Designation: D 5567 – 94 (Reapproved 2001)

Standard Test Method for Hydraulic Conductivity Ratio (HCR) Testing of Soil/Geotextile Systems[1]

This standard is issued under the fixed designation D 5567; 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 laboratory measurement of the hydraulic conductivity of water-saturated porous materials with a flexible-wall permeameter.

1.2 This test method may be used with undisturbed or compacted soil specimens that have a hydraulic conductivity less than or equal to 5×10^{-2} cm/s.

1.3 The filtration behavior of soils with hydraulic conductivities greater than 5×10^{-2} cm/s may be determined by the gradient ratio test (Test Method D 5101).

1.4 The values stated in SI units are to be regarded as the standard, although other units are provided for information and clarification purposes.

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.*

2. Referenced Documents

2.1 *ASTM Standards:*

D 422 Method for Particle-Size Analysis of Soils[2]

D 653 Terminology Relating to Soil, Rock, and Contained Fluids[2]

D 698 Test Method for Laboratory Compaction Characteristics of Soil Using Standard Effort (12 400 ft-lbf/ft^3 (600 kN-m/m^3)[2]

D 854 Test Method for Specific Gravity of Soil Solids by Water Pycnometer[2]

D 1587 Method for Thin-Walled Tube Sampling of Soils for Geotechnical Purposes[2]

D 2216 Test Method for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass[2]

D 2487 Classification of Soils for Engineering Purposes (Unified Soil Classification System)[2]

D 2488 Practice for Description and Identification of Soils (Visual-Manual Procedure)[2]

D 4220 Practice for Preserving and Transporting Soil Samples[2]

D 4318 Test Method for Liquid Limit, Plastic Limit, and Plasticity Index of Soils[2]

D 4354 Practice for Sampling of Geosynthetics for Testing[3]

D 4439 Terminology for Geotextiles[3]

D 4491 Test Methods for Water Permeability of Geotextiles by Permittivity[3]

D 4647 Test Method for Identification and Classification of Dispersive Clay Soils by the Pinhole Test[2]

D 4751 Test Method for Determining the Apparent Opening Size of a Geotextile[3]

D 5084 Test Method for Hydraulic Conductivity of Saturated Porous Materials Using a Flexible Wall Permeameter[3]

D 5101 Test Method for Measuring the Soil Geotextile System Clogging Potential by the Gradient Ratio[2]

3. Terminology

3.1 *Definitions:*

3.1.1 *filter*, *n*—a layer or combination of layers of previous materials designed and installed in such a manner as to provide drainage, yet prevent the movement of soil particles due to flowing water (Terminology D 653).

3.1.1.1 *Discussion*—A *geotextile filter* is the term used for a layer or combination of layers of pervious geosynthetic material(s) that are used in the capacity of a filter as defined above.

3.1.2 *geotextile*, *n*—any permeable textile material used with foundation, soil, rock, earth, or any other geotechnical engineering related material, as an integral part of a man-made product, structure, or system (Terminology D 4439).

3.1.3 *hydraulic conductivity (k)*, *n*—the rate of discharge of water under laminar flow conditions through a unit cross-sectional area of a porous medium under a unit hydraulic gradient and standard temperature conditions (20°C) (Test Method D 5084).

3.1.3.1 *Discussion*—The term *coefficient of permeability* is often used instead of *hydraulic conductivity,* but *hydraulic conductivity* is used exclusively in this test method. A complete discussion of the terminology associated with Darcy's law is given in the literature.[4]

3.1.4 *permeation*, *n*—the transmission of a fluid through a porous medium (NEW).

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[1] This test method is under the jurisdiction of ASTM Committee D35 on Geosynthetics and is the direct responsibility of Subcommittee D35.03 on Permeability and Filtration.

Current edition approved May 15, 1994. Published July 1994.

[2] *Annual Book of ASTM Standards*, Vol 04.08.

[3] *Annual Book of ASTM Standards*, Vol 04.09.

[4] Olsen and Daniel, "Measurement of Hydraulic Conductivity of Fine-Grained Soils," *ASTM STP 746*, ASTM, Philadelphia, PA, 1981, pp. 18–64.

3.1.5 *pore volumes of flow* (V_{pq}), *n*—the cumulative volume of flow through a test specimen divided by the volume of voids within the specimen (modified from Test Method D 5084).

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *hydraulic conductivity ratio (HCR), n*— the ratio of the hydraulic conductivity of the soil/geotextile system, k_{sg}, at any time during the test, to the initial hydraulic conductivity, k_{sgo}, measured at the beginning of the test (NEW).

4. Summary of Test Method

4.1 This test method presents a procedure for performing permeability tests of soil/geotextile systems. The technique requires placement of the soil and geotextile in a flexible-wall permeameter.

4.2 The soil/geotextile specimen is saturated using de-aired water and back pressure techniques. The specimen is consolidated at the effective stress anticipated in the proposed application. The sample is then permeated with water. The hydraulic conductivity of the soil/geotextile specimen is measured and plotted as a function of elapsed time and volume of water passing through the sample. The hydraulic conductivity may either increase or decrease during the test, depending on the behavior of the geotextile filter. The test is terminated when a stabilized hydraulic conductivity is obtained, or when the hydraulic conductivity decreases below the minimum value allowed by the drainage design.

5. Significance and Use

5.1 This test method is to be used for measuring the hydraulic conductivity of water-saturated soil/geotextile systems.

5.2 This test method is to be used as a design performance test, or as a comparative tool for evaluating the filtration behavior of soils with geotextiles. This test method is not intended for routine (index-style) testing, since the results will depend on the specific soil and hydraulic conditions that are evaluated. It is not appropriate to use the test results for job specifications or manufacturers' certifications.

5.3 This test method applies to the permeation of porous materials with water. Permeation with other liquids, such as chemical wastes, can be accomplished using procedures similar to those described in this test method. However, this test method is intended to be used only when water is the permeant liquid.

5.4 The mathematical concepts (primarily Darcy's law) used in this test method were originally developed for one-dimensional, laminar flow of water within porous materials, which is often the case with soil and geotextiles. When flow conditions are laminar and one-dimensional, the hydraulic conductivity is unaffected by hydraulic gradient. However, when flow occurs through some soil/geotextile systems, a change in hydraulic gradient could cause movement of soil particles, thereby changing the structure of the test specimen and hence changing the hydraulic conductivity of the soil/geotextile system. The mathematical expressions given by Darcy's law are still appropriate for application to this situation; however, it is therefore imperative that the hydraulic gradient be controlled carefully in the HCR test to simulate field conditions.

5.5 This test method provides a means of determining hydraulic conductivity at a controlled level of effective stress. Hydraulic conductivity varies with void ratio, which in turn varies with effective stress. The hydraulic conductivity of the test specimen will probably change if the void ratio is changed. It is therefore imperative that the effective stress (that is, the effective confining pressure) be controlled carefully in the HCR test to simulate field conditions.

6. Apparatus

6.1 *Triaxial Pressure Control Panel*— The triaxial control panel consists of three independent pressure-regulating systems. These three systems control the pressure of the following: (*1*) the triaxial chamber, (*2*) the specimen influent, and (*3*) the specimen effluent. Each system shall be capable of applying and controlling the pressure to within ± 1 % of the applied pressure. The influent and effluent pressure systems each consist of a reservoir connected to the permeameter cell and partially filled with fluid (usually water). The upper part of the reservoir is connected to a compressed gas supply. The gas pressure is controlled by a pressure regulator and measured by a pressure gage, electronic pressure transducer, or any other device capable of measuring to the prescribed tolerance. A schematic diagram of the HCR test equipment is shown in Fig. 1.

6.2 *Permeameter Cell*—An apparatus shall be provided in which the specimen and porous end pieces, enclosed by a membrane sealed to the cap and base, are subjected to controlled fluid pressures. It shall consist of a top plate and baseplate separated by a cylinder. The cylinder may be constructed of any material capable of withstanding the applied pressures. It is desirable to use a transparent material or have a cylinder provided with viewing ports so the specimen may be

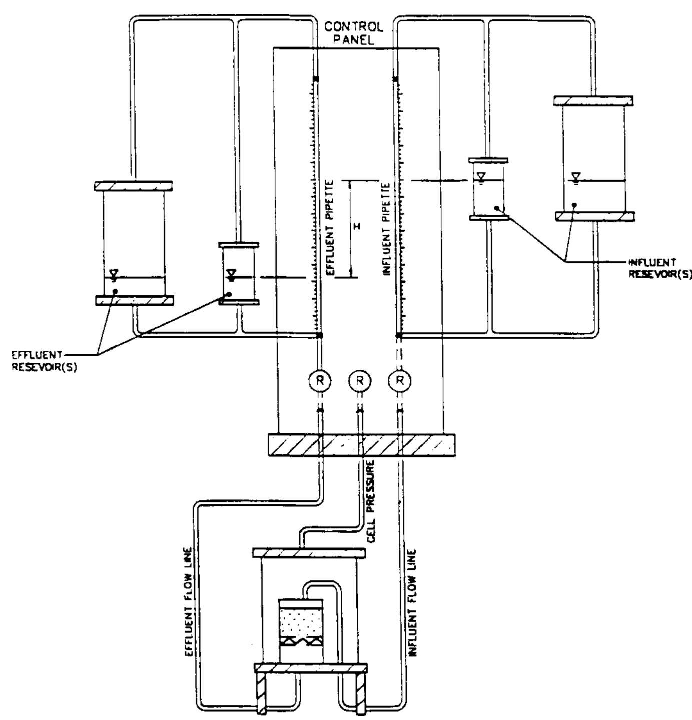

FIG. 1 Schematic Diagram of HCR Test Equipment

observed. The top plate shall have a vent valve such that air can be forced out of the chamber as it is filled. The baseplate shall have an inlet through which the permeameter cell is filled with the cell fluid. The baseplate shall have ports available for the influent and effluent flow lines to the test specimen. A diagram of the permeameter cell is shown in Fig. 2.

NOTE 1—The permeameter cell may allow for observation of the changes in height of the specimen, either by observation through the cell wall or by monitoring of either a loading piston or an extensometer extending through the top plate of the cell bearing on the top cap and attached to a dial indicator or other measuring device. The piston or extensometer should pass through a bushing and seal incorporated into the top plate and shall be loaded with sufficient force to compensate for cell pressure acting on the piston tip. If deformations are measured, the deformation indicator shall be a dial indicator or cathetometer graduated to 0.3 mm (0.01 in.) or finer and having an adequate travel range. Other measuring devices meeting these requirements are acceptable.

NOTE 2—Four drainage lines leading to the specimen, two each to the base and top cap, are recommended in order to facilitate gas removal and thus saturation of the hydraulic system. These lines may be used to flush air bubbles from the lines without causing permeation through the specimen. The drainage lines shall have controlled no-volume-change valves, such as ball valves, and shall be designed to minimize dead space in the lines.

6.3 *Influent and Effluent Reservoirs*— Reservoirs shall be provided to dispense and collect the permeant through the specimen. These reservoirs may vary in size (diameter and height), depending on the anticipated hydraulic conductivity of the specimen and the gradient at which the test is conducted. In general, large reservoirs are necessary for fast flow rates and small reservoirs are necessary for slow flow rates. The most versatile HCR panels have two or three sets of interchangeable reservoirs, with diameters ranging from 2 to 15 cm (1 to 6 in.). For materials with anticipated hydraulic conductivity values greater than 10^3 cm/s, 6-mm (0.25-in.) or larger diameter lines should be used for all flow lines to and from the reservoirs, and through the permeameter cell to the top and bottom of the specimen. The reservoirs are shown on the diagram in Fig. 1, and recommended sizes for the reservoirs are provided in 8.4.2.

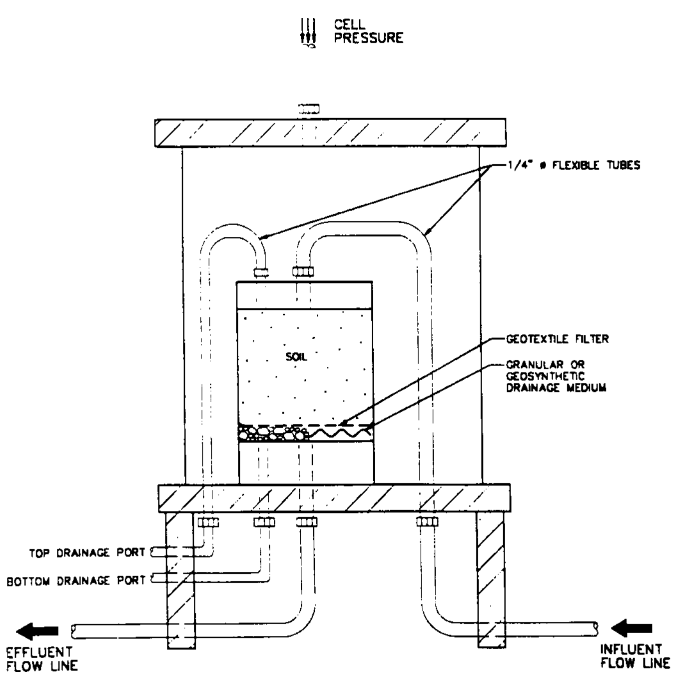

FIG. 2 HCR Permeameter Cell

6.4 *Specimen Cap and Base*—An impermeable rigid cap and base shall be used to prevent drainage of the specimen. The specimen cap and base shall be constructed of a noncorrosive impermeable material, and each shall have a circular plane surface of contact with the specimen and a circular cross section. The weight of the specimen cap shall produce an axial stress on the specimen below 1 kN/m^2 (0.15 psi). The diameter of the cap and base shall be equal to the initial diameter of the specimen. The specimen base shall be coupled to the base of the permeameter cell so as to prevent lateral motion or tilting. The cylindrical surface of the specimen base and cap that contacts the membrane to form a seal shall be smooth and free of scratches so as to minimize the potential for leaks. The specimen cap and base are shown in Fig. 2.

6.5 *Rubber Membranes*—The rubber membrane used to encase the specimen shall provide reliable protection from leakage. Membranes shall be inspected carefully prior to use, and the membrane shall be discarded if any flaws or pinholes are evident. In order to offer minimum restraint to the specimen, the unstretched membrane diameter shall be approximately 95 % of that of the specimen. The membrane shall be sealed to the specimen base and cap by any method that will produce a positive seal, preferably with O-rings or a combination of O-rings and rubber bands.

6.6 *Sample Extruder*—The sample extruder shall be capable of extruding the soil core from the sampling tube in the same direction of travel in which the sample entered the tube and with minimum disturbance of the sample. Care should be taken to avoid bending stresses on the soil core due to gravity if the core is not extruded vertically. Conditions at the time of sample removal may dictate the removal procedure, but the principal concern is to keep the degree of disturbance minimal.

6.7 *Equipment for Compacting a Specimen*—Equipment (including compactor and mold) suitable for the method of compaction specified by the requester shall be used.

6.8 *Specimen Size Measurement Devices*— Devices used to measure the height and diameter of the specimen shall be capable of measuring the desired dimension to within 1 % of its actual length and shall be constructed such that their use will not disturb the specimen.

6.9 *Timer*—A timing device indicating the elapsed testing time to the nearest 1 s shall be used for establishing the hydraulic conductivity.

6.10 *Balances*—The balance used to weigh specimens shall determine the mass of the specimens to within 0.1 % of the total mass.

6.11 *Apparatus for Water Content Determination*, as specified in Test Method D 2216.

6.12 *Miscellaneous Apparatus*—Specimen trimming and carving tools, membrane and O-ring expanders, and data sheets, as required.

6.13 *Head Losses*—Head losses in the tubes, valves, and other portions of the equipment may lead to error in determining the hydraulic conductivity. The permeameter shall be assembled with no specimen inside and then the hydraulic system filled to guard against such errors. The hydraulic pressures or heads that will be used in testing a specimen shall be applied, and the rate of flow measured with an accuracy of 5 % or better. This flow rate shall be at least two times greater than that which is measured when a specimen is placed inside the permeameter with the same hydraulic pressures or heads applied.

7. Sampling Test Specimens and Test Units

7.1 *Soil Specimen Size*—Cylindrical specimens shall have a minimum diameter of 30 mm, and the largest particle contained within the test specimen shall be smaller than ⅙ of the specimen diameter. For the purposes of establishing a reference standard, the recommended height of the standard HCR sample is to be 5.0 cm. The length may be increased if the maximum particle size is larger than 0.47 cm (U.S. Standard No. 4 sieve) or if the specimen hydraulic conductivity may be governed by the macro-structure (that is, cracks) of the specimen. If it is found that oversize particles are present after completion of a test, indicate this information in the report of test data under remarks. The average height and diameter of the test specimen shall be determined using the apparatus specified in 6.8.

7.2 *Undisturbed Soil Specimens*—Prepare undisturbed specimens from samples secured in accordance with Method D 1587 or other acceptable undisturbed tube sampling procedures. Undisturbed samples shall be preserved and transported as outlined for Groups C or D samples in Practice D 4220.

7.3 *Compacted Soil Specimens*—Prepare specimens using the compaction method, predetermined water content, and unit weight prescribed by the individual assigning the test.

NOTE 3—It is common for the unit weight of the specimen after removal from the mold to be less than the value based on the volume of the mold. This occurs as a result of the specimen swelling after removal of the lateral confinement due to the mold.

7.4 *Geotextile Filter Specimens*—The geotextile specimen should be selected from a larger geotextile sample in accordance with the procedures set forth in Practice D 4354. The geotextile specimen should be trimmed to a diameter that is approximately 0.6 cm (0.25 in.) greater than that of the soil specimen.

8. Procedure

8.1 *Specimen Setup*:

8.1.1 Prepare the soil specimen in such a way as to model the anticipated field conditions or to achieve the desired test objective. If the filter will be placed in in-situ conditions, obtain undisturbed samples of the soil as described in 7.2. If the filter will be placed in compacted fill, compact the soil specimen to meet the specified compaction criteria described in 7.3.

8.1.2 Obtain a specimen from an undisturbed sample by trimming the ends of the specimen such that they are perpendicular to the long axis of the sample, provided the soil characteristics are such that no significant disturbance results from sampling and the specimen is uniformly circular. Handle the specimens carefully in order to minimize disturbance, changes in cross section, or loss of water content. If compression or any type of noticeable disturbance would be caused by the extrusion device, split the sample tube lengthwise or cut it off in small sections to facilitate removal of the specimen with minimum disturbance. Prepare trimmed specimens in an environment in which the change in the water content of the soil is minimized. Specimens shall be of uniform, circular cross section perpendicular to the axis of the specimen. Where pebbles or crumbling cause excessive irregularity along the outside edges of the specimen or at the ends, pack soil from the trimmings in the irregularities to produce the desired surface. Determine the mass and dimensions (length and diameter) of the test specimen. Determine the water content using soil trimmings taken from the ends of the test specimen, in accordance with Test Method D 2216.

8.1.3 Prepare compacted specimens by compacting material in at least six layers, using a pressing or kneading action, into a split mold of circular cross section having dimensions meeting the requirements of 7.1. Batch the material required for the specimen by mixing soil thoroughly with sufficient water to produce the desired water content. After batching, store the material in a covered container in accordance with the guidelines set forth in Table 2 of Test Method D 698. Mold the specimens to the desired density by either (*1*) kneading or tamping each layer until the cumulative weight of the soil placed in the mold is compacted to a known volume or (*2*) adjusting the number of layers, number of tamps per layer, and force per tamp. Scarify the top of each layer prior to the addition of material for the next layer. The tamper used to compact the material shall have an area in contact with the soil equal to or less than ½ the area of the mold. After a specimen is formed, with the ends perpendicular to the longitudinal axis, remove the mold and determine the mass and dimensions of the specimen using the devices described in Section 6. Perform one or more water content determinations on excess material used to prepare the specimen in accordance with Test Method D 2216.

8.1.4 Mount the soil specimen in the triaxial cell using the configuration shown in Fig. 2. Place the proposed drainage material (typically pea gravel, coarse sand, or geosynthetic drainage core) on the bottom plate. Place the geotextile filter directly over the drain material. Then place the soil sample directly over the geotextile with a screen directly over the soil. The top screen may vary in opening size from approximately 1 mm (0.04 in.) for sandy soils to as small as 0.07 mm (0.0028 in.) for fine-grained soils. Several layers of the top screen may be placed on top of the soil specimen to help distribute the flow evenly across the entire specimen cross section. Then place the top platen over the top screen, and secure the specimen with the rubber membrane and O-rings. Then connect the top flow line to the top platen.

8.1.5 Assemble the triaxial chamber and fill it with chamber fluid (usually de-aired water), and apply the initial cell pressure.

8.2 *Back-Pressure Saturation*—Accomplish back-pressure saturation by raising the cell pressure and back pressure in increments.

8.2.1 Open the flow line valves and flush any free air bubbles out of the system. If an electronic pressure transducer or other measuring device is to be used during the test to measure pore pressures or applied hydraulic gradient, it should be bled of any trapped air. Take and record an initial reading of specimen height, if being monitored.

8.2.2 Adjust the applied confining pressure to the value of effective stress that will be used during saturation of the sample. Apply back pressure by simultaneously increasing the cell pressure and the influent and effluent pressures in increments. The maximum value of an increment in back pressure shall be sufficiently low that no point in the specimen is exposed to an effective stress in excess of that to which the specimen will be consolidated subsequently. At no time shall a head be applied so that the effective confining stress is below 7 kPa (1 psi) because of the danger of separation of the membrane from the test specimen. Maintain each increment of pressure for a period of a few minutes to a few hours, depending on the characteristics of the specimen. The increments of pressure should generally be increased at a slower rate for low-permeability soils than for high-permeability soils.

8.2.3 Verify the saturation by measuring the B coefficient as described in Test Method D 5084 (see Note 4). Consider the test specimen to be saturated adequately if (*1*) the B value is ≥ 0.95 or (*2*) the B value for relatively incompressible materials remains unchanged with the application of larger values of back pressure. The B value may be measured prior to or after completion of the consolidation phase (see 8.3). Accurate B-value determination can be made only if no gradient is acting across the specimen and all pore pressure induced by consolidation has dissipated.

NOTE 4—The B coefficient is defined for this type of test as the change in pore water pressure in the porous material divided by the change in confining pressure. Compressible materials that are fully saturated with water will have a B value of 1.0. Relatively incompressible, saturated materials have B values that are somewhat below 1.0.

8.3 *Consolidation*—Following back-pressure saturation, increase the cell pressure until the difference between the cell pressure and back pressure is equal to the desired effective stress. Allow very slow drainage from the top of the specimen only. Measure the volumetric strain at timed intervals throughout the consolidation phase. Stop the consolidation phase generally after the rate of volumetric strain becomes nearly zero, indicating that primary consolidation of the soil is complete.

8.4 *Permeation of Specimen*—Initiate flow across the test specimen upon completion of primary consolidation. The direction of the flow is such that the permeant flows through the soil and then the geotextile and drainage material. The flow direction would be from the top to the bottom of the specimen for the configuration shown in Fig. 2.

8.4.1 *Hydraulic Gradient*—When possible, the hydraulic gradient used for hydraulic conductivity measurements should be specified by the designer to be similar to that expected to occur in the field. Hydraulic gradients ranging from less than 1 to 5 generally cover most field conditions. However, the use of small hydraulic gradients can lead to very long testing time requirements for materials having low hydraulic conductivity (below approximately 1×10^{-6} cm/s). Somewhat larger hydraulic gradients may be used in the laboratory to accelerate testing, but excessive gradients must be avoided because high seepage pressures may consolidate the material, wash material from the specimen (that is, piping may occur), or wash fine particles downstream and clog the geotextile at the effluent end of the test specimen. These effects could increase or decrease hydraulic conductivity. If no gradient is specified by the requestor, the following guidelines may be used:

Hydraulic conductivity, cm/s	Recommended maximum hydraulic gradient
5×10^{-2} to 1×10^{-3}	2
1×10^{-3} to 1×10^{-5}	5
1×10^{-5} to 1×10^{-6}	10
1×10^{-6} to 1×10^{-7}	20
below 1×10^{-7}	30

NOTE 5—Seepage pressures associated with large hydraulic gradients can consolidate soft, compressible specimens and reduce their hydraulic conductivity. It may be necessary to use smaller hydraulic gradients (less than 10) for such specimens.

8.4.2 *Initialization of Flow*—Obtain and record a preliminary value of hydraulic conductivity, k_{sgo}, initially so that the correct set of reservoirs may be selected for the remainder of the test. Accomplish this by permeating a small amount of water through the specimen using a low hydraulic gradient. After measuring the initial hydraulic conductivity, select the hydraulic gradient from those recommended in 8.4.1. The selected gradient should then be set across the specimen, and the flow should be re-initialized, using the recommended size of reservoirs listed below:

Hydraulic conductivity, cm/s	Approximate recommended diameter of influent and effluent reservoirs
5×10^{-2} to 1×10^{-5}	15 cm
1×10^{-5} to 1×10^{-7}	7 cm
below 1×10^{-7}	pipette

8.4.3 *Flow Measurements*—Record measurements of the change in water levels in both the influent and effluent reservoirs (or pipettes) at regular intervals. Time these measurements such that the change in head across the specimen is at least 5 to 10 times greater than the smallest division on the water-level measuring scale. Continue the measurements at regular intervals until the gradient falls below a recommended minimum value, at which time reset the gradient by filling the influent reservoir with fresh de-aired water and emptying the effluent reservoir into a separate container.

8.4.4 *Analysis of Effluent Water*—One of the purposes of the HCR test is to evaluate the potential for soil piping through the geotextile filter. Observations should therefore be made regarding the presence of soil particles in the effluent reservoir. The general cloudiness of the effluent water should be recorded whenever a flow measurement is recorded. Although this is a qualitative and somewhat subjective measurement, the following designations for the cloudiness of the effluent reservoir have been adopted from and defined in Test Method D 4647: very dark, dark, moderately dark, slightly dark, barely visible, or completely clear. The effluent water may be evaporated in an oven and the dry weight of the piped soil may be recorded to further quantify the amount of piped soil. The amount of piped soil may be expressed at the end of the test as a percentage of the total weight of the soil specimen used in the test.

8.5 *Termination Criteria*—The permeation phase of the test may be terminated when one or more of the following criteria are satisfied:

8.5.1 A graph is generated that shows the hydraulic conductivity values plotted as a function of pore volumes of water passing through the specimen. The test may be terminated when the slope of this curve has become nearly horizontal for more than five consecutive pore volumes and the effluent water is relatively clear, indicating that a stabilized hydraulic conductivity has been achieved. The hydraulic conductivity is considered stable if the hydraulic conductivity values fall within ±50 % of the mean value and the plot of hydraulic conductivity versus pore volumes shows no significant upward or downward trend during the final five pore volumes. Additionally, the ratio of measured outflow to inflow rate should be between 0.75 and 1.25.

8.5.2 The hydraulic conductivity, k_{sg}, falls below a predetermined allowable design value.

8.5.3 The effluent does not become clear within the first 20 pore volumes, indicating that continuous piping of soil is occurring through the geotextile filter.

9. Calculation

9.1 Calculate the initial parameters associated with the specimen prior to starting the test. These are as follows:

(1) Soil specimen volume, V;
(2) Soil specimen moist density, ρ_m;
(3) Soil specimen dry density, ρ_d;
(4) Soil specimen total porosity, n; and
(5) Soil specimen pore volume, V_p.

9.1.1 Calculate the volume, V, as follows:

$$V = \frac{\pi}{4} D^2 L \tag{1}$$

where:
D = diameter of the soil specimen, and
L = height of the soil specimen.

9.1.2 Calculate the moist density, ρ_m, as follows:

$$\rho_m = \frac{M}{V} \tag{2}$$

where:
M = mass of the soil specimen.

9.1.3 Calculate the dry density, ρ_d, as follows:

$$\rho_d = \frac{\rho_m}{1 + w} \tag{3}$$

where:
w = compacted or natural water content of the soil, expressed as a decimal.

9.1.4 Calculate the total porosity, n, as follows:

$$n = 1 - \frac{\rho_d}{G_s \rho_w} \tag{4}$$

where:
G_s = specific gravity of the soil (see Test Method D 854), and
ρ_w = density of water (1.0 g/cm^3 or 62.4 lb/ft^3).

9.1.5 Calculate the pore volume, V_p, as follows:

$$V_p = nV \tag{5}$$

9.2 Calculate the following parameters at intervals throughout the permeation phase of the test:

(1) Hydraulic gradient, i;
(2) Hydraulic conductivity, k_{sg};
(3) Hydraulic conductivity ratio, HCR; and
(4) Cumulative volume that has passed through the specimen, V_q.

9.2.1 Calculate the gradient, i, at any given time, as follows:

$$i = \frac{1}{L}\left(h + \frac{(p_i - p_o)}{\rho_w}\right) \tag{6}$$

where:
h = difference in water levels in the or reservoirs (or pipettes) at any given time,
P_i = air pressure on the influent pipette or reservoir,
P_o = air pressure on the effluent pipette or reservoir, and
ρ_w = density of water (or of the permeant used).

9.2.2 Calculate the hydraulic conductivity of the soil/geotextile, k_{sg}, at any given time, as follows:

$$k_{sg} = \frac{aL}{2A(t_2 - t_1)} \ln\left(\frac{i_1}{i_2}\right) \tag{7}$$

where:
a = cross-section area of the pipettes or reservoirs used to measure the water levels at times t_1, and t_2,
L = height of the soil specimen,
A = cross-section area of the soil specimen,
t_1 = elapsed time one,
t_2 = elapsed time two,
i_1 = gradient at time one, and
i_2 = gradient at time two.

9.2.3 Correct the hydraulic conductivity to that for 20°C (68°F), k_{20}, as follows:

$$k_{20} = R_T k_{sg} \tag{8}$$

where:
R_t = correction factor for the temperature of the permeant (see Table 1).

9.2.4 At the same intervals used to calculate k_{sg}, calculate the hydraulic conductivity ratio (HCR) of the specimen as follows:

$$HCR = \frac{k_{sg}}{k_{sgo}} \tag{9}$$

where:
k_{sg} = hydraulic conductivity of the soil/geotextile composite at any time, t, and
k_{sgo} = initial hydraulic conductivity measured at the outset of the permeation phase of the test.

9.2.5 During permeation of the specimen, calculate the volume of flow that has passed through the specimen, V_q, as follows:

$$V_q = V_{q1} + (H_2 - H_1) \times a \tag{10}$$

TABLE 1 Correction Factor R_T for Viscosity of Water at Various Temperatures[A]

Temperature (degrees C)	R_T	Temperature (degrees C)	R_T
0	1.783	25	0.889
1	1.723	26	0.869
2	1.664	27	0.850
3	1.611	28	0.832
4	1.560	29	0.814
5	1.511	30	0.797
6	1.465	31	0.780
7	1.379	32	0.764
8	1.379	33	0.749
9	1.339	34	0.733
10	1.301	35	0.719
11	1.265	36	0.705
12	1.230	37	0.692
13	1.197	38	0.678
14	1.165	39	0.665
15	1.135	40	0.653
16	1.106	41	0.641
17	1.077	42	0.629
18	1.051	43	0.618
19	1.025	44	0.607
20	1.000	45	0.598
21	0.976	46	0.585
22	0.953	47	0.575
23	0.931	48	0.565
24	0.910	49	0.556

[A] ASTM Vol 4.08 Method D 5084

NOTE 1—RT = (−0.02452 T + 1.495) where T is the °C.

where:

$V_{q\,1}$ = volume that had passed through the sample at time t_1,
H_1 = level of water, relative to given datum, in the influent reservoir at time t_1,
H_2 = level of water, relative to a given datum, in the influent reservoir at time t_2, and
a = cross-section area of the influent reservoir.

The volume of water passed at any chosen point during permeation of the sample may also be expressed in terms of the cumulative pore volumes that have passed. Calculate this as follows:

$$V_{pq} = \frac{V_q}{V_p} \quad (11)$$

9.3 The specimen breakdown procedures should include determination of the final parameters of the soil specimen (V, ρ_m, w, ρ_d, n, and V_p), as was presented in 9.1.

10. Report

10.1 Include the following information regarding the soil sample in the report:

10.1.1 Specimen identifying information, such as project, location, boring number, sample number, depth, etc.

10.1.2 Visual description of the soil in accordance with Practice D 2488 or classified in accordance with Classification D 2487.

10.1.3 Particle-size distribution of the soil, if determined, in accordance with Method D 422.

10.1.4 Liquid and plastic limits, if determined, in accordance with Test Method D 4318.

10.1.5 The following parameters for the soil specimen measured or calculated both before and after the test (that is, initial and final conditions): (*1*) height and diameter of the specimen, (*2*) moist weight and volume, (*3*) moist density, (*4*) water content, (*5*) dry density, and (*6*) porosity.

10.1.6 Soil specimen preparation procedures used, for example, whether the specimen was compacted in the laboratory or was obtained from an undisturbed sample, or whether any special procedures were necessary, such as packing the soil trimmings into irregularities in the specimen, as was described in 8.1.2.

10.2 Include the following information regarding the geotextile filter in the report:

10.2.1 Identification and visual description of the geotextile, including the polymer type and manufacturing process (that is, woven, nonwoven, and the like).

10.2.2 If available from manufacturers' literature or from laboratory tests, the physical characteristics of the geotextile, including thickness, apparent opening size or O_{95} (see Test Method D 4751), percent open area or porosity of the geotextile, and permittivity (see Test Methods D 4491).

10.3 Include the following information regarding the HCR test in the report:

10.3.1 Effective confining stress used to consolidate the specimen.

10.3.2 Hydraulic gradient or range in hydraulic gradients used to permeate the specimen.

10.3.3 Initial and final values of hydraulic conductivity.

10.3.4 Final HCR value.

10.3.5 Graphs that show the hydraulic conductivity values plotted as a function of elapsed time and as a function of pore volume passed through the specimen. The range of hydraulic gradients should be shown on these plots and any remarks regarding the visual appearance of soil particles in the effluent reservoir (that is, cloudiness) should be included. Similar graphs should be provided that show the HCR values plotted as a function of elapsed time and pore volume. Example graphs are shown in Fig. 3A and Fig. 3B and Fig. 4A and Fig. 4B.

NOTE 6—Fig. 3A and Fig. 3B show the HCR test results of a soil/geotextile system that developed hydraulic conductivity conditions that are substantially less than the initial hydraulic conductivity of the system. This reduction in hydraulic conductivity is representative of significant retention of soil particles. It is noted that this condition may be desirable in certain drainage applications, or it may be undesirable in other applications. In general, the term "clogging" may be defined as the undesirable development of low-permeability conditions near the filter that render the filter unable to perform the intended drainage function. The quantitative definition of clogging must be defined by the drainage designer on a case-by-case basis.

Fig. 4A and Fig. 4B show the HCR test results of a soil/geotextile system of which the hydraulic conductivity has achieved a stable value. It is noted that a stable hydraulic conductivity may result from a soil type that, under given flow conditions, does not result in excessive transport of soil particles up against, or through, the filter. However, a stable hydraulic conductivity could result from a soil type that, under given flow conditions, exhibits continued transport of soil particles through the filter (a phenomenon known as "piping"). The quantitative definition of stabilized filter conditions and the level of acceptable soil piping must be defined by the drainage designer on a case-by-case basis.

10.3.6 In a remarks section, note any unusual conditions or other data that would be considered necessary to interpret the results obtained properly, for example, piping comments or

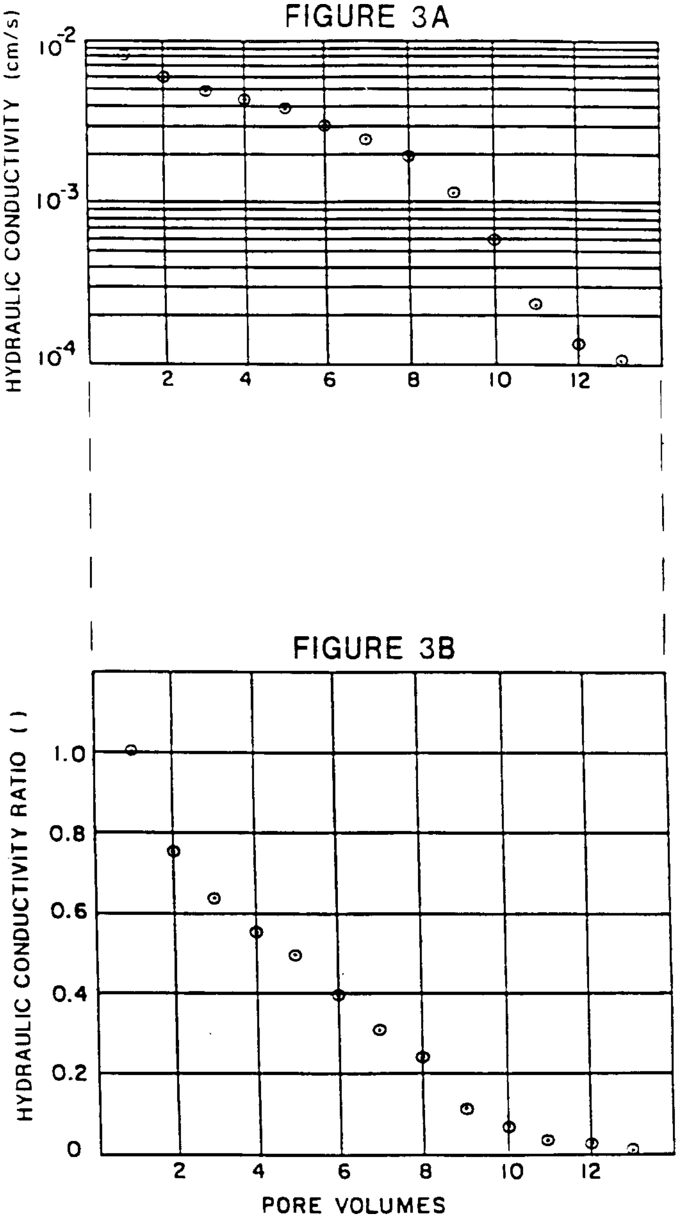

FIG. 3 Example Graphs—HCR Values Plotted as a Function of Elapsed Time and Pore Volume

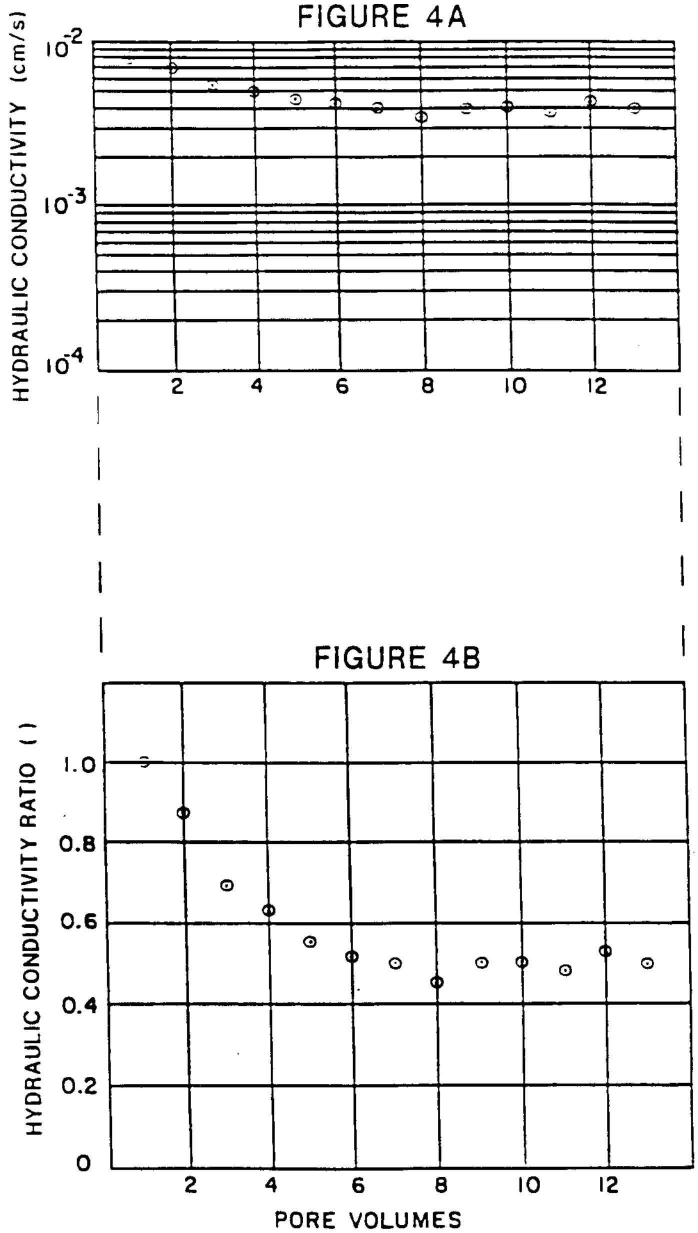

FIG. 4 Example Graphs—HCR Values Plotted as a Function of Elapsed Time and Pore Volume

photographs of the effluent reservoir at various stages throughout the test.

11. Precision and Bias

11.1 The precision of the procedure in this test method is being established.

11.2 The HCR value can be defined only in terms of the soil and geotextile and conditions used during testing. Because of the many variables involved and the lack of a superior standard or reference method, there are no direct data to determine bias.

12. Keywords

12.1 clogging; coefficient of permeability; geotextile filter; hydraulic conductivity; permeation; piping