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Standard Test Methods for Measurement of Hydraulic Conductivity of Coarse-Grained Soils[1]

This standard is issued under the fixed designation D2434; 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.

This standard has been approved for use by agencies of the U.S. Department of Defense.

1. Scope*

1.1 These test methods cover laboratory measurement of the hydraulic conductivity (also referred to as *coefficient of permeability*) of water-saturated coarse-grained soils (for example, sands and gravels) with $k > 10^{-7}$ m/s. The test methods utilize low hydraulic gradient conditions.

1.2 This standard describes two methods (A and B) for determining hydraulic conductivity of coarse-grained soils. Method A incorporates use of a rigid wall permeameter and Method B incorporates the use of a flexible wall permeameter. A single- or dual-ring rigid wall permeameter may be used in Method A. A dual-ring permeameter may be preferred over a single-ring permeameter when adverse effects from short-circuiting of permeant water along the sidewalls of the permeameter (that is, prevent sidewall leakage) are suspected by the user of this standard.

1.3 The test methods are used under constant head conditions.

1.4 The test methods are used under saturated soil conditions.

1.5 Water is used to permeate the test specimen with these test methods.

1.6 *Units*—The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

NOTE 1—Hydraulic conductivity has traditionally been reported in cm/s in the US, even though the official SI unit for hydraulic conductivity is m/s.

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

1.8 *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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.9 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D653 Terminology Relating to Soil, Rock, and Contained Fluids
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
D4753 Guide for Evaluating, Selecting, and Specifying Balances and Standard Masses for Use in Soil, Rock, and Construction Materials Testing
D5101 Test Method for Measuring the Filtration Compatibility of Soil-Geotextile Systems
D5716/D5716M Test Method for Measuring the Rate of Well Discharge by Circular Orifice Weir
D6026 Practice for Using Significant Digits and Data Records in Geotechnical Data
D6913/D6913M Test Methods for Particle-Size Distribution (Gradation) of Soils Using Sieve Analysis

3. Terminology

3.1 *Definitions:*

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

3.1.2 *hydraulic conductivity, k, n*—(also referred to as coefficient of permeability or permeability) the rate of discharge of

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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.

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

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).

3.1.3 *hydraulic gradient, i, n*—the change in total head (head loss, Δh) per unit distance (L) in the direction of fluid flow, in which $i = \Delta h/L$.

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

3.1.5 *nominal particle size, n*—the particle size corresponding to 75 % passing [that is, D_{75}] per methods in Test Methods D6913/D6913M.

4. Summary of Test Method

4.1 The standard includes methods for determining the hydraulic conductivity of free-draining soils (for example, sands and gravels with low fines content) by permeating samples with water under constant head conditions. Multiple methods are presented that include different permeameters (rigid wall, dual-ring rigid wall, and flexible wall). Different options for constant head systems include reservoirs, Mariotte Bottle, and a flow pump.

5. Significance and Use

5.1 These test methods are used to measure one-dimensional vertical flow of water through initially saturated coarse-grained, pervious (that is, free-draining) soils under an applied hydraulic gradient. Hydraulic conductivity of coarse-grained soils is used in various civil engineering applications. These test methods are suitable for determination of hydraulic conductivity for soils with $k > 10^{-7}$ m/s.

NOTE 2—Clean coarse-grained soils that are classified using Practice D2487-17 as GP, GW, SP, and SW can be tested using these test methods. Depending on fraction and characteristics of fine-grained particles present in soils, these test methods may be suitable for testing other soil types with fines content greater than 5 % (for example, GP-GC, SP-SM).

5.2 Coarse-grained soils are to be tested at a void ratio representative of field conditions. For engineered fills, compaction specification can be used to provide target test conditions, whereas for natural soils, field testing of in-situ density can be used to provide target test conditions.

5.3 Use of a dual-ring permeameter is included in these test methods in addition to a single-ring permeameter for the rigid wall test apparatus. The dual-ring permeameter allows for reducing potential adverse effects of sidewall leakage on measured hydraulic conductivity of the test specimens. The use of a plate at the outflow end of the specimen that contains a ring with a diameter smaller than the diameter of the permeameter and the presence of two outflow ports (one from the inner ring, one from the annular space between the inner ring and the permeameter wall) allows for separating the flow from the central region of the test specimen from the flow near the sidewall of the permeameter.

NOTE 3—Sidewall leakage has been reported to have significant influence on flow conditions for coarse-grained soils due to presence of larger voids at the boundary and higher void ratio in this region of the specimen. Three modifications that have been used to reduce this effect in rigid wall permeameters include: *i*) placing a piping barrier (for example, caulk rings along every approximately 25-mm length of sidewall), *ii*) spreading a layer of bentonite and petroleum jelly mixture along the entire surface area of the sidewall, and *iii*) using a closed-cell neoprene liner attached to the inside wall of the permeameter.

5.4 Use of a flexible wall permeameter is included in these test methods in addition to the rigid wall permeameters. The flexible wall permeameter reduces potential adverse effects of sidewall leakage on measured hydraulic conductivity of the test specimens and allows for application of hydrostatic confining stress conditions on the specimen during the hydraulic conductivity test. Confining stress allows for representing field conditions (that is, simulating stress states in the subgrade that may affect values of k).

5.5 Darcy's law is assumed to apply to the test conditions, flow is assumed to be laminar (see Note 4), and the hydraulic conductivity is assumed to be considered independent of hydraulic gradient. The validity of these assumptions may be evaluated by measuring the hydraulic conductivity of a specimen at three different hydraulic gradients. The discharge velocity ($v = k \times i$) is plotted against the applied hydraulic gradient. If the resulting relationship is linear and the measured hydraulic conductivity values are similar (that is, within 25 %), then these assumptions are considered valid.

NOTE 4—Previous studies suggest that the limit between turbulent flow and laminar flow for soils occurs for Reynolds numbers between 1 and 10 (**1 and 2**)[3]. A formulation for Reynolds number (and division for laminar and turbulent flow conditions) for flow through packed beds has been reported (**3**). The formulation is presented for uniformly graded, spherical particles in Eq 1.

$$Re^{*} = \frac{D v \rho_f}{\mu(1 - n)} \tag{1}$$

where:

Re^* = Reynolds Number for packed bed flow,
D = granule or particle diameter (m),
v = superficial fluid velocity (that is, Darcy velocity) through bed (m/s),
ρ_f = fluid density (kg/m^3),
μ = liquid viscosity (dynamic viscosity) (Pa s), and
n = porosity of bed (expressed as a ratio).

Provisions are provided in (**3**) for establishing equivalent particle diameter for use in this equation for nonuniform particle size distributions and nonspherical particles.

NOTE 5—Using sufficiently low gradients has been demonstrated to be important for obtaining representative results. Hydraulic gradients less than 0.05 have been reported (**4**). Using a long test specimen (on the order of 1.5 m) has been reported as an effective method for achieving appropriately low hydraulic gradients for materials with $k > 0.01$ m/s.

NOTE 6—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 result in reliable values. Reliable results depend on many factors; Practice D3740 provides a means of evaluating some of those factors.

6. Apparatus

6.1 *Constant-Head Hydraulic System*—The hydraulic system is used to apply, maintain, and measure heads and resulting

[3] The boldface numbers in parentheses refer to a list of references at the end of this standard.

hydraulic gradients in a test. The hydraulic system mainly consists of reservoirs that hold water and associated piping, tubing, valves, and connections. See Note 7. Pressure application setups also may be used to pressurize influent and effluent liquids. The system shall be capable of maintaining constant hydraulic head to within ±5 % or better and shall include means to measure the hydraulic pressures to within the prescribed tolerances. In addition, the head loss must be held constant to ±5 % or better and shall be measured with instruments providing the same accuracy and readability or better. Large-scale specimens have high flow capacities that may require specialized systems such as large reservoirs to provide adequate flow rates (see 8.1). Two alternate means of achieving constant head conditions for *k* testing included in this standard are: *a*) Mariotte Bottle and *b*) use of a flow pump.

NOTE 7—Use of reservoirs with an overflow function (such as an outlet pipe or overflow along the perimeter of a level reservoir) that remains at a set elevation for the duration of testing have been demonstrated to work well and will reduce the potential for changes in head during a test.

6.1.1 The head shall be measured with a rigid measuring tape, graduated reservoir, engineer's scale, pressure gage, electronic pressure transducer, or other device that has the resolution and accuracy required for the determination of head to the tolerances provided above. Hydraulic heads shall be measured at points along the length of a test specimen using piezometers and from the inflow and outflow elevations in the case of a rigid-wall permeameter. Hydraulic heads shall be measured from the inflow and outflow elevations in the case of a flexible-wall permeameter. If measurements at inflow and outflow measurement locations are to be used, the procedure specified in 8.1 shall be conducted to verify that negligible head loss occurs through the tubing and system residing between the specimen and the inflow and outflow measurement locations. A general configuration for piezometers is provided in Test Method D5716/D5716M. A porous filter is required for piezometers used in hydraulic conductivity tests to avoid soils clogging the piping. A screen placed on the inside of the nipple assembly has been reported for such a filter (U.S. Army Corps of Engineers (1980) Engineering and Design Laboratory Soils Testing, Engineer Manual no. 1110-2-1906).

6.1.2 *System De-airing*—The hydraulic system shall be designed to facilitate rapid and complete removal of free air bubbles from flow lines. This removal can be accomplished, for example, by using tubing and ball valves that are large enough to prevent entrapment of air bubbles, are large enough not to cause head losses as described in 8.1, and using fittings without pipe threads. Placement of valve(s) at points of high elevation within the hydraulic system can facilitate venting of air from the system. If de-aired water is used as permeant water, use a system with sufficient capacity to produce de-aired water for the test duration. Recirculated permeant water shall not be used in the test.

6.2 *Flow-Measurement System*—The flow-measurement system is used to determine the amount of flow through a specimen during a test. The measurement device shall allow for the measurement of the quantity of flow (inflow, outflow, or both inflow and outflow, if selected for verification of flow conditions) over an interval of time to within ±5 %. Flow-measurement system may consist of a graduated accumulator, Mariotte bottle, electromagnetic flow meter, flow pump (if used to apply constant head), or other mass/volume-measuring device that has the resolution and accuracy required to determine flow to the tolerances provided above. In most cases, these devices are common to the hydraulic system.

6.2.1 *De-airing and Dimensional Stability of the System*—The flow-measurement system shall contain minimal dead space (volumetric space in the system that does not contribute to hydraulic fluid flow) and shall be equipped to allow for complete and rapid de-airing so that the system remains de-aired for the duration of testing. Dimensional stability of the system with respect to changes in pressure shall be accomplished by using a stiff flow-measurement system that includes glass pipe or rigid metallic or thermoplastic tubing.

6.3 *Pressure Application System*—The system (if used) for applying pressure on the coarse-grained soil specimen in the permeameter shall allow for applying and controlling the pressure to within ±5 % of the set value. For a rigid wall permeameter (Method A), a vertical pressure application system is used. The vertical pressure application system may include a dead-weight load application setup; a hydraulic load application system; or other system that allows for application of the desired level of pressure to a specimen via the top of the specimen. The vertical effective stress on the test specimen (which is the difference between the applied vertical pressure and the pore water pressure—provided a system to control pore water pressure is used) shall be maintained to the desired value within ±10 % of set value. For a flexible wall permeameter (Method B), a system for pressurizing the permeameter cell shall be capable of applying and controlling the cell pressure to within ±5 % of the set value. The effective stress on the test specimen (which is the difference between the cell pressure and the pore water pressure) shall be maintained to the desired value within ±10 % of set value. The device for pressurizing the cell may consist of a reservoir connected to the permeameter cell and partially filled with de-aired water, with the upper part of the reservoir connected to a compressed gas supply or other source of pressure. A minimum of 2 to 3 m of water-filled distance within the apparatus between the pressurized gas and the specimen is required (see Note 8). The gas pressure shall be controlled by a pressure regulator and measured by a pressure gage, electronic pressure transducer, or other device capable of measuring to the prescribed tolerances. A hydraulic system pressurized by dead weight acting on a piston or other pressure device capable of applying and controlling the permeameter cell pressure within the tolerances prescribed in this section may be used.

NOTE 8—De-aired water is commonly used for the cell fluid to reduce the potential for diffusive air transport through the membrane into the specimen. Other fluids that have low gas solubilities such as oils, are also acceptable, provided they do not react with components of the permeameter. Also, use of a sufficiently long tube connecting the pressurized cell liquid to the cell helps to delay the appearance of air in the cell fluid and to reduce the flow of dissolved air into the cell.

6.4 *Permeameter*—The permeameter shall consist of a cell for containing the test specimen and attached equipment that allow for connecting the cell to the hydraulic system, the flow-measurement system, and the pressure application system