total soil loss from 2, 4, 6 in/hr rain @ 30 mins. (R = 307) = 7.2 T/acre

C = 0.79/7.2 = 0.110

Large-scale protected – Total soil loss from soil loss/R-factor curve @ R = 307 = 0.72 T/acre
Large-scale unprotected – Total soil loss from soil loss/R-factor curve @ R = 307 = 28 T/acre

C = 0.72/28 = 0.026

Correlation of products tested in both standard bench-scale and large-scale slope tests is shown in Figure 10.

7.2 Channel Erosion Testing: ASTM D 7207 (bench-scale using sand) vs. ASTM D 6460 (large-scale using sandy loam)

Comparison of Limiting Shears:
Soil loss is a function of shear stress, as well as, soil erodibility and cover. The cover is common between test methods and the soil erodibility is a fixed property of the soil used in the tests, thus, the primary concern is to compare performance at a common level of shear stress. That common level of shear stress is that at which an average of ½-inch of soil is lost during a 30 minute flow. As both test methods report this value, a direct comparison of test results can be made.

Example:
Bench-scale protected – ½-inch soil loss intercept on soil loss/shear stress curve = 1.36 psf

Large-scale protected – ½-inch soil loss intercept on cumulative soil loss/shear stress curve = 1.50 psf

Correlation of products tested in both standard bench-scale and large-scale channel shear tests is shown in Figure 11.

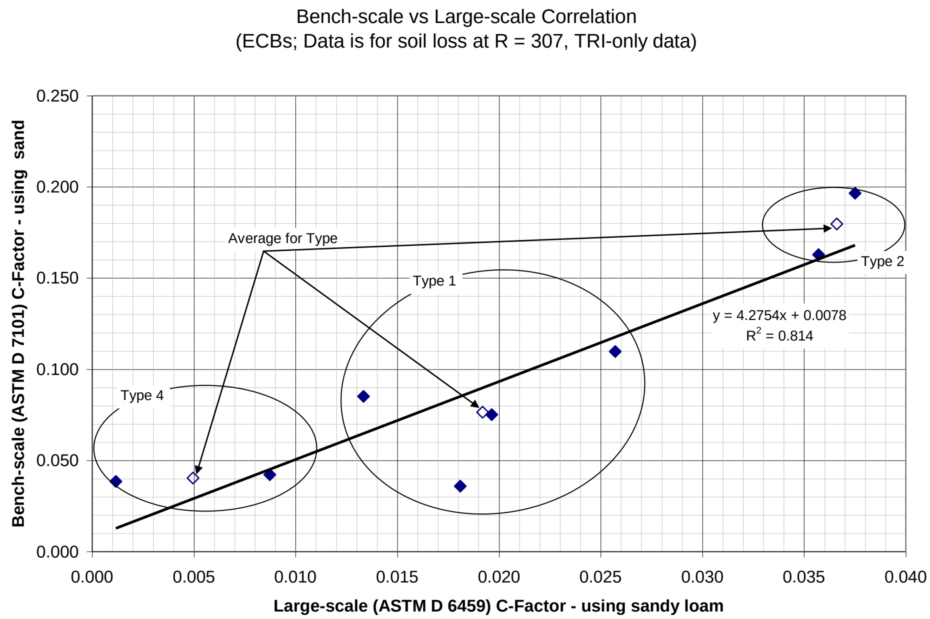

Figure 10. Bench-scale vs. Large-scale Slope Results

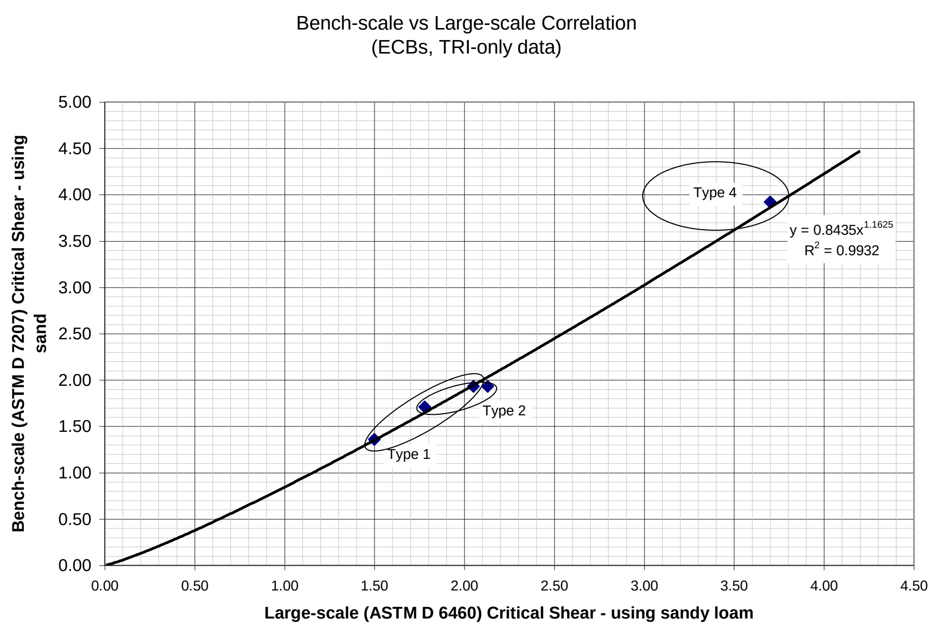

Figure 11. Bench-scale vs. Large-scale Channel Shear Results

8.0 Conclusion

Standardization of both bench-scale and large-scale slope and channel erosion testing has facilitated more orderly and frequent performance testing of RECPs. The NTPEP's use of standard test procedures as part of its nationwide quality assurance program is providing DOTs with independent data from which "apples-to-apples" product comparisons can be made. Additionally, standardized testing appears to offer the potential to correlate frequently run bench-scale tests with infrequent large-scale tests.