Designation: D5084 – 16a

Standard Test Methods for Measurement of Hydraulic Conductivity of Saturated Porous Materials Using a Flexible Wall Permeameter[1]

This standard is issued under the fixed designation D5084; 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 These test methods cover laboratory measurement of the hydraulic conductivity (also referred to as *coefficient of permeability*) of water-saturated porous materials with a flexible wall permeameter at temperatures between about 15 and 30°C (59 and 86°F). Temperatures outside this range may be used; however, the user would have to determine the specific gravity of mercury and R_T (see 10.3) at those temperatures using data from *Handbook of Chemistry and Physics*. There are six alternate methods or hydraulic systems that may be used to measure the hydraulic conductivity. These hydraulic systems are as follows:

1.1.1 *Method A*—Constant Head

1.1.2 *Method B*—Falling Head, constant tailwater elevation

1.1.3 *Method C*—Falling Head, rising tailwater elevation

1.1.4 *Method D*—Constant Rate of Flow

1.1.5 *Method E*—Constant Volume–Constant Head (by mercury)

1.1.6 *Method F*—Constant Volume–Falling Head (by mercury), rising tailwater elevation

1.2 These test methods use water as the permeant liquid; see 4.3 and Section 6 on Reagents for water requirements.

1.3 These test methods may be utilized on all specimen types (intact, reconstituted, remolded, compacted, etc.) that have a hydraulic conductivity less than about 1×10^{-6} m/s (1×10^{-4} cm/s), providing the head loss requirements of 5.2.3 are met. For the constant-volume methods, the hydraulic conductivity typically has to be less than about 1×10^{-7} m/s.

1.3.1 If the hydraulic conductivity is greater than about 1×10^{-6} m/s, but not more than about 1×10^{-5} m/s; then the size of the hydraulic tubing needs to be increased along with the porosity of the porous end pieces. Other strategies, such as using higher viscosity fluid or properly decreasing the cross-sectional area of the test specimen, or both, may also be possible. The key criterion is that the requirements covered in Section 5 have to be met.

1.3.2 If the hydraulic conductivity is less than about 1×10^{-11} m/s, then standard hydraulic systems and temperature environments will typically not suffice. Strategies that may be possible when dealing with such impervious materials may include the following: *(a)* controlling the temperature more precisely, *(b)* adoption of unsteady state measurements by using high-accuracy equipment along with the rigorous analyses for determining the hydraulic parameters (this approach reduces testing duration according to Zhang et al. (**1**)[2]), and *(c)* shortening the length or enlarging the cross-sectional area, or both, of the test specimen (with consideration to specimen grain size (**2**)). Other approaches, such as use of higher hydraulic gradients, lower viscosity fluid, elimination of any possible chemical gradients and bacterial growth, and strict verification of leakage, may also be considered.

1.4 The hydraulic conductivity of materials with hydraulic conductivities greater than 1×10^{-5} m/s may be determined by Test Method D2434.

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

1.5.1 The procedures used to specify how data are collected, recorded, and calculated in this standard are regarded as the industry standard. In addition, they are representative of the significant digits that should generally be retained. The procedures used do not consider material variation, purpose for 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.

1.6 This standard also contains a Hazards section (Section 7).

1.7 The time to perform this test depends on such items as the Method (A, B, C, D, E, or F) used, the initial degree of

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[2] The boldface numbers in parentheses refer to the list of references appended to this standard.

*A Summary of Changes section appears at the end of this standard saturation of the test specimen and the hydraulic conductivity of the test specimen. The constant volume Methods (E and F) and Method D require the shortest period-of-time. Typically a test can be performed using Methods D, E, or F within two to three days. Methods A, B, and C take a longer period-of-time, from a few days to a few weeks depending on the hydraulic conductivity. Typically, about one week is required for hydraulic conductivities on the order of 1×10^{-9} m/s. The testing time is ultimately controlled by meeting the equilibrium criteria for each Method (see 9.5).

1.8 *Units*—The values stated in SI units are to be regarded as the standard. The inch-pound units given in parentheses are mathematical conversions, which are provided for information purposes only and are not considered standard, unless specifically stated as standard, such as 0.5 mm or 0.01 in.

1.9 *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:*[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))
D854 Test Methods for Specific Gravity of Soil Solids by Water Pycnometer
D1140 Test Methods for Determining the Amount of Material Finer than 75-μm (No. 200) Sieve in Soils by Washing
D1557 Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort (56,000 ft-lbf/ft^3 (2,700 kN-m/m^3))
D1587 Practice for Thin-Walled Tube Sampling of Fine-Grained Soils for Geotechnical Purposes
D2113 Practice for Rock Core Drilling and Sampling of Rock for Site Exploration
D2216 Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass
D2434 Test Method for Permeability of Granular Soils (Constant Head) (Withdrawn 2015)[4]
D2435 Test Methods for One-Dimensional Consolidation Properties of Soils Using Incremental Loading
D3550 Practice for Thick Wall, Ring-Lined, Split Barrel, Drive Sampling of Soils (Withdrawn 2016)[4]
D3740 Practice for Minimum Requirements for Agencies Engaged in Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction
D4220 Practices for Preserving and Transporting Soil Samples
D4318 Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils
D4753 Guide for Evaluating, Selecting, and Specifying Balances and Standard Masses for Use in Soil, Rock, and Construction Materials Testing
D4767 Test Method for Consolidated Undrained Triaxial Compression Test for Cohesive Soils
D5079 Practices for Preserving and Transporting Rock Core Samples
D6026 Practice for Using Significant Digits in Geotechnical Data
D6151 Practice for Using Hollow-Stem Augers for Geotechnical Exploration and Soil Sampling
D6169 Guide for Selection of Soil and Rock Sampling Devices Used With Drill Rigs for Environmental Investigations
E177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods
E691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method

3. Terminology

3.1 *Definitions:*

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

3.1.2 *head loss, Δh*—the change in total head of water across a given distance.

3.1.2.1 *Discussion*—In hydraulic conductivity testing, typically the change in total head is across the influent and effluent lines connected to the permeameter, while the given distance is typically the length of the test specimen.

3.1.3 *permeameter*—the apparatus (cell) containing the test specimen in a hydraulic conductivity test.

3.1.3.1 *Discussion*—The apparatus in this case is typically a triaxial-type cell with all of its components (top and bottom specimen caps, stones, and filter paper; membrane; chamber; top and bottom plates; valves; etc.).

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

3.1.4.1 *Discussion*—In hydraulic conductivity testing, the term *coefficient of permeability* is often used instead of *hydraulic conductivity*, but *hydraulic conductivity* is used exclusively in this standard. A more complete discussion of the terminology associated with Darcy's law is given in the literature. (**3, 4**)

3.1.5 *pore volume of flow—in hydraulic conductivity testing*, the cumulative quantity of flow into a test specimen divided by the volume of voids in the specimen.

4. Significance and Use

4.1 These test methods apply to one-dimensional, laminar flow of water within porous materials such as soil and rock.

4.2 The hydraulic conductivity of porous materials generally decreases with an increasing amount of air in the pores of

[3] 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.

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

the material. These test methods apply to water-saturated porous materials containing virtually no air.

4.3 These test methods apply to permeation of porous materials with water. Permeation with other liquids, such as chemical wastes, can be accomplished using procedures similar to those described in these test methods. However, these test methods are only intended to be used when water is the permeant liquid. See Section 6.

4.4 Darcy's law is assumed to be valid and the hydraulic conductivity is essentially unaffected by hydraulic gradient.

4.5 These test methods provide a means for determining hydraulic conductivity at a controlled level of effective stress. Hydraulic conductivity varies with varying void ratio, which changes when the effective stress changes. If the void ratio is changed, the hydraulic conductivity of the test specimen will likely change, see Appendix X2. To determine the relationship between hydraulic conductivity and void ratio, the hydraulic conductivity test would have to be repeated at different effective stresses.

4.6 The correlation between results obtained using these test methods and the hydraulic conductivities of in-place field materials has not been fully investigated. Experience has sometimes shown that hydraulic conductivities measured on small test specimens are not necessarily the same as larger-scale values. Therefore, the results should be applied to field situations with caution and by qualified personnel.

4.7 In most cases, when testing high swell potential materials and using a constant-volume hydraulic system, the effective confining stress should be about 1.5 times the swell pressure of the test specimen or a stress which prevents swelling. If the confining stress is less than the swell pressure, anomalous flow conditions my occur; for example, mercury column(s) move in the wrong direction.

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

5. Apparatus

5.1 *Hydraulic System*—Constant head (Method A), falling head (Methods B and C), constant rate of flow (Method D), constant volume-constant head (Method E), or constant volume-falling head (Method F) systems may be utilized provided they meet the following criteria:

5.1.1 *Constant Head*—The system must be capable of maintaining constant hydraulic pressures to ±5 % or better and shall include means to measure the hydraulic pressures to within the prescribed tolerance. In addition, the head loss across the permeameter must be held constant to ±5 % or better and shall be measured with the same accuracy or better. A pressure gage, electronic pressure transducer, or any other device of suitable accuracy shall measure pressures to a minimum of three significant digits. The last digit may be due to estimation, see 5.1.1.1.

5.1.1.1 Practice D6026 discusses the use or application of estimated digits. When the last digit is estimated and that reading is a function of the eye's elevation/location, then a mirror or another device is required to reduce the reading error caused by parallax.

5.1.2 *Falling Head*—The system shall allow for measurement of the applied head loss, thus hydraulic gradient, to ±5 % or better at any time. In addition, the ratio of initial head loss divided by final head loss over an interval of time shall be measured such that this computed ratio is accurate to ±5 % or better. The head loss shall be measured with a pressure gage, electronic pressure transducer, engineer's scale, graduated pipette, or any other device of suitable accuracy to a minimum of three significant digits. The last digit may be due to estimation, see 5.1.1.1. Falling head tests may be performed with either a constant tailwater elevation (Method B) or a rising tailwater elevation (Method C), see Fig. 1. This schematic of a hydraulic system presents the basic components needed to meet the objectives of Method C. Other hydraulic systems or schematics that meet these objectives are acceptable.

5.1.3 *Constant Rate of Flow*—The system must be capable of maintaining a constant rate of flow through the specimen to ±5 % or better. Flow measurement shall be by calibrated syringe, graduated pipette, or other device of suitable accuracy. The head loss across the permeameter shall be measured to a minimum of three significant digits and to an accuracy of ±5 % or better using an electronic pressure transducer(s) or other device(s) of suitable accuracy. The last digit may be due to estimation, see 5.1.1.1. More information on testing with a constant rate of flow is given in the literature (**5**).

5.1.4 *Constant Volume-Constant Head (CVCH)*—The system, with mercury to create the head loss, must be capable of maintaining a constant head loss cross the permeameter to ±5 % or better and shall allow for measurement of the applied head loss to ±5 % or better at any time. The head loss shall be measured to a minimum of three significant digits with an electronic pressure transducer(s) or equivalent device, (**6**) or based upon the pressure head caused by the mercury column, see 10.1.2. The last digit may be due to estimation, see 5.1.1.1.

5.1.4.1 Schematics of two CVCH systems are shown in Fig. 2 and Fig. 3. In each of these systems, the mercury-filled portion of the tubing may be continuous for constant head loss to be maintained. For the system showed in Fig. 2, the head loss remains constant provided the mercury column is vertical and is retained in only one half of the burette system (left burette in Fig. 2). If the mercury spans both columns, a falling head exists. In the system shown in Fig. 3, the head loss remains constant provided the water-mercury interface on the effluent end remains in the upper horizontal tube, and the water-mercury interface on the influent end remains in the lower horizontal tube. These schematics present the basic components needed to meet the objectives of Method E. Other hydraulic systems or schematics that meet these objectives are acceptable.

5.1.4.2 These types of hydraulic systems are typically not used to study the temporal or pore-fluid effect on hydraulic conductivity. The total volume of the specimen is maintained constant using this procedure, thereby significantly reducing