Designation: D7277 – 16

Standard Test Method for Performance Testing of Articulating Concrete Block (ACB) Revetment Systems for Hydraulic Stability in Open Channel Flow[1]

This standard is issued under the fixed designation D7277; 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 The purpose of this test method is to provide specifications for the hydraulic testing of full-scale articulating concrete block (ACB) revetment systems under controlled laboratory conditions for purposes of identifying stability performance in steep slope, high-velocity flows. The testing protocols, including system installation, test procedures, measurement techniques, analysis techniques, and reporting requirements are described in this test method.

1.2 The values stated in inch-pound units are to be regarded as standard. The values given in brackets are mathematical conversions to SI units that are provided for information only and are not considered standard. Reporting or use of units other than inch-pound shall not be considered non-conformance as long as the selected parameters described regarding flume construction by the inch-pound system used in this method are met as a minimum.

1.2.1 The gravitational system of inch-pound units is used when dealing with inch-pound units. In this system, the pound (lbf) represents a unit of force (weight), while the unit for mass is slugs. The rationalized slug unit is not given, unless dynamic (F = ma) calculations are involved.

1.3 All observed and calculated values shall conform to the guidelines for significant digits and rounding established in Practice D6026.

1.3.1 The procedures used to specify how data are collected, recorded and calculated in this Guide are regarded as the industry standard. In addition they are representative of the significant digits that generally be retained. The procedures used do not consider material variation, purpose of obtaining the data, special purpose studies or any considerations for the user's objectives; and it is common practice to increase or reduce significant digits of reported data to be commensurate with these considerations. It is beyond the scope of this standard to consider significant digits used in analysis methods for engineering design.

1.4 *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.*

NOTE 1—The quality of the result produced by this standard is dependent on the competence of the personnel performing it and the suitability of the equipment and facilities used. Agencies that meet criteria of Practice D3740 are generally considered capable of competent and objective testing. Users of this standard are cautioned that compliance with Practice D3740 does not in itself assure reliable results. Reliable results depend on many factors and Practice D3740 provides a means of evaluating some of these factors.

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D422 Test Method for Particle-Size Analysis of Soils (Withdrawn 2016)[3]

D653 Terminology Relating to Soil, Rock, and Contained Fluids

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

D2216 Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass

D2487 Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)

D3740 Practice for Minimum Requirements for Agencies Engaged in Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction

D4318 Test Methods for Liquid Limit, Plastic Limit, and

[1] This guide is under the jurisdiction of ASTM Committee D18 on Soil and Rock and is the direct responsibility of Subcommittee D18.25 on Erosion and Sediment Control Technology.

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[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.

Plasticity Index of Soils

D5195 Test Method for Density of Soil and Rock In-Place at Depths Below Surface by Nuclear Methods

D6026 Practice for Using Significant Digits in Geotechnical Data

3. Terminology

3.1 *Definitions:*

3.1.1 For common definitions of technical terms in this test method, refer to Terminology D653.

3.1.2 *articulating concrete block (ACB) revetment system, n—in erosion control*, a matrix of interconnected concrete block units for erosion protection. Units are typically connected by geometric interlock, cables, ropes, geotextile, geogrids or a combination thereof and typically include a geotextile underlayment.

3.1.3 *depth of flow, y_o,* (**L**)*, n—in hydraulics*, the distance from the channel thalweg to the water surface, measured normal to the direction of flow, for a given discharge.

3.1.4 *design discharge, Q_d,* ($\mathbf{L^3T^{-1}}$)*, n—in erosion control*, the volumetric quantity of water flow within a channel which is typically used in determining required channel dimensions and suitable lining materials for ensuring adequate channel capacity and stability.

3.1.4.1 *Discussion*—The discharge associated with a specified frequency of recurrence, for example, an *n*-year flood. The *n*-year flood event has a probability of 1/*n* of being equaled or exceeded in any given year.

3.1.5 *discharge, Q,* ($\mathbf{L^3T^{-1}}$)*, n—in channel flow*, the volume of water flowing through a cross-section in a unit of time, including sediment or other solids that may be dissolved in or mixed with the water; usually cubic feet per second (ft^3/s) or cubic meters per second (m^3/s).

3.1.6 *hydraulic radius,* (**L**)*, n—in channel flow*, the cross-sectional area of flow divided by the wetted perimeter.

3.1.7 *local velocity,* ($\mathbf{L^3T^{-1}}$)*, n—in channel flow*, the velocity at a specific point in the flow region. May be defined as a direction-dependent quantity with components V_x, V_y, or V_z.

3.1.8 *mean velocity,* ($\mathbf{LT^{-1}}$)*, n—in hydraulics*, the average velocity throughout a channel cross section. Defined as the discharge divided by the cross-sectional area of flow usually expressed in meters per second (m/s) or feet per second (ft/s).

3.1.9 *subcritical flow,* ($\mathbf{LT^{-1}}$)*, n—in channel flow*, a characteristic of flowing water whereby gravitational forces dominate over inertial forces, quantified by a Froude Number less than 1.

3.1.10 *supercritical flow,* ($\mathbf{LT^{-1}}$)*, n—in channel flow*, a characteristic of flowing water whereby inertial forces dominate over gravitational forces, quantified by a Froude Number greater than 1.

3.1.11 *uniform flow,* ($\mathbf{LT^{-1}}$)*, n—in hydraulics*, the condition of flow where the rate of energy loss due to frictional and form resistance is equal to the bed slope of the channel.

3.1.11.1 *Discussion*—Where uniform flow exists, the slopes of the energy grade line, the water surface, and the channel bed are identical. Cross-sectional area and velocity of flow do not change from cross section to cross section in uniform flow.

3.1.12 *velocity, V,* ($\mathbf{LT^{-1}}$)*, n—in channel flow*, time rate of linear motion in a given direction.

4. Summary of Test Method

4.1 The test method is designed to determine the stability threshold values of shear stress and velocity of articulating concrete block (ACB) revetment systems under controlled laboratory conditions of steep-slope, high-velocity flow (flume test). Systems are tested as full-scale production units.

4.2 The procedures associated with test set-up, testing, data collection, and reporting are provided in this test method.

5. Significance and Use

5.1 An articulating concrete block revetment system is comprised of a matrix of individual concrete blocks placed together to form an erosion-resistant revetment with specific hydraulic performance characteristics. The system includes a filter layer compatible with the subsoil which allows infiltration and exfiltration to occur while providing particle retention. The filter layer may be comprised of a geotextile, properly graded granular media, or both. The concrete blocks within the matrix shall be dense and durable, and the matrix shall be flexible and porous.

5.2 ACB revetment system are used to provide erosion protection to underlying soil materials from the forces of flowing water. The term "articulating," as used in this standard, implies the ability of individual concrete blocks of the system to conform to changes in subgrade while remaining interconnected by virtue of geometric interlock, cables, ropes, geotextiles, geogrids, or combination thereof.

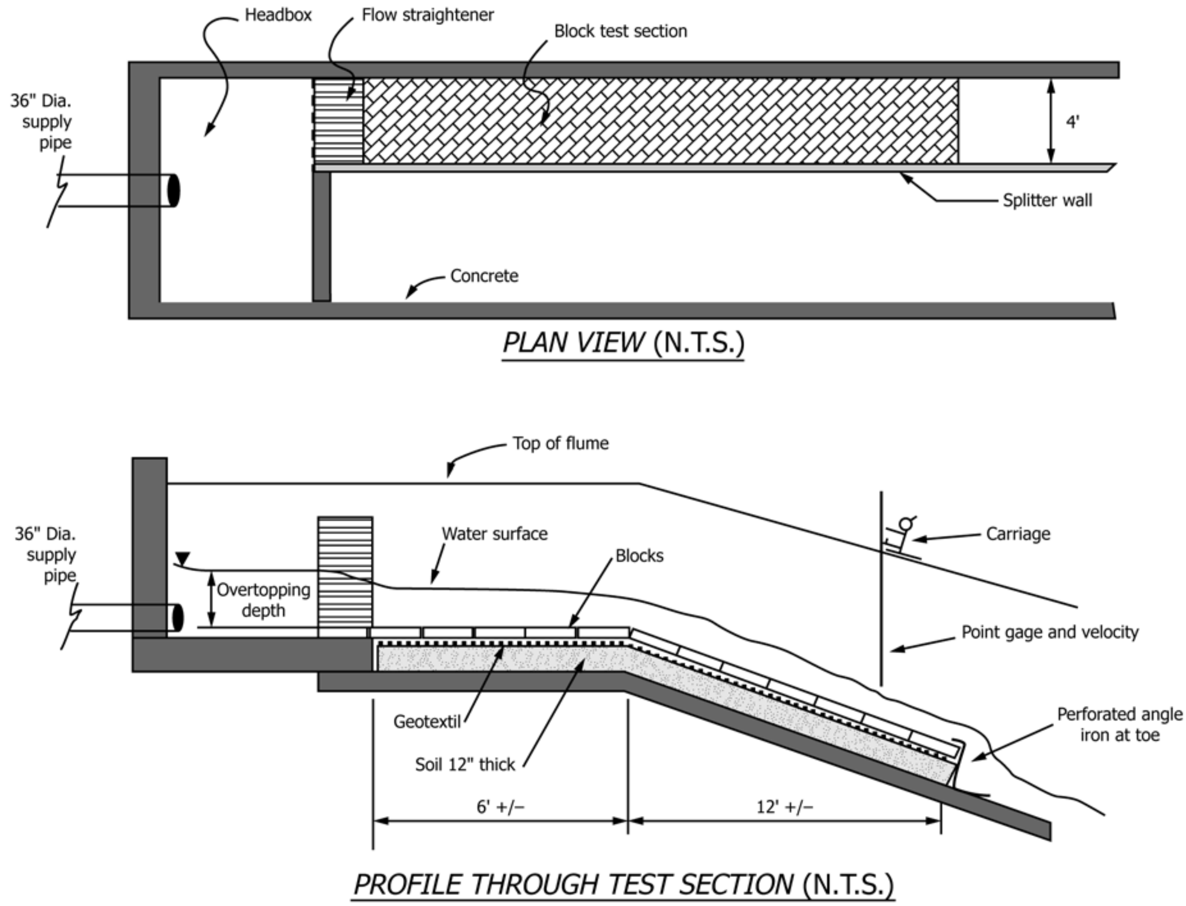
5.3 The definition of ACB revetment system does not distinguish between interlocking and non-interlocking block geometries, between cable-tied and non-cable-tied systems, between vegetated and non-vegetated systems or between methods of manufacturing or placement. Furthermore, the definition does not restrict or limit the block size, shape, strength, or longevity; however, guidelines and recommendations regarding these factors are incorporated into this standard. Blocks are available in either open-cell or closed-cell configurations.

6. Preparation of Test Section

6.1 *Soil Subgrade Construction:*

6.1.1 The testing program includes the construction of an earthen test subgrade compacted between vertical walls of the testing flume (Fig. 1). The soil subgrade shall be placed and compacted in horizontal lifts of 4 to 6 in. [100 to 150 mm] in thickness to a minimum subgrade thickness of 12 in. [300 mm]. The distance between the walls shall be a minimum of 4.0 ft [1.2 m]; installation shall be reflective of standard field usage and shall accommodate full-scale block units such that at least one block is not adjacent to a sidewall, at least every other row of the revetment matrix.

6.1.2 The soil subgrade shall consist of a silty sand with a plasticity index (PI) in the range of 2 to 6 %, and will be compacted at optimum water content to between 90 and 95 % of Standard Effort density (Test Methods D698). The embankment shall be constructed to a height such that the finished



NOTE 1—Drawing not to scale, and slope, as shown, is not 2H:1V.
NOTE 2—1 ft = 0.305 m.

FIG. 1 Schematic Profile of Typical Testing Flume

surface of the revetment consists of a horizontal crest section at least 6 ft [1.8 m] in length followed by a downstream slope angle typically set at 2H:1V.

NOTE 2—Test conditions may incorporate slopes other that the 2H:1V identified as the benchmark. Variations from the procedures identified must be included in the report. Additionally, engineering judgment must accompany utilizing and interpreting the results from tests varying from the proposed test method.

6.1.3 Soil information to be determined and documented prior to and during test embankment construction includes, as applicable:

6.1.3.1 Standard Effort moisture-density curve, Test Methods D698.

6.1.3.2 Soil textural classification, Practice D2487.

6.1.3.3 Particle size distribution curve (including hydrometer fraction), Test Method D422, and

6.1.3.4 Atterberg Limits (liquid limit, plastic limit), Test Methods D4318.

6.1.4 Following the preparation of the soil subgrade, the following information is determined within 24 h prior to installation of the revetment system. This information shall include as a minimum the soil water (moisture) content (Test Methods D2216) and density/unit weight determined by sand cone (Test Method D1556) or nuclear gauge (Test Method D5195) at a minimum of two locations along the centerline of the test embankment.

6.2 *Installation of ACB Revetment System:*

6.2.1 A properly designed filter (geotextile, granular filter, or both), properly engineered or selected for the soil subgrade utilized for testing, and the ACBs shall be placed on the crest and downstream slope in accordance with the manufacturer's recommendations. Potential artificially induced scour along the sidewalls will be prevented by placing geotextile wadding, protective flashing, loose grout or a combination, along the edge of the ACB revetment system (Fig. 2). The chosen side protection shall allow nominal block movement and not press the block onto the subgrade. Side protection shall permit a gap a above the blocks a minimum of 0.25 in. [6.4 mm] and a maximum of 0.75 in. [19 mm] in the vertical direction. Horizontal projection of the side protection shall extend a minimum of 0.5 in. [13 mm] and a maximum of 2.5 in. [64 mm] into the flume. The ACB revetment system will be secured at the embankment toe by means of a bolted or welded toe retention system designed for the specific system to be tested (Fig. 3). Depending on the geometry of the system being

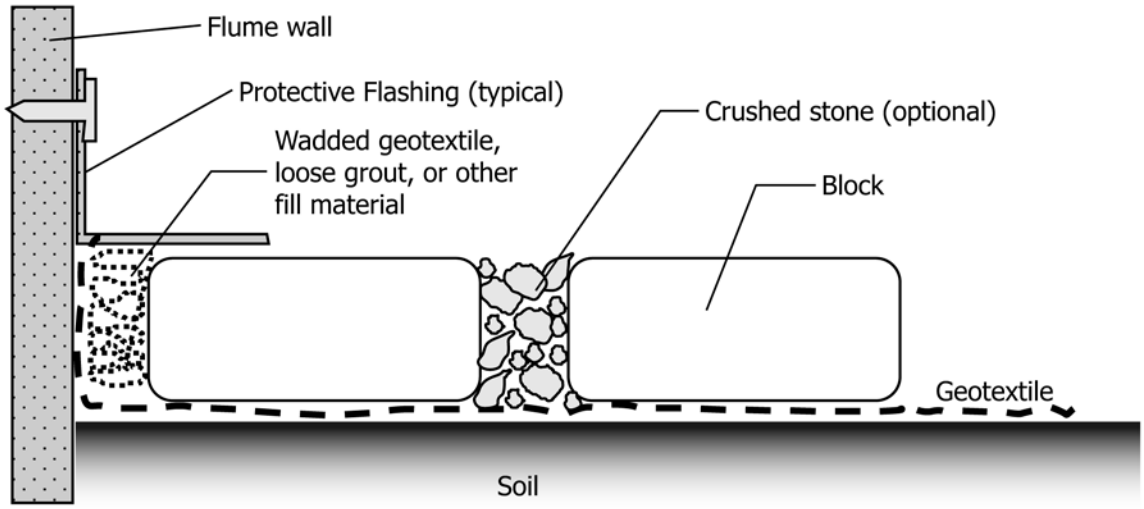


FIG. 2 Recommended Sidewall Detail (Cross Section View)

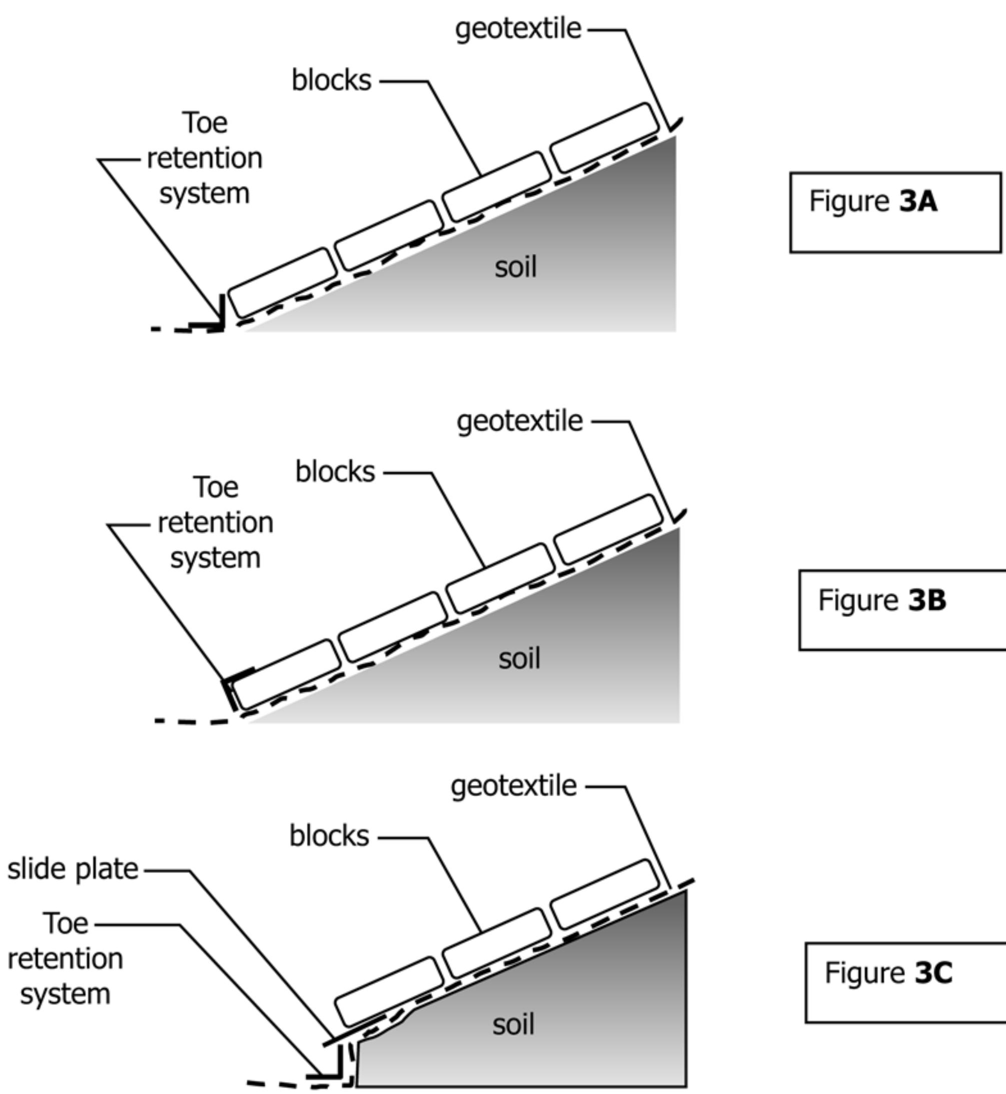


FIG. 3 Recommended Toe Detail Options (Profile View)

tested, void spaces next to the sidewalls greater than 3 in. [75 mm] should be filled with partial blocks specially cut with a masonry saw to fill the void, while maintaining the proper geometric relationship of the matrix. Under no circumstances should the void spaces against the sidewall be filled any compound that bonds the block to the sidewall or prevents the system from its inherent ability to articulate. As shown in Fig. 1, a joint between the ACBs shall occur at the crest (top) of the slope.

7. Procedure

7.1 *Definition of Test*—A test consists of a continuous four-hour flow over the ACB revetment system at a uniform discharge. Providing that the ACB revetment system successfully survives the four-hour flow without deformation, soil loss, or loss of solid contact with the soil subgrade, the procedure is repeated at the next higher target discharge or until the flow capacity of the testing facility is reached. Typically, target discharges correspond to predetermined overtopping depths above the revetment system's crest elevation (for example, 1 ft [0.3 m], 2 ft [0.6 m], etc.), although any discharge may be utilized provided proper measurement and reporting procedures are followed as described in this document. Even if minor system deformation occurs during the test, hourly data collection shall be maintained for the entire four-hour test duration, unless catastrophic ACB revetment system failure occurs.

7.2 *Water Surface and Bed Elevation Profiles*—Hourly measurements of water surface elevation will be made at 2-ft [0.6-m] intervals (stations) along the centerline of the embankment during each test. Bed elevations (top of ACB revetment surface) shall be established prior to each test and again after the cessation of each test, at the same measurement stations as the water surface readings. When testing ACBs that exhibit a staggered layout pattern such that there may not be a block at the centerline location at every measurement station, an adjacent block to the left or right of the centerline may be selected as the measurement point. Those ACBs should be identified with a paint mark to ensure consistency in measurement. Measurements should be made to the nearest 0.01 ft [0.003 m] using point gauge, survey level, or other suitable elevation-measuring device. Suitable stationing positions should be established so that the horizontal location of each measurement station does not vary between subsequent measurements.

7.3 *Water Velocity Measurements*—Hourly measurements of point velocity shall be made at two-tenths, six-tenths, and eight-tenths depth of flow, measured from the water surface down, at 4-ft [1.2-m] intervals along the centerline stationing, and shall correspond to every other water surface measurement station. In areas where depth is insufficient to provide velocity measurements at these three depths, one measurement at six-tenths depth shall be made. The velocity measurements shall be made with an electromagnetic current meter, Price-type pygmy (mini) current meter ("spinning cup"), or pitot tube flow meter. The axis of the device shall be maintained at an angle normal to the plane of the embankment while the measurement is made.

7.4 *Total Discharge Determination*—The total discharge, Q_t, shall be determined independently of the measurements being made in the test section. Suitable determinations can be made by using primary flow meter, in-line flow meters (ultrasonic, propeller, orifice plate, etc.) placed in the supply pipe, or by funneling the flow through an open-channel primary flow meter, such as a Parshall or cutthroat flume, sharp-crested or volumetric tank, after the water exits the test section.

8. Documentation of Test Conditions: Test Records

8.1 This section describes the presentation of the data collected during a test, including the determination of hydraulic conditions, qualitative observations and quantitative descriptions of any damage to the ACB revetment system and soil subgrade.

8.2 *Hydraulic Conditions*—Accurately quantifying the hydraulic conditions that existed during the test is crucial to the accurate establishment of stability performance thresholds.

8.2.1 Total discharge, Q_t, is determined by use of the primary flow meter, as described in 7.4, and another value of discharge, Q_p, shall also be computed at each of the measurement cross sections by the continuity equation:

$$Q_{p,n} = A(V_{p,n}) \tag{1}$$

where:

$V_{p,n}$ = the average of the three centerline point velocity measurements, 1/3 ($V_{0.2} + V_{0.6} + V_{0.8}$) at each station (n = 1, 2, 3, etc.) or $V_{0.6}$ in areas where three velocity measurements are not available, and

A = the cross-sectional area of flow at the same station, measured normal to the embankment surface.

8.2.2 From the results of these calculations, the most representative value of Q shall be identified and used for all further analyses, such as the average Q_p values (omitting outliers), or Q_t, and identified as Q_r.

8.2.2.1 Section-average velocity, V_{ave}, is computed as the best value of Q_r (determined above) divided by the cross-sectional area A, normal to the ACB surface.

8.2.2.2 Flow depth, y_0, is computed as the difference in the measured centerline water surface elevation (WSEL) and the elevation of the ACB surface, corrected for the slope angle as appropriate, at each measurement station. Flow depths are to be reported as being collected either normal, or vertical in reference to the embankment slope.

8.3 *Threshold Conditions*—The hydraulic conditions at the threshold of stability determine the hydraulic stability parameters that characterize the ACB revetment system's performance. Both shear stress and velocity at the stability threshold are typically used for purposes of developing selection and design criteria for a particular ACB revetment system. This test method is intended to be a measure of the resistance of the ACB revetment system to these hydrodynamic forces. The stability threshold of the ACB revetment system is based on incipient motion criteria similar to riprap, gabion and sediment transport stability theories. In some cases the observed stability threshold in this test method will not likely be observed based upon the rotation of individual concrete blocks since it is not always possible to detect their initial movement. As a result, the determination of stability threshold may be determined based upon their interaction with the subgrade. Carefully check to see if the ACBs will rock/wobble against the subgrade. If yes, then the stability threshold most likely has occurred. The following covers other methodologies to determine stability threshold.

8.3.1 The researcher's determination of the stability threshold of tested revetment system is somewhat subjective, and depends on the interpretation of the point on the embankment at which "loss of solid contact" between the revetment system and the subgrade soil occurred. In practice, all of the following conditions have been used as guidance for this interpretation (listed in decreasing order of frequency of occurrence):

8.3.1.1 *Vertical Displacement or Loss of a Block (or Group of Blocks)*—At the conclusion of each test period, a distorted surface to the revetment matrix will indicate that there was sufficient force to initiate overturning. The system is considered to have reached the stability threshold if the movement is such that the base of any block has been uplifted from contact with the filter.

8.3.1.2 *Loss of Soil Beneath the Geotextile, Resulting in Voids*—Following each test segment, the embankment is inspected for the formation of voids under the revetment matrix. Utilizing a small rod, the researcher may investigate the open areas within the matrix by pressing the rod to the filter fabric and noting any areas offering little or no resistance. Inspection of the soil embankment at the conclusion of testing and documenting the formation of gullies remains the most definitive method for determining the system having reached its stability threshold.

8.3.1.3 *Liquefaction and Mass Slumping/Sliding of the Subsoil*—Observations of significant siltation washing through the filter are an indication that loss of solid contact has occurred. While minor siltation that occurs immediately after startup and does not increase with time is normal, a significant increase in siltation that does not stabilize over time is an indication of uplift of the revetment system.

8.3.2 Occasionally one identification mode will be apparent and dominate the interpretation of the stability threshold of the system having been exceeded. However, it is not necessary to relate the cause of system instability to one distinct mode. Any observations that one or more blocks have lost solid contact with the subgrade shall be interpreted as the system having reached its stability threshold.

9. Report

9.1 A summary report of the revetment testing program shall be prepared, which documents, at a minimum, the elements listed in this section.

9.1.1 The name(s) of the person(s) conducting the test.

9.1.2 The date(s) the test was performed.

9.1.3 The location of where the test was performed.

9.1.4 Description of the test section, including plan/profile schematics, measurement devices and instrumentation.

9.1.5 Description of the revetment system, including dimensioned drawings of block components, description of infill material (if used), drainage media (if used), geotextile properties, and any ancillary features such as cables, anchors, connectors, etc.

9.1.6 Documentation of the embankment soil properties and testing results identified in Sections 6 and 7, along with a description of the embankment construction methods and a final survey of the embankment slope prior to the placement of the revetment system.

9.1.7 Description of the revetment installation, including wall details, crest and toe terminations, and ancillary components such as anchors, cables, grids, etc. Include photographs and documentation illustrating all aspects of the system relevant to embankment stability.

9.1.8 Description of the testing procedures, including the overtopping depth(s) and discharge(s) examined, data collection procedures, and qualitative description of revetment system performance, including photos of tests in progress and post-test revetment system condition.

9.1.9 Summary of measured data and calculated hydraulic conditions for each test.

9.1.10 Discussion of the identification (interpretation) of the location where the system's stability threshold was exceeded.

9.1.11 Appendix containing raw data and measurements.

10. Precision and Bias

10.1 *Precision*—Test data on precision is not presented due to the nature of this test method. It is either not feasible or too costly at this time to have ten or more agencies participate in performing this test method on a given soil and ACB revetment system.

10.1.1 Subcommittee D18.25.04 is seeking any data from users of this test that might be used to make a limited statement.

10.2 *Bias*—There is no accepted reference value for this test method, therefore, bias cannot be determined.

11. Keywords

11.1 articulating concrete block (ACB) revetment system; channel; channel lining; channel stability; erosion; erosion control; open-channel flow; permissible shear stress; permissible velocity; shear stress; velocity