Designation: D6460 – 12

Standard Test Method for Determination of Rolled Erosion Control Product (RECP) Performance in Protecting Earthen Channels from Stormwater-Induced Erosion[1]

This standard is issued under the fixed designation D6460; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope*

1.1 This test method covers the guidelines, requirements and procedures for evaluating the ability of Rolled Erosion Control Products (RECPs) to protect earthen channels from stormwater-induced erosion. Critical elements of this protection are the ability of the RECP to:

1.1.1 Neutralize and absorb the hydraulic force of stormwater, thereby reducing soil particle loosening through "scour" mechanisms;

1.1.2 Slow runoff and encourage sedimentation, thereby reducing soil particle transport downstream;

1.1.3 Absorb shear forces of overland flow;

1.1.4 Trap soil particles beneath; and

1.1.5 Promote the establishment of vegetation.

1.2 This test method utilizes full-scale testing procedures, rather than reduced-scale (bench-scale) simulation, and is patterned after conditions typically found on construction sites prior to and after revegetation work. Further, procedures for evaluation of baseline conditions are provided. Thus, test preparation, test execution, data collection, data analysis and reporting procedures herein are intended to be suitable for testing of bare soil, unvegetated RECP, vegetated soil and vegetated RECP conditions.

1.3 This test method provides a comparative evaluation of an unvegetated RECP to baseline bare soil conditions and a vegetated RECP to a baseline, vegetated condition under controlled and documented conditions.

1.4 The values stated in SI units are to be regarded as standard. The inch-pound units given in parentheses are provided for information purposes only.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use. Also, the user must comply with prevalent regulatory codes, such as OSHA (Occupational Health and Safety Administration) guidelines, while using the test method.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

C136 Test Method for Sieve Analysis of Fine and Coarse Aggregates
D422 Test Method for Particle-Size Analysis of Soils
D698 Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (12 400 ft-lbf/ft^3 (600 kN-m/m^3))
D1556 Test Method for Density and Unit Weight of Soil in Place by Sand-Cone Method
D2922 Test Methods for Density of Soil and Soil-Aggregate in Place by Nuclear Methods (Shallow Depth) (Withdrawn 2007)[3]
D4318 Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils
D4595 Test Method for Tensile Properties of Geotextiles by the Wide-Width Strip Method
D6475 Test Method for Measuring Mass Per Unit Area of Erosion Control Blankets (Withdrawn 2015)[3]
D6525 Test Method for Measuring Nominal Thickness of Rolled Erosion Control Products
D6526 Test Method for Analysis of Toluene by Capillary Column Gas Chromatography
D6566 Test Method for Measuring Mass per Unit Area of Turf Reinforcement Mats
D6567 Test Method for Measuring the Light Penetration of a Turf Reinforcement Mat (TRM)
D6818 Test Method for Ultimate Tensile Properties of Rolled Erosion Control Products

[1] This test method is under the jurisdiction of ASTM Committee D18 on Soil and Rock; Subcommittee D18.25 on Erosion and Sediment Control Technology; and is the direct responsibility of Section .02 on Erosion Control Blankets (ECBs).

Current edition approved March 1, 2012. Published April 2012. Originally approved in 1999. Last previous edition approved in 2007 as D6460–07. DOI: 10.1520/D6460-12.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] The last approved version of this historical standard is referenced on www.astm.org.

***A Summary of Changes section appears at the end of this standard**

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *erosion control blanket (ECB), n*—a degradable material, composed primarily of processed natural organic materials, manufactured or fabricated into rolls designed to reduce soil erosion and assist in the growth, establishment and protection of vegetation.

3.1.2 *erosion control net (ECN), n*—a planar woven natural fiber or extruded synthetic mesh used as a component in the manufacture of ECBs.

3.1.3 *index test, n*—a test procedure which may contain a known bias, but which may be used to establish an order for a set of specimens with respect to the property of interest.

3.1.4 *lot, n*—a unit of production, or a group of other units or packages, taken for sampling or statistical examination, having one or more common properties and being readily separable from other similar units.

3.1.5 *natural, n*—a class name of various fibers of animal, mineral or vegetable origin.

3.1.6 *open weave textile (OWT), n*—a temporary degradable ECB composed of natural or polymer yarns woven into a matrix used to provide erosion control and facilitate vegetation establishment.

3.1.7 *point gauge assembly, n*—an adjustable, calibrated rack assembly mounted to a manually controlled pinion used to determine the distance from a surface to a plane of reference. Typically, a point gauge assembly is mounted to a data acquisition cart traversing a hydraulic testing flume and measures the relative distance from a surface within the flume to the zero mark of the pinion housing. The rack is graduated and adjustable to accommodate variable offsets. Distance can be recorded manually or electronically.

3.1.8 *polymer, n*—a chemical compound or mixture of compounds formed by polymerization and consisting essentially of repeating molecular structural units.

3.1.9 *rolled erosion control product (RECP), n*—a temporary degradable or long-term non-degradable material manufactured or fabricated into rolls designed to reduce soil erosion and assist in the growth, establishment and protection of vegetation.

3.1.10 *sample, n*—a portion of material which is taken for testing or documentation and used in the laboratory as a source of individual specimens.

3.1.11 *shear stress, n*—the force of flowing water applied to the surface of a channel in Newtons per square meter (pounds per square foot); also, commonly referred to as "tractive force."

3.1.12 *temporary degradable, adj*—composed of biologically, photochemically or otherwise degradable materials that temporarily reduces soil erosion and enhances the establishment of vegetation.

3.1.13 *turf reinforcement mat (TRM), n— in erosion control*, a non-degradable geosynthetic or geocomposite processed into a matrix sufficient to increase the stability threshold of otherwise unreinforced established vegetation.

3.1.13.1 *Discussion*—Products in this category may incorporate ancillary degradable components to enhance the germination and establishment of vegetation.

4. Summary of Test Method

4.1 The performance of an RECP in reducing stormwater-induced erosion is determined by subjecting the material to simulated stormwater flow in a controlled and documented environment in reference to identical testing on baseline conditions.

4.2 Key elements of the testing process include:

4.2.1 Calibration of the stormwater simulation and measurement equipment;

4.2.2 Preparation of the test channel;

4.2.3 Documentation of the RECP to be tested (if applicable);

4.2.4 Installation of the RECP (if applicable);

4.2.5 Establishment of vegetative stand (if applicable);

4.2.6 Execution of the test;

4.2.7 Collection of hydraulic, topographical, and associated data;

4.2.8 Analysis of the resultant data; and

4.2.9 Reporting.

5. Significance and Use

5.1 This test method evaluates RECPs and their means of installation to:

5.1.1 Reduce soil loss and sediment concentrations in stormwater runoff under conditions of varying channel conditions and soil type;

5.1.2 Function within a composite system acting as vegetative reinforcement; and

5.1.3 Improve water quality exiting the area disturbed by earthwork activity by minimizing mobilization of in-situ particles within the streambed.

5.2 This test method models and examines conditions typically found on construction sites involving earthwork activities, including: highways and roads; airports; residential, commercial and industrial developments; pipelines, mines, and landfills; golf courses; etc.

5.3 This test method is a performance test, but can be used for quality control to determine product conformance to project specifications. Caution is advised since information regarding laboratory specific precision is incomplete. For project specific conformance, unique project-specific conditions should be taken into consideration.

6. Apparatus

6.1 *Water Delivery System*—The water delivery system shall include pump(s), piping, channels, water control structures, and water measurement instrumentation as necessary to achieve the desired hydraulic conditions. The water control structures shall regulate and direct the flow into the desired test channel. Fig. 1 presents a schematic showing an example of a series of test channels and water delivery system. The water delivery system shall be constructed such that turbulence at the entrance to the test channel is minimized. Use of flow

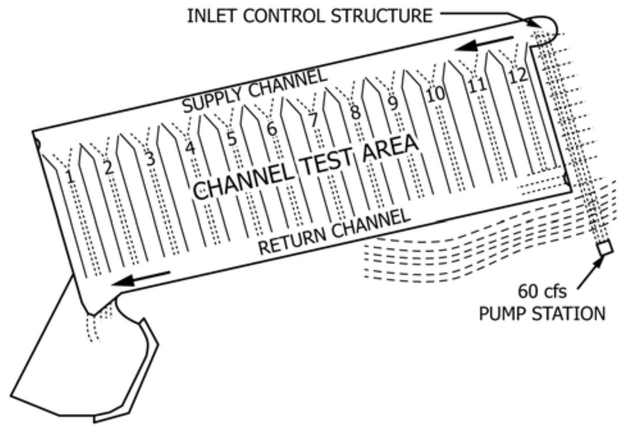


FIG. 1 Typical Closed Looped Water Delivery System

straighteners (for example, tube racks or vanes) are recommended to reduce turbulence and achieve uniform flow conditions. A direct flow system (that is, controlled flow diverted from a natural waterway) may also be employed for this purpose. Testing of bare soil conditions requires minimal channel gradient and minimal water flow. Testing of vegetated, reinforced conditions typically requires steep gradient channels and a maximum discharge in excess of 2.8 cubic meters per second (cms) (98.9 cubic feet per second (cfs)).

6.2 *Water Source*—Water derived for testing may be gravity fed or pump supplied to the testing facility in a closed loop or pass through system. Water delivered should be regulated to ensure consistent discharge and be free of debris with little or no turbidity. Discharge must be measured by hydraulic control structure, calibrated hydraulic structure, or calibrated flow meter.

6.3 *Survey Apparatus*—Channel gradient must be measured in a three-dimensional coordinate system with respect to a fixed benchmark. A total station apparatus or survey level is required to determine elevations within the test reach. The total station system is a standard surveying instrument capable of measuring distance simultaneously with vertical and horizontal angles to determine the coordinates of a location (that is, *X*, *Y* and *Z* axis) within a defined coordinate system and store the data electronically in a data logger. In lieu of a total station system, manual surveying equipment may be used. Precision and bias of either instrument must be known. Soil loss may be recorded using survey apparatus referenced to a known bench mark or by calibrated point gauge assembly referenced to relative locations within the facility.

6.4 *Velocity Probe*—A propeller-type probe shall be used to identify flow conditions during test operation. In lieu of a propeller-type probe, other velocity measurement devices including electromagnetic or sonic type flow meters may be used, provided that equivalent accuracy (±5 %) is achievable. Periodic calibration and certification of this equipment shall be performed.

6.5 *Earthwork Equipment*—Typical equipment utilized in construction of test channels includes: skid loader, wheel barrow, hand tamper, shovels, rakes, vibratory plate compactor and excavation template.

6.6 *Geotechnical Testing Equipment*—Equipment sufficient to conduct testing described in Test Methods D422, C136, D698, D4318, D1556, and D2922. Geotechnical evaluation may be outsourced to a laboratory with sufficient equipment and expertise to conduct sediment characteristic evaluation.

6.7 *Vegetative Stand Quantification Equipment*—A calibrated template used to ensure height of vegetation and counting box are necessary for vegetated testing. Vegetation is cut to a specific, uniform stand height by placing a template on the soil surface and trimming blades/stems at the top of the template. An open, square box is used to count vegetation stems and blades to determine stand density. The box may be constructed of metal or wood with an internal opening measuring 76.2 mm (3 in.) square and 25.4 to 50.8 mm (1 to 2 in.) in height.

6.8 *Photographic Equipment*—At a minimum, still and video footage must be recorded throughout the preparation and testing process to document the testing. 35 mm still and 8 mm video formats or digital equivalents are acceptable.

6.9 *Miscellaneous*—Other miscellaneous equipment includes: meteorological equipment (wind speed, temperature, precipitation).

7. Procedure

7.1 *Test Channel Preparation:*

7.1.1 Construct earthen test channels using conventional earthwork placement techniques. A rectangular or trapezoidal cross section channel may be used; however, a rectangular channel is recommended for consistency of construction and explicit computation of shear stress. Perform compaction of channel bed material to create a geotechnically (structurally) stable subgrade. General soil types to be used for testing shall be loam, clay and sand. Target grain sizes and plasticity indices are included in Table 1. Fig. 2 presents a schematic showing a typical test channel profile. Record geotechnical characteristics in file to include: visual description and classification, grain size distribution (course and sub 200 fraction), plasticity indices, moisture-density relationship, USDA, ASTM or USCS classification and in-situ compaction.

NOTE 1—Construction of steep slope and shallow soil layer plots may

TABLE 1 Target Grain Sizes and Plasticity Indices

Particle size (mm)	Sand	Loam	Clay
D_{100} (mm)	25 > D_{100} > 3.0	10 > D_{100} > 0.3	3.0 > D_{100} > 0.02
D_{85} (mm)	4.0 > D_{85} > 0.8	0.8 > D_{85} > 0.08	0.08 > D_{85} > 0.003
D_{50} (mm)	0.9 > D_{50} > 0.2	0.15 > D_{50} > 0.015	0.015 > D_{50} > 0.0008
D_{15} (mm)	0.3 > D_{15} > 0.01	0.03 > D_{15} > 0.001	D_{15} < 0.002
Plasticity Index	N/A (nonplastic)	2 < PI < 8	10 < PI

lead to geotechnical instability. Evaluation of test facility prior to operation is advised.

7.1.2 Plate the channel surface with a minimum 30.5-cm (12-in.) thick veneer of test soil. Place soil in a minimum of two lifts and compact to 90 ± 3 % of standard Proctor density in accordance with Test Method D698. In the case previous testing was completed in channel, remove top layer of soil to a depth of 25.4 mm (1 in.) deeper than deepest erosion and replace veneer. In-situ density of soil must be measured for each lift utilizing Test Methods D1556 or D2922.

7.1.3 Excavate and fill the soil surface to the design cross section and grade and ensure a smooth surface throughout the test reach. The test channel may be comprised of a trapezoidal cross section or rectangular cross section. Trapezoidal cross section should incorporate a 0.61-m (2-ft) bottom width and 2H:1V side slopes. A rectangular cross section must be 0.61 m (2 ft) minimum in width. The test channels shall be a minimum of 12.2 m (40 ft) in length.

7.1.4 Locate test section sufficiently downstream of inlet structure or transitions of flow to ensure straight and parallel stream lines. Flow should enter test section as uniform flow, or as close to uniform flow as possible. Maintenance or modification of the reach of channel upstream from the test section may be required to provide similar roughness to the test section to attain near uniform flow conditions entering the test section.

7.1.5 Prepare soil surface to mimic field conditions to be tested. In the case of bare soil testing, prepare a smooth or roughened surface as necessary. If soil surface differs from final, compacted surface (that is, hand roughened), measure in-situ density of surface by Test Methods D1556 or D2922. If results are to be representative of bare soil conditions proceed to 7.2. Otherwise, soil preparation methods for bare soil testing utilized as a baseline, control plot for product or vegetated testing should be identical to soil preparation methods for the protected scenario.

7.1.6 *Optional*—If results are to be specific to RECP unvegetated performance, install RECP by manufacturer's guidelines or by specifications for testing required. Sample product to be tested (one per installation) and determine mass per unit area (Test Method D6475), tensile strength and elongation (Test Method D4595 for ECBs, Test Method D6818 for TRMs), thickness (Test Method D6526), and light penetration (Test Method D6567). Record staple size, staple locations, product description, seam details (that is, checkslots or overlaps used) and any other pertinent information. If the depth of flow will exceed the boundaries of the installation (that is, a rectangular channel or trapezoidal channel with insufficient freeboard), secure the edges by placing mechanical seal along edges of installation to prohibit flow from circumventing the RECP. Typically a mechanical seal is achieved by securing dimensional lumber or angle iron along walls of testing facility, placed in contact with the RECP. Sufficient downward pressure must be applied in placing the longitudinal, mechanical seal to ensure intimate contact with the RECP over the length of the installation; however, the seal should not act as ancillary stabilization to the RECP. The angle iron or lumber is sealed with a silicone sealant to ensure flow does not circumvent the mechanical seal. Mechanical seal should be installed to minimize disturbance of the flow. Proceed to 7.2.

7.1.7 *Optional*—If results are to be specific to an unreinforced stand of vegetation, prepare seed bed and seed as desired. Provide water and fertilizer or other additives as required to establish vegetation. Record seed type, preparation methodology, watering schedule, fertilizer and additives used, and climatic variables over the entirety of the maturation period. Photograph test reach weekly. Include photographs and notes regarding vegetation establishment in log with seed type, seed source and date of planting. Allow vegetation to mature to reflect desired conditions. If a uniform vegetation height is desired, trim vegetation using hand shears and height template, or by other suitable means, immediately prior to testing.

7.1.8 *Optional*—If results are to be specific to a stand of vegetation reinforced with an RECP, prepare and document seed bed as described in 7.1.7, install the RECP as described in 7.1.6 and allow vegetation to mature as required, documenting maturation of vegetation as described in 7.1.7. Prepare vegetation for testing as described in 7.1.7.

7.2 *Pre-Test Documentation:*

7.2.1 Maintain a test folder for each test cycle, including information on:

7.2.1.1 Site conditions;

7.2.1.2 Geotechnical and soil conditions including grain size distribution, liquid limit, plastic limit, plasticity index, USDA, USCS or ASTM classification, K factor and in-situ compaction results;

7.2.1.3 Meteorological data from on-site weather station at time of testing (if testing outdoors);

7.2.1.4 RECP product type/description including product data sheet and the following index test results from subsamples of the products tested (if product test): Thickness (Test Method D6525), Mass per Unit Area (Test Method D6475 for ECBs; Test Method D6566 for TRMs), Tensile Strength (Test Method D4595 for ECBs; Test Method D6818 for TRMs), and Light Penetration (Test Method D6567);

7.2.1.5 Vegetative component variables including seed type, seed source, stand density and maturity at time of testing, stand height, visual classification of vegetation, and photo and note log from vegetation (if vegetative element incorporated in testing);

7.2.1.6 Installation procedure including dates of installation and descriptions of RECP and vegetative component incorporated. Include all documentation listed in 7.1.6 and 7.1.7;

7.2.1.7 Photo documentation of installation immediately prior to testing; and

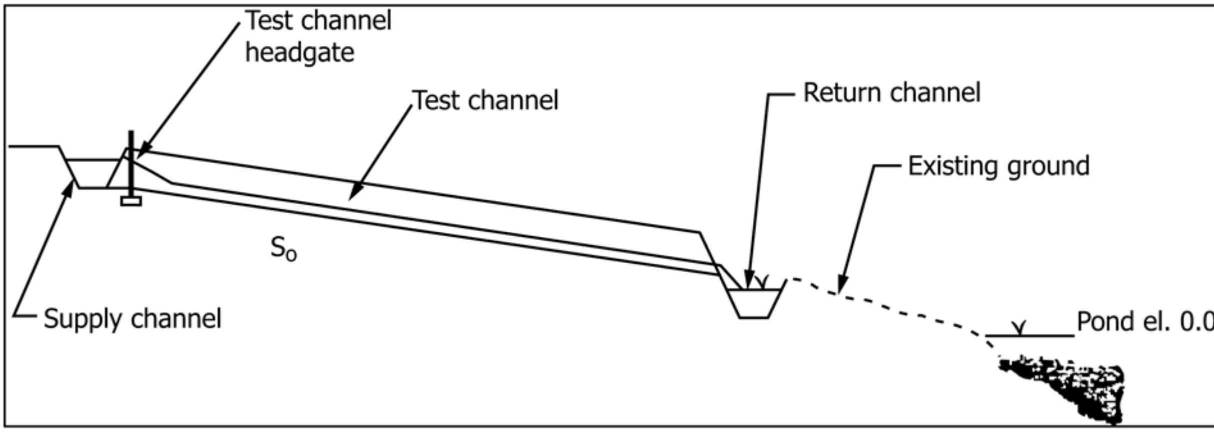


FIG. 2 Typical Channel Profile

7.2.1.8 Document any conditions not specifically mentioned herein that could potentially influence the results of testing.

7.3 *Initial Data Collection and Test Preparation:*

7.3.1 Immediately prior to testing, delineate cross sections for data acquisition. At a minimum, eight cross sections should be included through the test reach, with a maximum spacing between sections of one channel width in the direction of flow. Locate data acquisition locations within each cross section to record water surface elevation and bed elevation. At a minimum, three data acquisition locations along the bed of the channel and two data acquisition locations on each bank of the channel (if using a trapezoidal section) must be identified and monitored at each cross section. Record the elevation of each data acquisition location by survey apparatus or point gauge assembly. If using a point gauge assembly in a relative frame of reference, determine the longitudinal slope of the installation by survey apparatus. Elevation readings can be sensitive to the diameter of the probe (rod or point gauge assembly) in contact with the ground surface. Thus, the point gauge assembly or survey rod should include an extension rod between 6.4 mm (0.25 in.) and 9.5 mm (0.375 in.) in diameter to make contact with the ground surface.

7.3.2 If vegetative component is incorporated in testing, quantify vegetative stand density using count box described in 6.7. A minimum of three vegetation stem density counts are to be performed. Place count box on ground surface; count and record the number of stems and the number of blades within the opening of the box. Three vegetation stem density counts are to be performed; one located within the upstream, middle and downstream third of the test section. Minimize damage to vegetated system by limiting foot traffic and stepping carefully around vegetation stem/blade density count location. Subsequent counts during testing are to be performed in the same location as the initial count. Document condition of vegetation immediately prior to testing, recording stand height as obtained by trimming to template height, density obtained from box counts, photographs and video footage and visual classification of vegetative stand. Classify and record condition of vegetation as described in USDA Agricultural Handbook #667 (USDA 1987). If variable vegetation height is used, record description of vegetation and a range of heights and USDA classification.

7.3.3 Determine initial, target discharge. Initial discharge determination must consider conditions to be tested (bare soil, unvegetated RECP, bare vegetation or reinforced vegetation), slope of test channel, and cross section size and shape of channel. The objective of the performance test is to subject the installation incrementally increasing hydraulic forces, thus, the initial discharge should cause little migration of soil from the test channel. Each subsequent target discharge will be determined from the computation of hydraulic forces of the previous test.

7.3.4 Prepare facility for testing. Provide access to each data acquisition cross section to permit measurement of bed elevation without walking on channel surface. Provide access to each data acquisition cross section to permit measurement of water surface elevation by means of survey apparatus or point gauge assembly.

7.4 *Test Operation and Data Collection:*

7.4.1 Include the following test data: operator name and title; actual discharge recorded during testing, time flow began; time flow stopped; time runoff stopped; flow depths; and measured velocities. Also record accuracy of all instruments involved. If using hydraulic control structure or calibrated hydraulic structure flow control into test channel, include summary of accuracy determination and statement of expected accuracy.

7.4.2 Slowly increase flow to initial target discharge. Allow flow to increase over approximately ten minutes to minimize shock to the system.

7.4.3 Once the flow has been increased to the target discharge, allow the flow to reach equilibrium. Record water surface elevation measurements at each data acquisition location at each cross section using the point gauge assembly or survey apparatus used to record bed elevations. Record velocity measurements at the centerline point of each test cross section using the velocity probe (see Fig. 3). If the depth of flow is less than 20 cm (8 in.), take only the six-tenths depth reading. Record photographs and video footage of the testing. For unvegetated conditions, convey flow for thirty minutes at the target discharge. For vegetated conditions, convey flow for one hour at the target discharge. If catastrophic failure occurs, suspend testing.

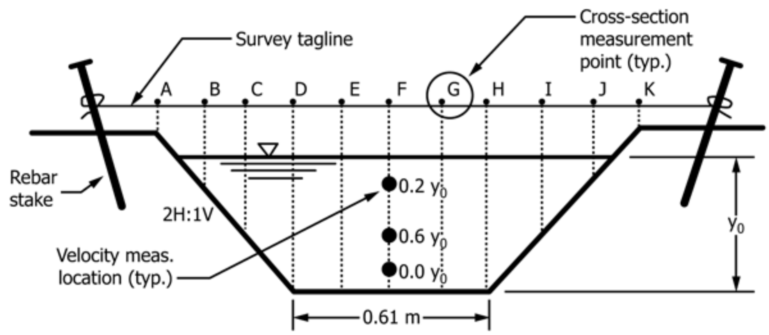


FIG. 3 Typical Channel Cross Section

7.4.4 At the conclusion of the initial target discharge, inspect the test channel noting any changes in vegetative condition, RECP condition or bed soil condition. Record photographs and video footage of the installation. Record elevation of each data acquisition location as recorded during initial data collection. Perform vegetation stem and blade density counts identically as prior to testing (if performing vegetated testing).

7.4.5 Estimate shear stress, velocity, soil loss and vegetation loss from testing and determine if testing at proceeding target discharges should be conducted. For bare soil or unvegetated RECP evaluation, testing may be terminated if the average soil loss over the test reach is greater than 12.7 mm (0.5 in.) (as defined by Clopper Soil Loss Index (CSLI) demonstrated by Eq 10) or catastrophic failure occurs. Vegetated testing may be discontinued if the average soil loss over the test channel exceeds 12.7 mm (0.5 in.), catastrophic failure occurs or the soil subsurface is eroded sufficiently to allow for continuous flow underneath the RECP.

7.4.6 Determine proceeding target discharge. Using data from initial test, estimate roughness and compute discharge necessary to achieve proceeding target shear stress. Recommended target shear stresses are as follows:

Test Number	Bare Soil	Unvegetated RECP	Unreinforced Vegetation	Vegetated RECP
1	24 N/m^2 (0.5 psf)	24 N/m^2 (0.5 psf)	48 N/m^2 (1.0 psf)	96 N/m^2 (2.0 psf)
2	36 N/m^2 (0.75 psf)	48 N/m^2 (1.0 psf)	96 N/m^2 (2.0 psf)	192 N/m^2 (4.0 psf)
3	48 N/m^2 (1.0 psf)	72 N/m^2 (1.5 psf)	144 N/m^2 (3.0 psf)	288 N/m^2 (6.0 psf)
4	60 N/m^2 (1.25 psf)	96 N/m^2 (2.0 psf)	192 N/m^2 (4.0 psf)	384 N/m^2 (8.0 psf)
5	72 N/m^2 (1.5 psf)	120 N/m^2 (2.5 psf)	240 N/m^2 (5.0 psf)	480 N/m^2 (10.0 psf)
6	84 N/m^2 (1.75 psf)	144 N/m^2 (3.0 psf)	288 N/m^2 (6.0 psf)	576 N/m^2 (12.0 psf)
7	96 N/m^2 (2.0 psf)	168 N/m^2 (3.5 psf)	336 N/m^2 (7.0 psf)	672 N/m^2 (14.0 psf)

7.4.6.1 During the course of testing, conditions of the soil base or vegetative component may change sufficiently to affect the roughness estimates used to determine target discharges. Thus, it is not required to achieve recommended target shear stresses. Target shear stresses are provided as a guideline for ensuring an appropriate range for testing of the various types of systems. At a minimum, three tests causing less than one-half inch of soil loss (as defined by CSLI, shown in Eq 10) and one test causing greater than one-half inch of soil loss are required to evaluate a bare soil or unvegetated RECP condition. Vegetated testing is continued until the system can be classified as failed by: catastrophic failure, greater than one inch of soil loss over the test reach or the soil surface underlying the vegetation or RECP is sufficiently scoured to permit continuous flow underneath the system. A minimum of three vegetative tests prior to failure and one test defined as failure are required to evaluate a vegetated system.

7.4.7 Continue testing at incrementally increasing target shear stresses as shown in 7.4.6 until the system or bare soil condition has exhibited failure as described in 7.4.5. Follow procedures outlined above, recording bed elevation, water surface elevation, flow velocity, discharge, observations, notes, photos and video identically for each test.

7.4.8 At the conclusion of the test series, record channel surface elevation measurements identically as initial and post-test elevations were recorded. Perform vegetation stem and blade density counts as performed initially and after each test.

7.4.9 Record general observations regarding the condition of the tested ECB at the conclusion of the data collection.

7.4.10 Carefully remove the ECB from the channel, with as little disturbance of the soil as possible. Note general observations regarding the condition and scour patterns. Take photographs, videotape, or both to record the condition of the test channel. Markers may be used to identify any scour patterns for the pictorial documentation. Photographs should show the final condition of the test plot with and without the RECP in place (if tested and if possible).

7.4.11 A total of three test series (3 installations) should be performed to obtain an average threshold of performance. Each test series should follow identical procedures as noted above.

8. Analysis

8.1 *Calibrated Hydraulic Structure Flow Measurement:*

8.1.1 *Weir Equation*—Discharge may be determined from inline flow meter, calibrated channel section, hydraulic control structure or calibrated hydraulic structure. A standard weir equation and the velocity-area method are presented here as standard computations. The elevation difference between the measured water surface and the bottom of the weir is the total head. An example weir equation utilized to determine discharge is as follows:

$$Q = 1.65(L)(H)^{3/2} \tag{1}$$

where:

Q = discharge, m^3/s,
L = width of weir, m, and
H = total head, m.

NOTE 2—Facility specific weir equations may be required to accurately determine volumetric flow rate in test channels.

8.1.2 *Velocity-Area Equation*—Based on the trapezoidal cross section and the three-point cross section velocity measurements, the discharge in the channel is computed as:

$$Q = V_1 A_1 + V_2 A_2 + V_3 A_3 \quad (2)$$

Q = discharge, m^3/s,
V_n = measured velocity at each location, m/s,
A_1, A_3 = flow area, m^2 (@ B = 1.83 m, SS = 2H:1V ⇒ $0.45y_0 + y_0^2$), and
A_2 = flow area, m^2 (@ B = 1.83 m ⇒ $0.9y_0$).

8.2 *Evaluation of Test Data:*

8.2.1 The objective of the analysis of test data is to determine the relationship between shear stress and soil loss, determine the relationship between velocity and soil loss and to determine the hydraulic conditions associated with failure of the test channel. Fig. 4 presents a diagram that defines variables of interest bounded by a control volume within the test section.

8.2.2 Determine total discharge from inline flow meter or procedure outlined in 8.1.

8.2.3 Develop profile plot for each test to include bed surface, water surface and energy grade line. Bed elevation prior to testing should be plotted in conjunction with the water surface elevation measured during testing. Flow depth is computed as the adjusted, vertical difference between water surface and bed surface elevation measurements, as defined by Eq 3. Cross section average flow depth is defined as the average of the three flow depths at each cross section. Cross section average velocity is computed as the total discharge divided by the total cross sectional area, as defined by Eq 4. Elevation of the energy grade line is computed using Eq 5.

$$y = (WSEL - Z)\cos(\theta_B) \quad (3)$$

where:

$WSEL$ = measured water surface elevation, m,
Z = measured bed surface elevation immediately prior to conveyance of flow generating $WSEL$, m, and
θ_B = angle of bed slope, degrees.

$$V_{csave} = \frac{Q}{A} \quad (4)$$

where:

V_{csave} = cross section average velocity, m/s,
Q = total discharge from inline flow meter or hydraulic structure computation, cms, and
A = cross section area (computed using cross section average depth), m^2.

$$H = Z + y_{csave} + \alpha\frac{V_{csave}^{\ 2}}{2 \cdot g} \quad (5)$$

where:

H = elevation of the energy grade line, m,
Z = bed elevation, m,
y_{csave} = cross section average flow depth, m,
γ = unit weight of water, N/m^3,
V_{csave} = cross section average velocity, m/s,
g = acceleration due to gravity, m/s^2, and
α = energy coefficient.

8.2.4 Evaluate sensitivity of each profile plot to individual members of the data set. Define control volume for analysis by excluding data showing disproportionate influence on the data set. Guidelines for control volume selection are as follows:

8.2.4.1 Ensure flow depth remains positive and does not vary significantly from the trend in flow depth along the length of the channel.

8.2.4.2 Ensure slope of the energy grade line is equal to or less than the bed slope.

8.2.4.3 Ensure water surface slope is not influenced by flow depth readings recorded in the upstream portion of the channel, as flow transitions to the test section.

8.2.4.4 Maintain the longest control volume possible, with a minimum length of 6.1 m (20 ft).

8.2.4.5 Slope of the energy grade line should demonstrate agreement with other tests within the series.

8.2.4.6 Ensure water surface and energy grade line exhibit linear behavior over the reach of the control volume.

NOTE 3—If a control volume cannot be defined as described above, a numerical, hydraulic model can be employed to compute average velocity and shear stress.

8.2.5 Calculate the Manning resistance coefficient, *n*, over the control volume defined in 8.2.4 as follows:

Rectangular Channel

$$n = \frac{C}{V_{cvave}} \cdot y_{cvave}^{\ 2/3} \cdot S_f^{1/2} \quad (6)$$

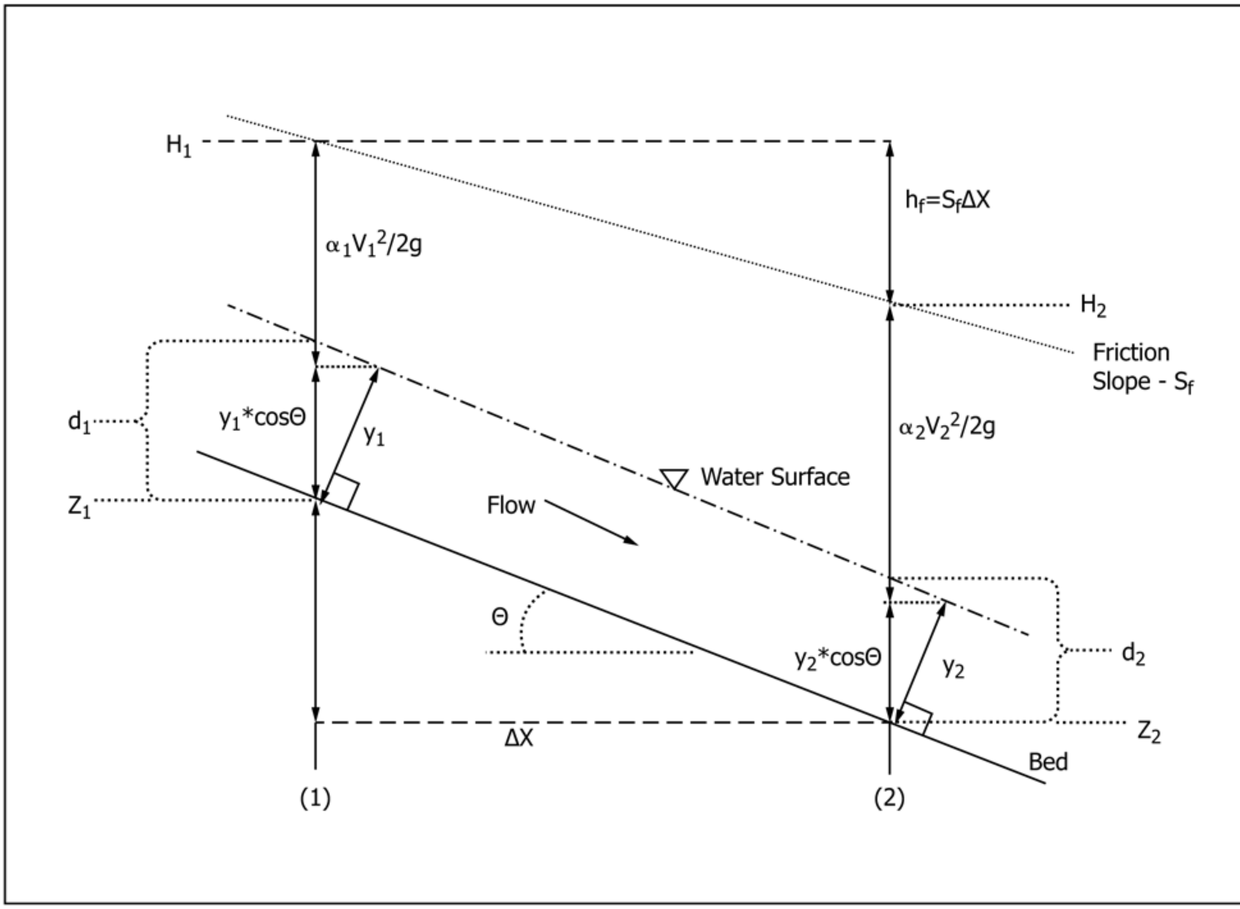
Trapezoidal Channel

$$n = \frac{C}{V_{cvave}} \cdot R_{cvave}^{\ 2/3} \cdot S_f^{1/2} \quad (7)$$

where:

V_{cvave} = control volume average velocity, m/s,
C = unit conversion constant, 1,
R_{cvave} = control volume average hydraulic radius (computed as the average hydraulic radius from each cross section within the control volume), m,
y_{cvave} = control volume average flow depth (computed as the average flow depth over the control volume), m,
n = Manning's coefficient of hydraulic resistance, and
S_f = friction slope, m/m.

8.2.5.1 Manning's *n* is computed using the flow depth in a rectangular channel to reflect the smooth side walls compared to the relatively rough bed surface. The substitution of flow depth for hydraulic radius accounts for the smooth side walls and yields a roughness value more accurately reflecting the conditions tested.



where:

H_1	=	Elevation of the energy grade line at section (1) (m)
H_2	=	Elevation of the energy grade line at section (2) (m)
Z_1	=	Bed elevation at section (1) (m)
Z_2	=	Bed elevation at section (2) (m)
d_1	=	Vertical depth at section (1) (m)
d_2	=	Vertical depth at section (2) (m)
y_1	=	Flow depth at section (1) (m)
y_2	=	Flow depth at section (2) (m)
V_1	=	Velocity at section (1) (m/s)
V_2	=	Velocity at section (2) (m/s)
Θ	=	Angle of bed slope (degrees)
g	=	Acceleration due to gravity (m/s^2)
α_1	=	Energy coefficient at section (1)
α_2	=	Energy coefficient at section (2)
Δx	=	Horizontal distance from section (1) to section (2) (ft)
h_f	=	Head loss from section (1) to section (2)
S_f	=	Slope of energy grade line (Friction Slope) (ft/ft)

FIG. 4 Hydraulic Analysis and Control Volume Variable Definition

8.2.6 The maximum boundary shear stresses shall be determined, as follows:

8.2.6.1 The term y_1 should be the flow depth at the upstream end of the selected control volume and the term y_2 should be the downstream depth of the selected control volume. Eq 8 is particularly sensitive to the value of flow depths entered into the equation. Thus, the values of y_1 and y_2 could be determined from the difference of linear regression functions describing the bed and water surface at the corresponding stations y_1 and y_2. For trapezoidal channels, use Eq 8; for rectangular channels, use Eq 9.

$$\tau_0 = \frac{B - C + D - E}{G} \tag{8}$$

where:

$$B = \gamma d_1(\cos\theta)\left[\frac{W_B d_1}{2} + \frac{z_R d_1^2}{3} + \frac{z_L d_1^2}{3}\right]$$

$$C = \gamma d_2(\cos\theta)\left[\frac{W_B d_2}{2} + \frac{z_R d_2^2}{3} + \frac{z_L d_2^2}{3}\right]$$

$$D = \frac{\gamma L}{2}\left[W_B(d_1 + d_2) + \frac{(z_R + z_L)(d_1 + d_2)^2}{4}\right]\sin\theta$$

$$E = Q^2\rho\left(\frac{1}{W_B d_2 + (1/2)(z_R d_2^2 + z_L d_2^2)} - \frac{1}{W_B d_1 + (1/2)(z_R d_1^2 + z_L d_1^2)}\right)$$

$$G = L\left[W_B + \frac{(d_1 + d_2)\left(\sqrt{1 + z_R^2} + \sqrt{1 + z_L^2}\right)}{2}\right]$$

where:

d = flow depth normal to the channel bed, m,
L = control volume reach length along the channel, m,
γ = unit weight of water, N/m^3,
Q = volumetric flow rate, cms,
W_B = channel bottom width, m,
W_T = channel top width, m,
z_L = side slope on the left side of the channel, m/m,
z_R = side slope on the right side of the channel, m/m,
θ = bedslope angle, degrees, and
τ_0 = boundary shear stress, Pa.

$$\tau_0 = \gamma/2(y_1 + y_2)\sin\theta_B + 1/L[\gamma/2(y_1{}^2 - y_2{}^2)\cos\theta_B - \rho q^2(1/y_2 - 1/y_1)] \tag{9}$$

where:

τ_0 = shear stress, Pa,
γ = unit weight of water, N/m^3,
y_1 = upstream flow depth, m,
y_2 = downstream flow depth, m,
θ_B = angle of bed slope, degrees,
ρ = density of water, kg/m^3,
q = unit discharge, cms/m, and
L = length of control volume, ft.

8.2.7 Calculate the Clopper Soil Loss Index (CSLI) from the topographic data gathered before and after test flows using the total station equipment. Use the change in channel topography to define the performance of the ECB. Quantify areas of degradation (soil loss) as "cut" and quantify areas of aggradation (sediment deposition) as "fill." Compute CSLI as follows:

$$CSLI = C_T/A_T \times 100 \tag{10}$$

where:

$CSLI$ = Clopper Soil Loss Index, cm,
C_T = total cut (degradation), m^3, and
A_T = wetted channel area, m^2.

NOTE 4—The CSLI evaluates channel lining materials only on their ability to reduce soil loss (erosion). It neither nor penalize the lining material on its ability to capture soil (sedimentation).

8.3 *Sensitivity and Alternate Methods*—In the event variability within the raw data set yields inconsistent or inaccurate results, the proceeding, alternative methods to quantify shear stress and velocity are acceptable. First, use of linear regression techniques can potentially mitigate the effect of variability within the measured data set sufficiently to produce accurate results. Define the bed and water surface by a best fit linear function as determined by sum of least squares analysis. Define flow depth as the adjusted, vertical distance between the regression functions as shown in Eq 3. Compute cross section average and control volume average parameters using the regression defined flow depth to produce regression defined results. Thus, shear stress and velocity are computed using regression generated terms entirely. The regression analysis must be conducted over a reach of data exhibiting linear trends. If linearity is not present within the data set, a direct step or standard step, one-dimensional, numerical hydraulic model is acceptable for quantification of shear stress and velocity over the test reach. However, the roughness value input into the model must be determined by a sum of least squares optimization with respect to the measured water surface elevation to standardize the selection of the Manning's *n* roughness value. It is recommended that evaluation of the measured data and quantification of shear stress, velocity and soil loss be performed by a licensed professional engineer with experience in hydraulic analysis.

9. Report

9.1 An engineering report documenting the test facility, test preparation, test execution, collected data, data analysis and results must be generated to include:

9.1.1 General information, including test facility location, date, time and operator(s),

9.1.2 Test channel preparation including geotechnical properties of test soil, in-situ compaction validation, RECP product data sheets and index test results, vegetative stand preparation, classification and quantification,

9.1.3 Calibration data and analysis,

9.1.4 Materials documentation including blanket material and anchor description and installation details,

9.1.5 Test set-up activities including roll out pattern of blanket(s), anchor pattern and average anchor density (anchor per unit area),

9.1.6 Test operation and data collection (including "raw" data), and

9.1.7 Analysis (including hydraulic conditions and CSLI), plot shear stress versus soil loss, velocity versus soil loss, critical velocity and shear stress determination and documentation of data and analysis. Further, documentation of the vegetated condition throughout testing should be reported, if applicable.

9.2 *Reporting of Significant Digits:*

9.2.1 Round values from computation to the number of decimal places justified by the data. All calculations and reporting of experimental results shall adhere to the procedures described in "Experimental Methods for Engineers" (Holman 1984).[4]

9.2.2 *Examples of Significant Digits:*

Number as Written	Number of Significant Digits	Implied Range
341	3	340.5 to 341.5
34.1	3	34.05 to 34.15
.00341	3	0.003405 to 0.003415
3410.	4	3409.5 to 3410.5
341 EE7	3	340.5 EE7 to 341.5 EE7
3.41 EE-2	3	3.405 EE-2 to 3.415 EE-2

[4] Holman, J. P., *Experimental Methods for Engineers*, McGraw-Hill Book Company, Fourth Edition, 1984.

10. Precision and Bias

10.1 *Precision*—The precision of this test method is being established.

10.2 *Bias*—The true value of erosion control performance of RECPs can be defined only in terms of a test method. Within this limitation, the procedure described herein has no known bias and, since there is not an accepted refereed test method, the procedures of this test method have no inherent bias.

11. Keywords

11.1 channel lining; ECB; erosion control; erosion control blanket; RECP; rolled erosion control product; scour; sediment; soil loss; TRM; turf reinforcement mat

APPENDIX

(Nonmandatory Information)

X1. ADDITIONAL REFERENCES

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SUMMARY OF CHANGES

Committee D18 has identified the location of selected changes to this test method since the last issue, D6460–07, that may impact the use of this test method. (Approved March 1, 2012)

(*1*) Revised 6.2 to add clarity to the statement and provides the user with a more detailed description of the facility required to perform the test.
(*2*) Revised Fig. 4 and explanatory notes.
(*3*) Added new Note 1 and renumbered subsequent notes.
(*4*) Revised Fig. 2.
(*5*) Revised 7.1.7.
(*6*) Revised 7.2.1.4.
(*7*) Revised Table 1.