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Standard Test MethodMethods for Permeability of Granular Soils (Constant Head)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 Scope*

1.1 This test method covers the determination of the coefficient of permeability by a constant-head method for the laminar flow of water through granular soils. The procedure is to establish representativeThese test methods cover laboratory measurement of the hydraulic conductivity (also referred to as *values of the coefficient of permeability*) of granular soils that may occur in natural depositswater-saturated coarse-grained soils (for example, sands and gravels) with *ask* placed in> 10^{-7} embankments, or when used as base courses under pavements. In order to limit consolidation influences during testing, this procedure is limited to disturbed granular soils containing not more than 10 % soil passing the 75-µm (No. 200) sieve.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. The values given in parentheses after SI units are provided for information only and are not considered 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] This test method is under the jurisdiction of ASTM Committee D18 on Soil and Rock and is the direct responsibility of Subcommittee D18.04 on Hydrologic Properties and Hydraulic Barriers.

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

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

D422D5101 Test Method for Particle-Size Analysis of SoilsMeasuring the Filtration Compatibility of Soil-Geotextile Systems (Withdrawn 2016)

D4253D5716/D5716M Test Methods for Maximum Index Density and Unit Weight of Soils Using a Vibratory TableMethod for Measuring the Rate of Well Discharge by Circular Orifice Weir

D6026 Practice for Using Significant Digits and Data Records in Geotechnical Data

D4254D6913/D6913M Test Methods for Minimum Index Density and Unit Weight of Soils and Calculation of Relative DensityParticle-Size Distribution (Gradation) of Soils Using Sieve Analysis

3. Fundamental Test Conditions

3.1 The following ideal test conditions are prerequisites for the laminar flow of water through granular soils under constant-head conditions:

3.1.1 Continuity of flow with no soil volume change during a test,

3.1.2 Flow with the soil voids saturated with water and no air bubbles in the soil voids,

3.1.3 Flow in the steady state with no changes in hydraulic gradient, and

3.1.4 Direct proportionality of velocity of flow with hydraulic gradients below certain values, at which turbulent flow starts.

3.2 All other types of flow involving partial saturation of soil voids, turbulent flow, and unsteady state of flow are transient in character and yield variable and time-dependent coefficients of permeability; therefore, they require special test conditions and procedures.

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 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.

[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.

3.1.5 *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.

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

[3] The ~~last approved version of this historical standard is referenced on www.astm.org.~~ boldface numbers in parentheses refer to a list of references at the end of this standard.

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 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 (if applicable), as well as provisions to support a specimen and to permeate the specimen. The permeameter shall consist of a cylindrical cell (rigid for Method A, flexible for Method B), cover plate, base plate, and attachments to hold the components together without leakage during a test. The diameter of the permeameter shall be determined based on the D_{95} (that is, the particle size corresponding to 95 % passing per methods in D6913/D6913M) of the soil to be tested. A permeameter diameter at least 10 times D_{95} is required. The permeameter length shall be greater than 6 times D_{95}.

6.5 *Rigid Wall Permeameter (Method A)*—The permeameter shall consist of a rigid-wall cell into which the soil specimen to be tested is placed and in which the test specimen is permeated. The permeameter shall be constructed of a rigid material such as steel, aluminum, brass, or plastic that will not be damaged during placement/compression/compaction of the specimen in the cell. The cross-sectional area along the direction of flow shall not vary by more than ±2 % and the height shall not vary by more than ±2 %. The permeameter shall be designed and operated such that permeant water flows upward or downward through the test specimen. If upward flow operation is used, protect the top of the specimen from upward movement of soil particles using a rigid porous element. Provisions may be included along the sidewall of the permeameter to directly attach the device to the constant-head hydraulic system or the flow-measurement system, or both. Schematic diagrams of a typical permeameter cell are presented in Figs. 1 and 2 for single- and dual-ring rigid wall permeameter cells, respectively.

6.5.1 *Top Plate*—The top plate shall be constructed of a rigid material that does not react adversely with the test material or permeant water. The top plate may be sealed to the rigid-wall permeameter cell using an O-ring or similar preventing leakage or the plate may be perforated and not sealed to the permeameter cell based on the design of the test setup. A sealed top plate is used when the hydraulic or flow measurement system, or both, are connected to the top plate (or the permeameter cell) through leak-proof ports or valves, whereas a perforated top plate is used when water is ponded directly above a specimen. The perforated plate shall not impede flow. The procedure specified in 8.1 shall be conducted to verify that this criterion is satisfied. The top plate shall be designed to distribute permeant water to the cross section of the specimen such that flow through the test specimen is one-dimensional.

6.5.2 *Base Plate*—The bottom plate shall be constructed of a rigid material that does not react adversely with the test material or permeant water. The base plate shall be sealed to the rigid-wall permeameter cell using an O-ring or similar preventing leakage. The plate shall be designed to distribute permeant water to the cross section of the specimen such that flow through the test specimen is one-dimensional.

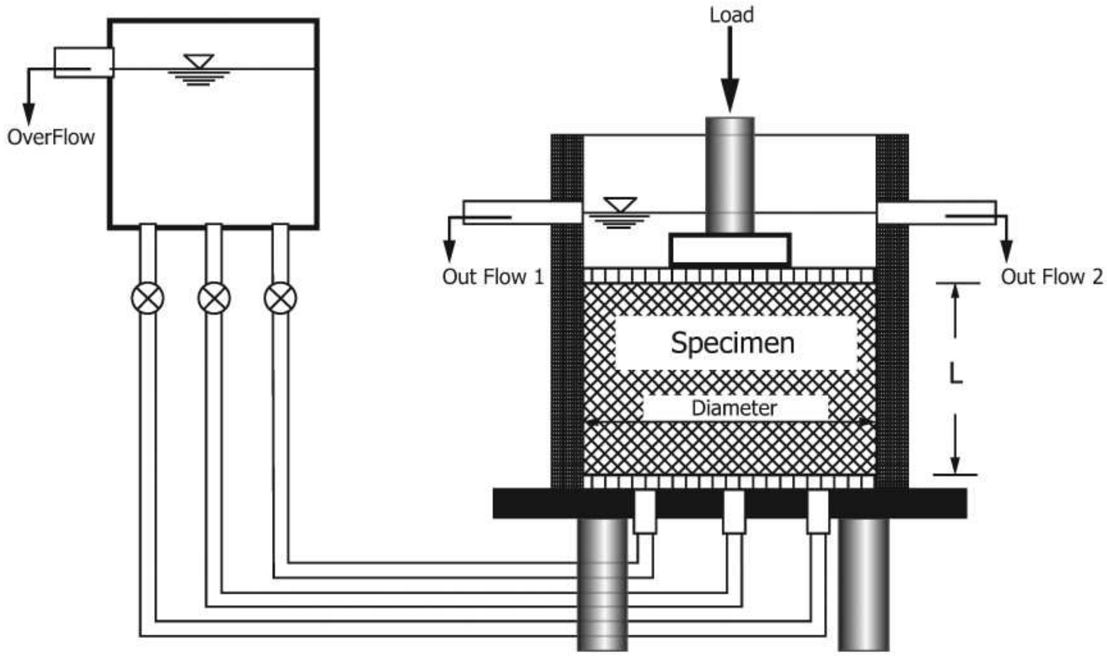

FIG. 1 ~~Constant-Head Permeameter~~Example Single-Ring Rigid Wall Permeameter (This schematic depicts a system with multiple inflow and outflow ports to the specimen, which is not necessary to maintain desired head conditions, but can accommodate large flow volumes.)

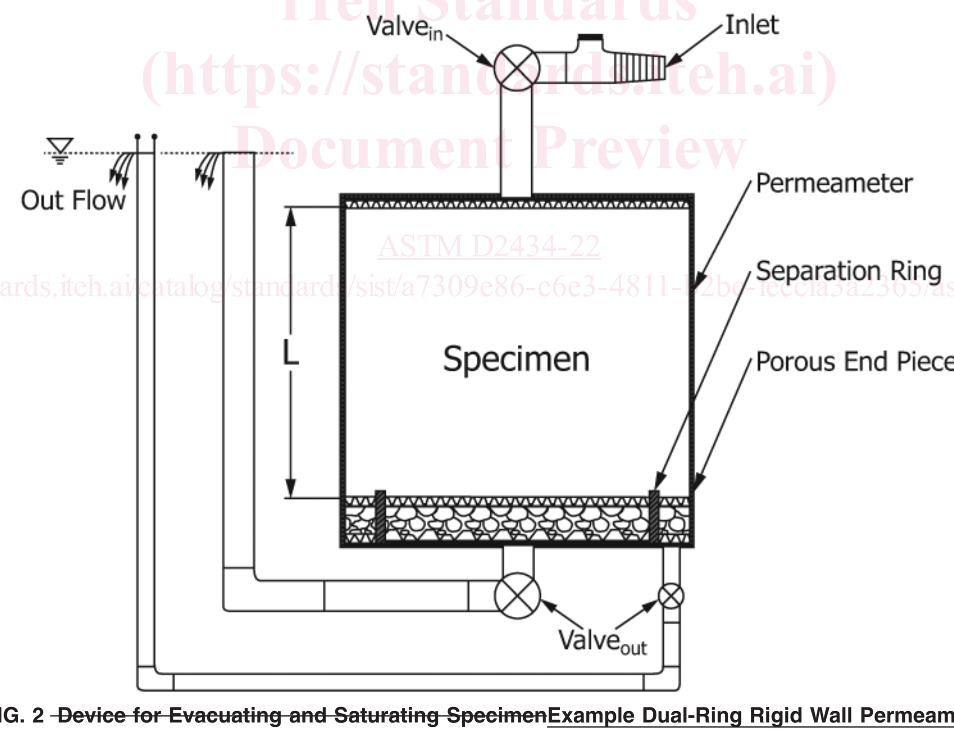

FIG. 2 ~~Device for Evacuating and Saturating Specimen~~Example Dual-Ring Rigid Wall Permeameter

6.5.3 If a dual-ring permeameter is used, the plate corresponding to the outflow end of the specimen (that is, bottom plate for downward flow conditions) shall contain a ring extending outward from the plate in a perpendicular orientation to the plate. The ring shall be constructed of stiff material (for example, steel, aluminum) of as thin as practical configuration to prevent deformation upon placement (for example, compaction) of soil in the permeameter and not disrupt overall flow regime within the permeameter. It is recommended that the diameter of the ring on the plate at the outflow end of the specimen be no larger than 85 % of the diameter of the permeameter cell. The diameter of the ring shall not vary by more than 2 %. The ring shall be concentric to the permeameter. The annular space between the ring and the permeameter wall shall be at least as wide as the nominal particle size. The height of the ring shall be greater than the nominal particle size.

6.5.4 *Porous End Pieces*—The specimen shall be overlain and underlain by porous end pieces. Porous end pieces shall be used to distribute permeant water uniformly over the surfaces of a test specimen (that is, areas perpendicular to the direction of flow) and shall not limit flow (that is, impedance to flow shall be less through the end pieces than through the system). Porous end pieces shall be constructed of a material that does not react with the specimen or the permeant water. Geosynthetic materials such as geotextiles, geonets, and geotextile-geonet composites (that is, geocomposites) may be used when flow through the system is less than the flow capacity of the geosynthetics. A flow distributor plate manufactured from plastic also has been demonstrated to be effective. Holes in the flow distributor plate shall be large enough as to not inhibit flow through the system. In addition, a metal mesh may be used. The top porous end piece shall have the same diameter (±5 % or better) as the specimen, and shall have sufficient strength (that is, thickness) to prevent breaking. If a dual-ring permeameter is used, two porous end pieces are required at the outflow end of the specimen due to the use of the plate containing the ring. The first porous end piece with a circular shape shall have a diameter within 5 % of the diameter of the inner ring. The second porous end piece with a ring shape shall have a width within 5 % of the width of the annular space between the inner collector ring and the permeameter cell. The end pieces shall be free from clogging. The flow capacity of the porous end pieces shall be at least five times greater than that of the specimen to be tested. The requirements outlined in 8.1 shall be applied to verify that this criterion is satisfied.

6.5.5 *Filter Paper*—If necessary to prevent intrusion of soil into the pores of the porous end pieces, one or more sheets of filter paper shall be placed between the top and bottom porous end pieces and the specimen. The paper shall have a negligibly small hydraulic impedance. The requirements outlined in 8.1 shall be applied to verify that the impedance is sufficiently small.

6.6 *Flexible Wall Permeameter (Method B)*—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. A schematic diagram of a typical flexible wall permeameter cell is presented in Fig. 3.

6.6.1 In order to facilitate gas removal, and thus saturation of the hydraulic system, four drainage lines leading to the specimen, two each to the base and top caps, are recommended. The drainage lines shall be controlled by no-volume-change valves, such as ball valves, and shall be designed to reduce the potential for presence of dead space (volumetric space in the system that does not contribute to hydraulic fluid flow) in the lines.

6.6.2 *Top Cap and Base*—An impermeable, rigid top cap and base shall be used to support the specimen and provide for transmission of permeant water to and from the specimen. The diameter or width of the top cap and base shall be equal to the diameter or width of the specimen to ±5 % or better. The base shall prevent leakage, lateral motion, or tilting, and the top cap shall be designed to receive the piston or extensometer, if used, such that the piston-to-top cap contact area is concentric with the cap. The surfaces of the base and top cap that contacts the membrane to form a seal shall be smooth and free of scratches.

6.6.3 *Flexible Membrane*—The flexible membrane used to encase the specimen shall provide reliable protection against leakage. The membrane shall be carefully observed prior to use. If flaws or pinholes are evident, the membrane shall be discarded. To reduce the potential restraint to the specimen, the diameter or width of the non-stretched membrane shall be between 90 and 95 % of that of the specimen. The membrane shall be sealed to the specimen base and cap with rubber O-rings for which the unstressed, inside diameter or width is less than 95 % of the diameter or width of the base and cap, or by other method that will produce an adequate seal.

NOTE 9—Membranes may be tested for flaws by placing them around a form sealed at both ends with rubber O-rings, subjecting them to a small air pressure on the inside, and then dipping them into water and monitoring for presence of air bubbles emitting from the membrane.

6.6.4 *Porous End Pieces*—The specimen shall be overlain and underlain by porous end pieces. Porous end pieces shall be used to distribute water uniformly over the surfaces of a test specimen (that is, areas perpendicular to the direction of flow) and shall not limit flow (that is, flow through system shall be less than flow through end pieces). Porous end pieces shall be constructed of a material that does not react with the specimen or the permeant water. Geosynthetic materials such as geotextiles, geonets, and geotextile-geonet composites (that is, geocomposites) may be used when flow through the system is less than the flow capacity of the geosynthetics. A flow distributor plate manufactured from plastic also has been demonstrated to be effective. Holes in the flow distributor plate shall be large enough as to not inhibit flow through the system. In addition, a metal mesh may be used. The top porous end piece shall have the same diameter (±5 % or better) as the specimen, and shall have sufficient strength (that is, thickness) to prevent breaking. The end pieces shall be free from clogging. The hydraulic conductivity of the porous end pieces shall be at least 5 times greater than that of the specimen to be tested. The requirements outlined in 8.1 shall be applied to verify that this criterion is satisfied.

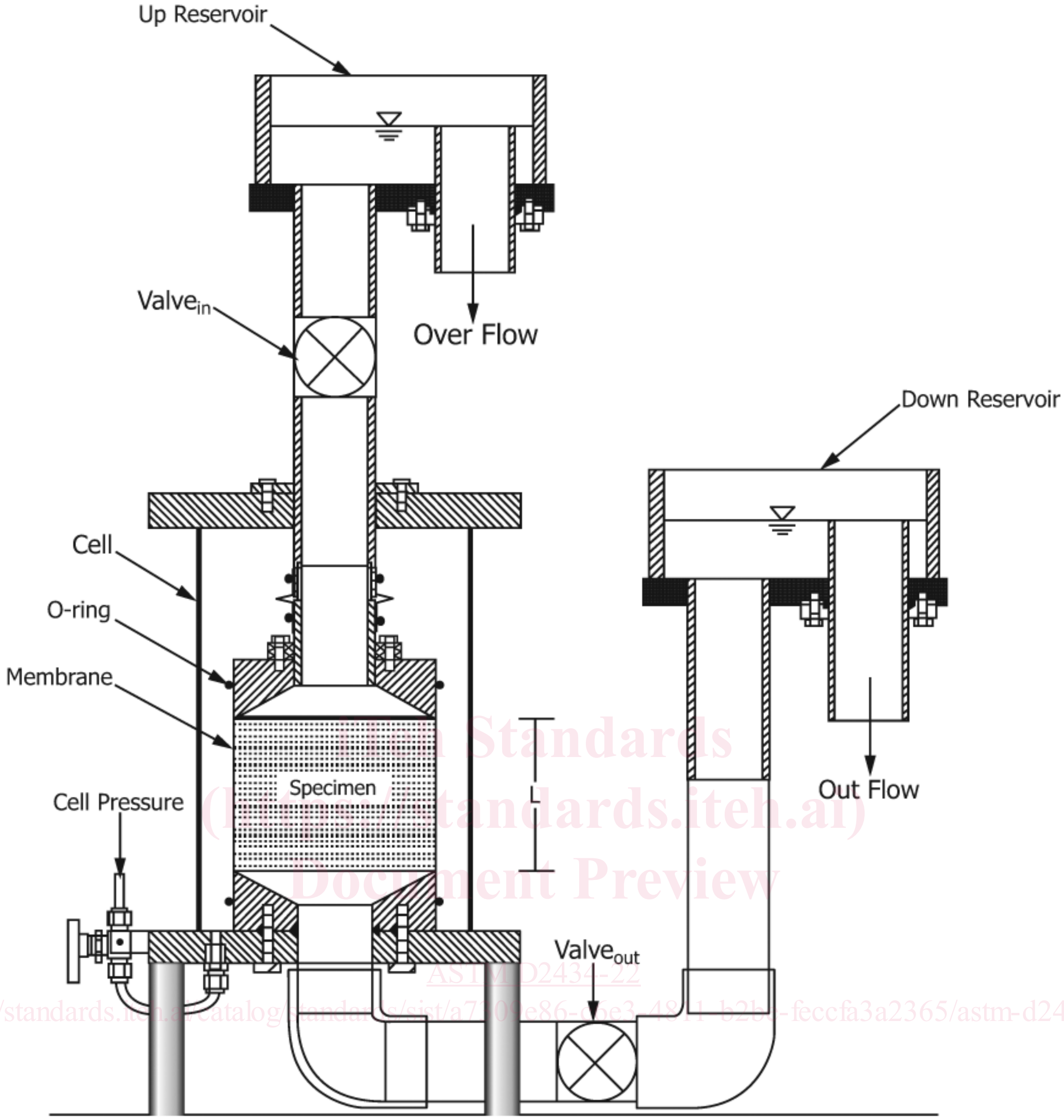

FIG. 3 ~~Permeability Test Data Sheet~~Example Flexible Wall Permeameter

6.6.5 *Filter Paper*—If necessary to prevent intrusion of soil into the pores of the porous end pieces, one or more sheets of filter paper shall be placed between the top and bottom porous end pieces and the specimen. The paper shall have a negligibly small hydraulic impedance. The requirements outlined in 8.1 shall be applied to verify that the impedance is sufficiently small.

6.7 ~~*Permeameters,*~~ *Specimen Length and Deformation Measurement*—~~as shown in Fig. 1, shall have specimen cylinders with minimum diameters approximately 8 or 12 times the maximum particle size in accordance with Table 1.~~ The permeameter ~~should be fitted with: (~~shall be equipped ~~1) a porous disk or suitable reinforced screen at the bottom with a permeability greater than that of the soil specimen, but with openings sufficiently small (not larger than 10 % finer size) to prevent movement of particles; (2) manometer outlets for measuring the loss of head,~~ for determination of axial ~~h,~~ length ~~over a length, l, equivalent to at least the diameter of the cylinder; (~~of ~~3) a porous disk or suitable reinforced screen with a spring attached to the top, or any other device, for applying a light spring pressure of 22 to 45-N (5 to 10-lbf) total load, when~~ a specimen during placement or during a test. The length of a specimen shall be determined to the nearest 1 mm. The length of a specimen may be monitored by direct observation through the cell wall using a cathetometer, camera setup, or other instrument that has the resolution and accuracy required for the determination of length as prescribed above. The deformation (that is, change in length) of a specimen may also be monitored using a deformation gage connected to the top plate ~~is attached in place. This will hold the placement density and volume of soil without significant change during the saturation of the specimen and the permeability testing to satisfy the requirement prescribed in~~ above a specimen or a deformation gage attached to a loading piston connected to the top plate above a specimen. The deformation can be determined using a dial gage, LVDT, or other device that has the resolution and accuracy required for the determination of deformation as prescribed above.3.1.1.

4.2 *Constant-Head Filter Tank,* as shown in Fig. 1, to supply water and to remove most of the air from tap water, fitted with suitable control valves to maintain conditions described in 3.1.2.

NOTE 1—De-aired water may be used if preferred.

4.3 *Large Funnels,* fitted with special cylindrical spouts 25 mm (1 in.) in diameter for 9.5-mm (⅜-in.) maximum size particles and 13 mm (½ in.) in diameter for 2.00-mm (No. 10) maximum size particles. The length of the spout should be greater than the full length of the permeability chamber—at least 150 mm (6 in.).

6.8 *Mariotte Bottle—*Specimen Compaction Equipment—Compaction equipment as deemed desirable may be used. The following are suggested: a vibrating tamper fitted with a tamping foot 51 mm (2 in.) in diameter; a sliding tamper with a tamping foot 51 mm (2 in.) in diameter, and a rod for sliding weights of 100 g (0.25 lb) (for sands) to 1 kg (2.25 lb) (for soils with a large gravel content), having an adjustable height of drop to 102 mm (4 in.) for sands and 203 mm (8 in.)The bottle assembly, if used, shall be large enough to permit unimpeded water flow during permeation. The bottle assembly also shall be large enough to permit unimpeded air flow through the bubble tube during permeation. The bottle design shall provide acceptable reading accuracy for fluid levels (in relation to 6.1 forand 6.2soils with large gravel contents.).

4.5 *Vacuum Pump or Water-Faucet Aspirator,* for evacuating and for saturating soil specimens under full vacuum (see Fig. 2).

6.9 *Manometer Tubes, Balances—*with metric scales for measuring head of water.The balance shall be suitable for determining the mass of a specimen. The balance shall be selected based on the guidelines provided in Specification D4753. The mass of specimens shall be determined to the nearest 0.1 %.

6.10 *Balance, Time Measurement Devices—*of 2-kg (4.4-lb) capacity, sensitive to 1 g (0.002 lb).Devices to measure the duration of each permeation trial, which shall be readable to 1 s, such as a clock with second hand or stopwatch (or equivalent), or both. For trials that occur over a duration less than 60 s, a clock with both accuracy and readability to 0.1 s shall be used.

6.11 *Scoop, Thermometer—*with a capacity of about 100 g (0.25 lb) of soil.An instrument to determine temperature to an accuracy of ±1°C with a readability of 1°C or less.

6.12 *Miscellaneous Apparatus—Vacuum Pump—*Thermometers, clock with sweep second hand, 250-mL graduate, quart jar, mixing pan, etc.A vacuum pump may be used to assist with de-airing of permeant water or saturation of specimens.

5. Sample

5.1 A representative sample of air-dried granular soil, containing less than 10 % of the material passing the 75-μm (No. 200) sieve and equal to an amount sufficient to satisfy the requirements prescribed in 5.2 and 5.3, shall be selected by the method of quartering.

5.2 A sieve analysis (see Method D422) shall be made on a representative sample of the complete soil prior to the permeability test. Any particles larger than 19 mm (¾ in.) shall be separated out by sieving (Method D422). This oversize material shall not be used for the permeability test, but the percentage of the oversize material shall be recorded.

NOTE 2—In order to establish representative values of coefficients of permeabilities for the range that may exist in the situation being investigated, samples of the finer, average, and coarser soils should be obtained for testing.

5.3 From the material from which the oversize has been removed (see 5.2), select by the method of quartering, a sample for testing equal to an amount approximately twice that required for filling the permeameter chamber.

7. Reagents

7.1 *Permeant Water:*

7.1.1 The permeant water is the liquid used to permeate the test specimen and is also the liquid used in backpressure saturation of the specimen.

7.1.2 The type of permeant water shall be specified by the requestor. If no specification is made, potable tap water shall be used for the permeant water. The type of permeant water utilized shall be indicated in the test data sheet/form.

8. PreparationVerification of Specimens System Flow

6.1 The size of permeameter to be used shall be as prescribed in Table 1.

6.2 Make the following initial measurements in centimetres or square centimetres and record on the data sheet (Fig. 3); the inside diameter, *D*, of the permeameter; the length, *L*, between manometer outlets; the depth, H_1, measured at four symmetrically spaced points from the upper surface of the top plate of the permeability cylinder to the top of the upper porous stone or screen temporarily placed on the lower porous plate or screen. This automatically deducts the thickness of the upper porous plate or screen from the height measurements used to determine the volume of soil placed in the permeability cylinder. Use a duplicate top plate containing four large symmetrically spaced openings through which the necessary measurements can be made to determine the average value for H_1. Calculate the cross-sectional area, *A*, of the specimen.

6.3 Take a small portion of the sample selected as prescribed in 5.3 for water content determinations. Record the weight of the remaining air-dried sample (see 5.3), W_1, for unit weight determinations.

6.4 Place the prepared soil by one of the following procedures in uniform thin layers approximately equal in thickness after compaction to the maximum size of particle, but not less than approximately 15 mm (0.60 in.).

6.4.1 For soils having a maximum size of 9.5 mm (3⁄8 in.) or less, place the appropriate size of funnel, as prescribed in 4.3, in the permeability device with the spout in contact with the lower porous plate or screen, or previously formed layer, and fill the funnel with sufficient soil to form a layer, taking soil from different areas of the sample in the pan. Lift the funnel by 15 mm (0.60 in.), or approximately the unconsolidated layer thickness to be formed, and spread the soil with a slow spiral motion, working from the perimeter of the device toward the center, so that a uniform layer is formed. Remix the soil in the pan for each successive layer to reduce segregation caused by taking soil from the pan.

6.4.2 For soils with a maximum size greater than 9.5 mm (3⁄8 in.), spread the soil from a scoop. Uniform spreading can be obtained by sliding a scoopful of soil in a nearly horizontal position down along the inside surface of the device to the bottom or to the formed layer, then tilting the scoop and drawing it toward the center with a single slow motion; this allows the soil to run smoothly from the scoop in a windrow without segregation. Turn the permeability cylinder sufficiently for the next scoopful, thus progressing around the inside perimeter to form a uniform compacted layer of a thickness equal to the maximum particle size.

6.5 Compact successive layers of soil to the desired relative density by appropriate procedures, as follows, to a height of about 2 cm (0.8 in.) above the upper manometer outlet.

6.5.1 *Minimum Density (0 % Relative Density)*—Continue placing layers of soil in succession by one of the procedures described in 6.4.1 or 6.4.2 until the device is filled to the proper level.

6.5.2 *Maximum Density (100 % Relative Density):*

6.5.2.1 *Compaction by Vibrating Tamper*—Compact each layer of soil thoroughly with the vibrating tamper, distributing the light tamping action uniformly over the surface of the layer in a regular pattern. The pressure of contact and the length of time of the vibrating action at each spot should not cause soil to escape from beneath the edges of the tamping foot, thus tending to loosen the layer. Make a sufficient number of coverages to produce maximum density, as evidenced by practically no visible motion of surface particles adjacent to the edges of the tamping foot.

6.5.2.2 *Compaction by Sliding Weight Tamper*—Compact each layer of soil thoroughly by tamping blows uniformly distributed

~~over the surface of the layer. Adjust the height of drop and give sufficient coverages to produce maximum density, depending on the coarseness and gravel content of the soil.~~

~~6.5.2.3 *Compaction by Other Methods*—Compaction may be accomplished by other approved methods, such as by vibratory packer equipment, where care is taken to obtain a uniform specimen without segregation of particle sizes (see Test Methods D4253 and D4254).~~

~~6.5.3 *Relative Density Intermediate Between 0 and 100 %*—By trial in a separate container of the same diameter as the permeability cylinder, adjust the compaction to obtain reproducible values of relative density. Compact the soil in the permeability cylinder by these procedures in thin layers to a height about 2.0 cm (0.80 in.) above the upper manometer outlet.~~

~~NOTE 3—In order to bracket, systematically and representatively, the relative density conditions that may govern in natural deposits or in compacted embankments, a series of permeability tests should be made to bracket the range of field relative densities.~~

8.1 ~~*Preparation of Specimen for Permeability Test:*~~ *Determination of System Flow Capacity—*

~~6.6.1 Level the upper surface of the soil by placing the upper porous plate or screen in position and by rotating it gently back and forth.~~Excessive head losses in the tubes, valves, porous end pieces, and filter papers (collectively described in Section 6) may limit flow in the test system and lead to errors in measurements during permeation. System flow capacity shall be determined using the actual permeant water that will be used in the test. The permeameter shall be assembled without a specimen and then water shall be passed through the system. The hydraulic heads that will be used in testing a specimen shall be applied, and the rate of flow shall be measured to within ±5 %. The rate of flow shall be at least five times greater when no specimen is within the permeameter than the rate of flow that is measured when a specimen is placed inside the permeameter with the same hydraulic heads applied. Determination of system flow shall be conducted annually at a minimum. Retesting of the system flow capacity shall be conducted subsequent to any change to the system configuration (for example, hardware setup, observed clogging during previous testing). If five times flow of the system without a soil specimen (as compared to with a soil specimen) is not obtained, the permeameter can still be used for testing if *a*) flow through the system without a soil specimen is greater than through the system with soil and *b*) for head loss measurements taken at the reservoirs, a flow verification curve is developed for the system and used together with the test results to determine a net change in head on the soil specimen, as presented in Annex A1.

~~6.6.2 Measure and record: the final height of specimen, $H_1 - H_2$, by measuring the depth, H_2, from the upper surface of the perforated top plate employed to measure H_1 to the top of the upper porous plate or screen at four symmetrically spaced points after compressing the spring lightly to seat the porous plate or screen during the measurements; the final weight of air-dried soil used in the test $(W_1 - W_2)$ by weighing the remainder of soil, W_2, left in the pan. Compute and record the unit weights, void ratio, and relative density of the test specimen.~~

~~6.6.3 With its gasket in place, press down the top plate against the spring and attach it securely to the top of the permeameter cylinder, making an air-tight seal. This satisfies the condition described in 3.1.1 of holding the initial density without significant volume change during the test.~~

~~6.6.4 Using a vacuum pump or suitable aspirator, evacuate the specimen under 50 cm (20 in.) Hg minimum for 15 min to remove air adhering to soil particles and from the voids. Follow the evacuation by a slow saturation of the specimen from the bottom upward (Fig. 2) under full vacuum in order to free any remaining air in the specimen. Continued saturation of the specimen can be maintained more adequately by the use of (*1*) de-aired water, or (*2*) water maintained in an in-flow temperature sufficiently high to cause a decreasing temperature gradient in the specimen during the test. Native water or water of low mineral content (Note 4) should be used for the test, but in any case the fluid should be described on the report form (Fig. 3). This satisfies the condition described in 3.1.2 for saturation of soil voids.~~

~~NOTE 4—Native water is the water occurring in the rock or soil in situ. It should be used if possible, but it (as well as de-aired water) may be a refinement not ordinarily feasible for large-scale production testing.~~

~~6.6.5 After the specimen has been saturated and the permeameter is full of water, close the bottom valve on the outlet tube (Fig. 2) and disconnect the vacuum. Care should be taken to ensure that the permeability flow system and the manometer system are free of air and are working satisfactorily. Fill the inlet tube with water from the constant-head tank by slightly opening the filter tank valve. Then connect the inlet tube to the top of the permeameter, open the inlet valve slightly and open the manometer outlet cocks slightly, to allow water to flow, thus freeing them of air. Connect the water manometer tubes to the manometer outlets and fill with water to remove the air. Close the inlet valve and open the outlet valve to allow the water in the manometer tubes to reach their stable water level under zero head.~~