ECTC provides guidelines for rolled erosion-control products

The performance and design guidelines developed by the Erosion Control Technology Council make it easy to select the most appropriate, cost effective product for your erosion-control application.

By Deron N. Austin and Lynn E. Ward

The use of rolled erosion-control products (RECPs) has grown at a swift pace during the last decade. As a result, engineers and designers have prompted government officials, university researchers and product manufacturers to develop reliable methods to determine the effectiveness of these products in slope protection, stream bank rehabilitation and channel lining applications. These demands have resulted in several organizations focusing on developing standard performance and design guidelines for the use of erosion-control materials.

One of these organizations is the Erosion Control Technology Council (ECTC), which is made up of 13 RECP manufacturers (Niemeier and Rodencal, 1994). The International Erosion Control Association (IECA) and American Society for Testing and Materials (ASTM) also are working on standards. These organizations enlist the support of engineers, researchers and manufacturers in establishing industry guidelines for erosion-control practices.

There are two basic RECP types; temporary degradable and long-term nondegradable. Temporary degradable RECPs are used to protect newly seeded areas from environmental forces, such as wind, rain and intense sunlight, and to enhance the growth of vegetation. Once established, the vegetation itself must be able to resist erosive forces, since temporary products will degrade. Long-term nondegradable RECPs, constructed of ultraviolet-stabilized synthetic materials, also protect the seed and inhibit erosion prior to germination. In addition, these products provide permanent vegetation reinforcement, capable of withstanding much higher velocities and shear stresses than vegetation alone (Lancaster and Austin, 1994).

Designers use documentation of past product performance, full-scale and lab-

Figure 1. The Texas Transportation Institute (TTI) has conducted full-scale field evaluations to test the effectiveness of RECPs used in slope and channel applications.

oratory testing, industry standards, design programs and field experience to properly select any RECP.

Performance evaluations

Case histories

The oldest and most commonly accepted method of initially selecting an appropriate RECP is to use project case histories. The first question a designer often asks is, "Where has it been successfully used under similar conditions in my area?" Nothing lends more credibility to a civil engineering product than its successful use in a similar application. Extensive lists, job reports and case histories of completed projects in various environments typically are available from RECP manufacturers or distributors.

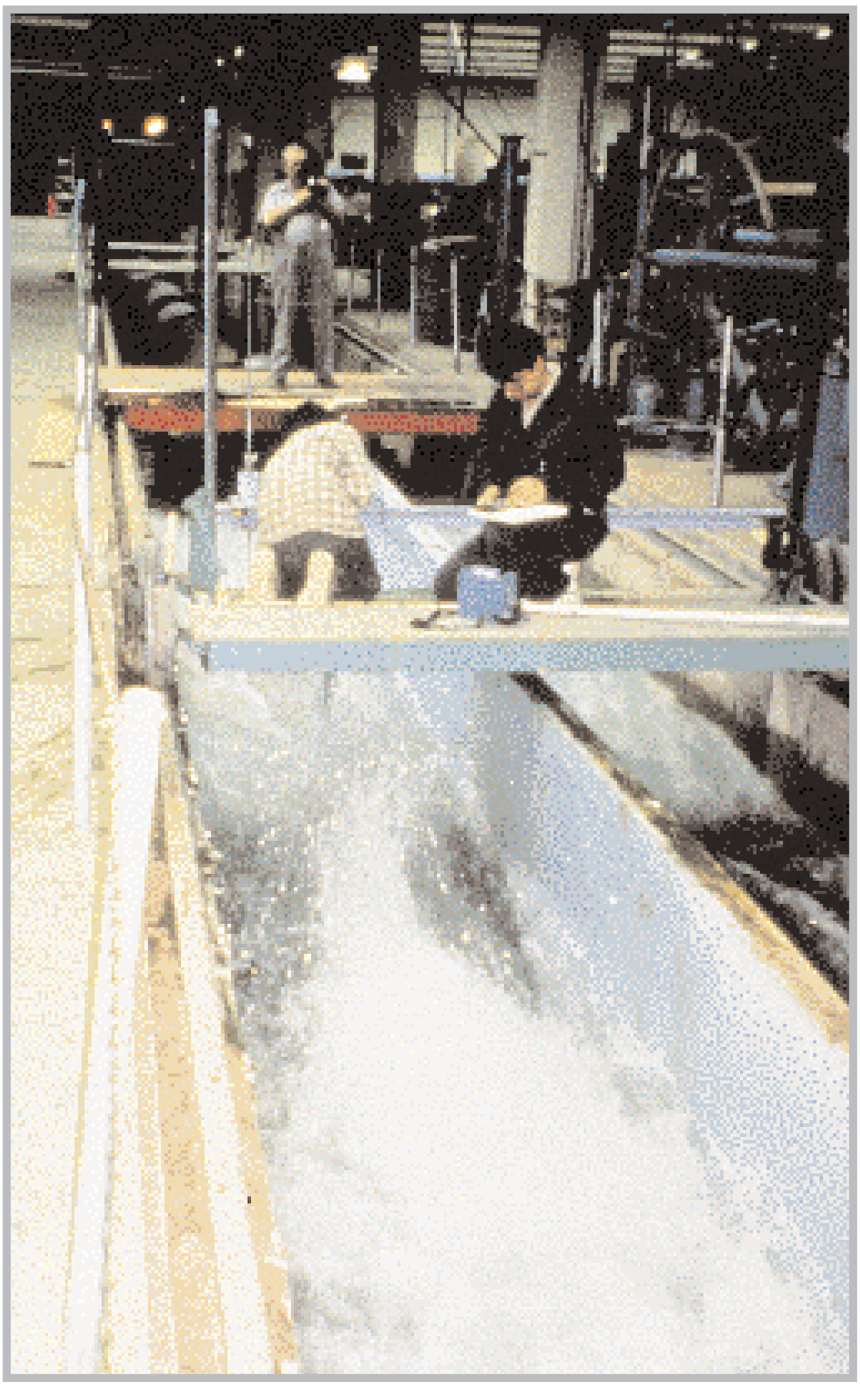

Figure 2. Extensive laboratory flume tests have been conducted to determine the performance limits of RECPs.

Full-scale tests

Well-documented field testing has provided valuable data for designing with, and selecting RECPs for erosion-control projects. The Construction Industry Research and Information Association (CIRIA) conducted a two-year study to determine the erosion resistance of plain and reinforced grass when subjected to channelized flows. CIRIA developed recommendations for the use of RECPs, using velocity as the limiting criteria.

The limiting velocities for mature unreinforced grass were 4.5 m/sec. (14.7 ft./sec.) for short-flow durations (0.5 hours), and 2 m/sec. (6.5 ft./sec.) for long-term flows (50 hours). Typical long-term nondegradable products, when fully vegetated, resulted in elevated limiting velocities of 6 m/sec. (19.6 ft./sec.) for the short-flow duration and 4.4 m/sec. (14.4 ft./sec.) for the longer, 50-hour duration (Hewlett et al., 1987). Over time, these recommendations have proven highly reliable for fully vegetated waterways.

The Texas Transportation Institute (TTI) has conducted similar testing on the effectiveness of RECPs used in slope and channel applications (**Figure 1**). Under contract with the Texas Department of Transportation (TX DOT), TTI conducted a series of tests on 2H:1V and 3H:1V clay and sandy slopes, and several 3 percent and 7 percent earthen flumes. RECP manufacturers submitted candidate materials to TTI for evaluation. Erosion-control products that pass the performance criteria set by TX DOT are added to the list of approved materials (Northcutt, 1993). The Federal Highway Administration (FHWA) and other state DOTs recently have performed smaller scale evaluations of RECPs.

Laboratory tests

University and independent testing laboratories have used indoor hydraulic flumes and rainfall simulators to measure the ability of RECPs to protect soil and establish vegetation when subjected to various flow rates and rainfall events. Extensive tests conducted by Colorado State University and the Utah State University Water Research Laboratory have determined the velocity and shear stress resistance of RECPs used in channel lining applications.

Table 1. Typical range of maximum shear stress of various RECPs

Typical maximum shear stresses for short duration flows

RECP category	Product type	lbs/ft.^{2}	N/m^2
Low velocity degradable	ECN	0.1–0.2	4.5–9.5
	ECM	0.4–3.0	20–140
	ECB–single net	1.4–2.0	70–95
High velocity degradable	ECB–double net	2.0–3.0	95–140
Long-term nondegradable	TRM–unvegetated	3.0–6.0	140–280
	TRM–vegetated	5.0–8.0	240–380

Note: Adapted from Chen and Cotton, 1988; Gray, 1995; Northcutt, 1995

Laboratory test flumes are typically 0.6 to 1.2 m (2 to 4 feet) wide, 0.6 to 1.2 m (2 to 4 feet) deep and up to 15.2 m (50 feet) long. They are either rectangular or trapezoidal in shape; some have adjustable bed slopes. Usually, a smooth approach section precedes the flume to allow turbulent flow to stabilize before it enters the instrumented test area (**Figure 2**).

Test specimen size is based on the flume's dimensions and the desired results. Larger flumes typically are used to evaluate the performance of RECPs by installation of 14.6–m– (48–foot–) long test specimens on a soil subgrade. Larger specimens can be evaluated on vegetated or unvegetated test conditions.

Smaller flumes are used to evaluate the shear stress resistance of unvegetated RECPs by placing a 1.5–m– (5–foot–) long specimen on rigid floor. The RECP to be evaluated is anchored to the bottom of the flume with staples. A product usually can be tested for up to 50 hours duration until material "failure" (or the maximum capacity of the flume is reached). Although results of these evaluations can be obtained from manufacturers, short-term velocities of 6 m/sec. (19.6 ft./sec.) and shear stresses of up to 384 N/m^2 (8 psf) have been reported under standard vegetated conditions.

Rainfall simulators have been used around the world for many years to measure the runoff, infiltration and erosion rates of various bare and protected soil slopes. Drexel University's Geosynthetic Research Institute (GRI) and Utah State University's Water Research Laboratory have constructed such testing equipment to evaluate RECPs.

The test devices consist of a rainfall-producing unit, an adjustable test slope and a measurement/data collection system. The artificial rainfall impacts the sloped soil surface, allowing researchers to measure the effectiveness of a product. Results from one study conducted at GRI indicate that all RECPs tested reduced the sediment yield by a minimum of 60 percent, compared to unprotected conditions (Rustom and Weggel, 1993).

Channel lining design criteria

Hydraulic characteristics of a wide variety of channel lining materials have been available for years, as evidenced by research similar to that discussed earlier. The introduction of RECPs as channel liners simply required modifications to existing flumes and development of limiting hydraulic conditions. The test results mentioned previously allow engineers to evaluate confidently the performance of reinforced vegetated waterways.

Federal guidance

The Hydraulic Engineering Circular Number 15 (HEC-15), published by the FHWA in 1988, endorses flexible lining materials by providing step-by-step design procedures (Chen and Cotton, 1988). The document proposes limiting shear stress values for bare soil, riprap, vegetation, fiber roving systems and a wide variety of rolled erosion-control products, including meshes, blankets and permanent synthetic mats. The FHWA also developed a corresponding computer software titled, "Flexlin."

Dozens of well-documented laboratory investigations and full-scale field tests, however, demonstrate that the performance limits of reinforced vegetation far exceed the guidelines given in HEC-15 (Carroll et al., 1991; Dodson, 1990; Hewlett et al., 1987; Hoffman and Adamsky, 1982; Keller and Middlebrooks, 1988; Theisen, 1992). In fact, reinforced vegetated channel linings have resisted velocities in excess of 4.3 m/sec. (14.1 ft./sec.) and shear stresses greater than 384 N/m^2 (8 psf) for durations up to 50 hours (Carroll et al., 1991, Hewlett et al., 1987; Theisen, 1991; Theisen, 1992). The design guidelines shown in **Table 1** are a result of these findings. Using product classifications previously defined by the ECTC, the table gives a range of values for erosion-control nets (ECNs), erosion-control meshes (ECMs), erosion-control blankets (ECBs) and turf reinforcement mattings (TRMs) (Lancaster and Austin, 1994).

Manufacturers guidance

Most RECP manufacturers have established maximum permissible velocity and shear stress values for use in channel lining design. These values typically are conservative and already include factors of safety. Two commercially available computer software programs also assist engineers in designing reinforced vegetated waterways. Generally sold for a modest cost by the manufacturer or local representative, these programs perform simple to complex channel analysis.

The software can determine flow velocities and shear stresses on the channel bottom and on each side slope from given channel geometry, hydraulic condition and vegetative class. The results are compared to the critical values for the proposed RECP by dividing expected design velocities and shear stresses by actual permissible velocities and shear stresses of the proposed lining material. If this value is greater than 1.0, the RECP is adequate as a channel lining material.

Design calculations

Regardless of the guidance or tools used, the actual calculations are basically the same. Open channel flow conditions are a function of geometry, discharge, roughness and channel slope (French, 1985).

Velocity in the channel is computed as:

$$V_{ave} = \frac{\varnothing}{n} R^{2/8} S_f^{1/2}$$

Where:
V_{ave} = average velocity in the cross section, m/sec. (ft./sec.)
$\varnothing$ = factor correcting system of units used ($\varnothing$ = 1.49 for English units and $\varnothing$ = 1.0 for SI units)
n = Manning's roughness coefficient
R = hydraulic radius, equal to the cross-sectional area, A, divided by the wetted perimeter, P
S_f = friction slope of the channel approximated by the average bed slope (for uniform flow conditions).

Shear stress, or tractive force, is then calculated as:

$$\Upsilon_{ave} = \delta R S_f$$

Where:
Υ = average shear stress in cross sec-

Table 2. Typical range of sandy soil slopes of various RECPs for surficial protection

Category	Product type	Batter (H:V)
Low velocity degradable	ECN	up to 3:1
	ECM	up to 2:1
	ECB–single net	up to 1.5:1
High velocity degradable	ECB–double net	up to 1.5:1
Long-term nondegradable	TRM	up to 0.5:1

Note: Adapted from TX DOT, 1995

tion, kg/m^2 (psf)
δ = unit weight of water, 9.8 kN/m^3 (62.4 lbs./ft.^{3})
R = hydraulic radius, equal to the cross-sectional area, A, divided by the wetted perimeter, P; can also be equal to the maximum flow depth, d_{max}, when the channel is considered "hydraulically wide" (eg. the channel width is greater than 5 times d_{max})
S_f = friction slope of the channel approximated by the average bed slope (for uniform slope conditions).

Slope protection design criteria

Selection of an appropriate RECP to protect disturbed soil slopes depends on many factors, including expected project life, down-slope length, soil type, vegetative class, local climactic conditions, slope angle, slope orientation, drainage patterns and personal experience.

Manufacturers guidance

Since many RECPs display sufficient tensile strength to reduce surficial soil erosion and promote vegetative growth on a variety of stable soil slopes, manufacturers typically bracket their products based upon specific slope angles and maximum slope lengths. **Table 2** illustrates general material recommendations for stable, sandy soil slopes.

Design calculations

Although initial selection of the RECP is based on a combination of somewhat arbitrary factors, determination of the annual soil loss from a disturbed slope may be predicted using the Universal Soil Loss Equation (USLE). By comparing the expected annual amount of erosion from an unvegetated soil slope to one protected with an RECP, one can calculate the amount of erosion prevented using the following equation:

$$A = R\ K\ L\ S\ C\ P$$

Where:
A = computed soil loss per unit area per year, metric tons/ha (tons/acre)
R = rainfall and runoff factor
K = soil erodibility factor
L = slope-length factor
S = slope-steepness factor
C = cover and management factor (protected and unprotected conditions)
P = support practice factor.

Some of the full-scale field tests and rainfall simulator studies previously described have resulted in computed C factors for soil slopes protected with RECPs. Although these values are unique to the specific conditions and products tested, some manufacturers have applied C factors to individual products. This value can help describe the degree of protection offered by a specific RECP. By calculating the difference between unprotected and RECP-protected conditions, the amount of soil loss prevented can be predicted.

Conclusions

The growth of rolled erosion-control products complements the increasing focus on reducing surface water runoff, controlling sediment release and eliminating soil losses from construction sites. Researchers, practitioners and product manufacturers are keeping pace with designers by developing performance standards and design guidelines to determine the effectiveness of RECPs in slope protection, stream bank rehabilitation and channel lining applications. With a thorough understanding and selection of the proper vegetation, these guidelines can be used with confidence to select the most appropriate, cost-effective erosion-control product.

RECPs are technically superior to spray-on mulches and bonded fiber matrixes and more economical than hard armor systems. Members of the ECTC can be contacted if additional aid is needed to select an appropriate RECP for challenging erosion-control applications. Most manufacturers can provide extensive case histories, field and laboratory test data and design software to make your job easier, save your client money and help preserve our environment. It's a win-win-win proposition. For further information, contact the ECTC, P.O. Box 9485, Moscow, Idaho 83843

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References

Carroll, Jr., R.G., J. Rodencal and M.S. Theisen, "Evaluation of Turf Reinforcement Mats and Erosion Control and Revegetation Mats under High Velocity Flows," Proceedings of the XXII Annual Conference of the IECA, Orlando, Fla., 1991, pp. 131–145.

Chen, Y.H., and B.A. Cotton, "Design of Roadside Channels with Flexible Linings," Hydraulic Engineering Circular No. 15 (HEC-15), FHWA, Publication No. FHWA-IP-87-7, USDOT/FHWA, McClean, Va. 1988.

Dodson, G.I., "Vegetated Waterway Linings Reinforced with Geomatrix Matting: Design Methodology and Performance," Proceedings of the XXI Annual Conference of the IECA, Washington, D.C., February 1990, pp. 249–255.

French, R.H., "Open-Channel Hydraulics," McGraw-Hill Inc. New York, N.Y., 1985.

Gray, D., and R. Sortir, "A Guidebook for Biotechnical and Soil Bioengineering of Slopes," Chapter 9 draft text, expected for publication by John Wiley & Sons Inc., late 1995.

Hewlett, H.W.M., L.A. Boorman, and M.E. Bramley, "Design of Reinforced Grass Waterways," Construction Industry Research and Information Association, Report No. 116, London, England, 1987.

Hoffman, G.L., and R. Adamsky, "Nylon Erosion Mat," presented at the Transportation Research Board 61st Annual Meeting, Washington, D.C., January 1982.

Keller, E.J., and P.B. Middlebrooks, "Channel Protection Criteria Update," Georgia Department of Transportation Research Project No. 8307, Atlanta, Ga., 1989.

Lancaster, T., and D.N. Austin, "Classifying Rolled Erosion Control Products: A Current Perspective," *Geotechnical Fabrics Report*, October/November 1994, pp. 16–22.

Niemeier, J., and J. Rodencal, "Who Is The ECTC?," Erosion Control magazine, September/October 1994, pp. 40–41.

Northcutt, P.E., "Field Performance Testing of Roll-Type Erosion Control Blankets through the Erosion Control Field Laboratory," Proceedings of the XXIV Annual Conference of the IECA, Indianapolis, Ind., February 1993, pp. 187–202.

Northcutt, G., "Geosynthetics Add Another Dimension to Erosion Control," Erosion Control magazine, May/June 1995, pp. 34–41.

Rustom, R.N., and J.R. Weggel, "A Study of Erosion Control Systems: Experimental Results," Proceedings of the XXIV Annual Conference of the IECA, Indianapolis, Ind., February 1993, pp. 255–275.

Texas Department of Transportation, "Final Performance Analysis through the 1994 Test Cycle–Class 1 Slope Protection," Performance Testing of Selected Erosion Control Products at the TX DOT/TTI Hydraulics and Erosion Control Laboratory, prepared by Paul Northcutt, September 1995.

Theisen, M.S., "Evaluation of Biotechnical Composites Under High Velocity and Shear Conditions," Proceedings of the XXIII Annual Conference of the IECA, Reno, Nev., 1992, pp. 285–305.

Theisen, M.S., "The Role of Geosynthetics in Erosion and Sediment Control: An Overview," Proceedings of the 5th GRI Seminar, Philadelphia, Pa., December 1991, pp. 188–203.