Designation: D7760 – 12

Standard Test Method for Measurement of Hydraulic Conductivity of Tire Derived Aggregates Using a Rigid Wall Permeameter[1]

This standard is issued under the fixed designation D7760; 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 (also referred to as *coefficient of permeability*) of water-saturated tired derived aggregates (TDA) obtained from scrap tires using a rigid-wall permeameter. The tire materials covered in this method include tire chips, tire shreds, and tire derived aggregate (TDA) as described in Practice D6270 with particle sizes ranging from approximately 12 to 305 mm. Whole scrap tires are not included in this standard. A clear trend between hydraulic conductivity and shred size has not been established at a given vertical pressure for shreds ≥50 mm (**1**).[2]

1.2 A single- or dual-ring permeameter may be used in the tests. A dual-ring permeameter may be preferred over a single-ring permeameter to take into account and prevent short-circuiting of permeant along the sidewalls of the permeameter. The effects of sidewall flow is more significant at high stresses and when the cell diameter is less than 6 times the particle size (**1**).

1.3 The test method is used under constant head conditions.

1.4 Water is used as the permeant with the test method.

1.5 Test Method D2434 also can be used for determination of hydraulic conductivity of TDAs with sizes smaller than 19 mm under constant head conditions in a rigid-wall permeameter. Method D2434 includes the use of a permeameter with a single ring.

1.6 The standard units for the hydraulic conductivity values are the SI units, unless other units are specified. Hydraulic conductivity has traditionally been expressed in cm/s in the U.S., even though the official SI unit for hydraulic conductivity is m/s.

1.7 *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

D2434 Test Method for Permeability of Granular Soils (Constant Head)

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

D6026 Practice for Using Significant Digits in Geotechnical Data

D6270 Practice for Use of Scrap Tires in Civil Engineering Applications

3. Terminology

3.1 *Definitions:*

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

3.1.2 For definitions of terms related to scrap tires, refer to Practice D6270.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *hydraulic conductivity, k*—(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).

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

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

[1] This test method is under the jurisdiction of ASTM Committee D18 on Soil and Rock and is the direct responsibility of Subcommittee D18.14 on Geotechnics of Sustainable Construction.

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

[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. Significance and Use

4.1 This test method is used to measure one-dimensional vertical flow of water through initially saturated TDAs under an applied hydraulic gradient. Hydraulic conductivity is required in various civil engineering applications of TDAs.

4.2 TDAs are to be tested at a unit weight and under an overburden pressure representative of field conditions. Data from the literature indicate a reduction in hydraulic conductivity with increasing vertical pressure (**1**).

4.3 Use of a dual-ring permeameter is included in this test method in addition to a single-ring permeameter. The dual-ring permeameter allows for minimizing potential adverse effects of sidewall leakage on measured hydraulic conductivity of the test specimens. The use of a bottom plate with an inner ring with a diameter smaller than the diameter of the permeameter and two outflow ports (one from the inner ring, one from the annular space between the inner ring and the permeameter) allows for separating the flow from the central part of the test specimen from the flow near the sidewall of the permeameter.

4.4 Darcy's law is assumed to be valid, flow is assumed to be laminar (Reynolds number less than approximately 2000–3000), and the hydraulic conductivity is assumed to be essentially independent of hydraulic gradient. The validity of Darcy's law may be evaluated by measuring the hydraulic conductivity of a specimen at three 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 (i.e., within 25 %), then Darcy's law may be taken as valid.

NOTE 1—The quality of the result produced by this standard is dependent of the competence of the personnel using this standard and the suitability of the equipment and facilities. 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 these factors.

5. Apparatus

5.1 Schematics of the various components of two setups used to determine hydraulic conductivity of TDAs using rigid-wall permeameters under constant head conditions are provided for single-ring and dual-ring devices in Fig. 1(a) and (b), respectively.

5.2 *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. Pressure application setups may also be used to pressurize influent and effluent liquids, in particular to apply high hydraulic gradients. The system shall allow for maintaining constant hydraulic head to within ±5 % or better accuracy during a test. The system shall allow for measurement of the constant head to within ±5 % or better accuracy during a test. The head shall be measured with a graduated pipette, engineer's scale, pressure gauge, electronic pressure transducer, or any other device that has the resolution required for the determination of head to the accuracy provided above.

5.2.1 *System De-airing*—The hydraulic system shall be designed to facilitate rapid and complete removal of free air bubbles from flow lines. This can be accomplished for example by using properly sized tubing and ball valves, and fittings without pipe threads. Properly sized components are small enough to prevent entrapment of air bubbles, but are large enough not to cause head losses as described in 6.1.

5.3 *Flow-Measurement System*—Flow-measurement system is used to determine the amount of inflow and outflow from a specimen during a test. The measurement device shall allow for the measurement of the quantity of flow (both inflow and outflow) over an interval of time to within ±5 % or better accuracy. Flow-measurement system may consist of a graduated accumulator, Mariotte bottle, vertical standpipe in conjunction with an electronic pressure transducer, electromagnetic flow meter, or other volume-measuring device that has the resolution required to determine flow to the accuracy provided above. In most cases, these devices are common to the hydraulic system.

5.3.1 *De-airing and Dimensional Stability of the System*—The flow-measurement system shall contain a minimum of dead space and shall be equipped to allow for complete and rapid de-airing. Dimensional stability of the system with respect to changes in pressure shall be ensured by using a stiff flow-measurement system that includes glass pipe or rigid metallic or thermoplastic tubing.

5.4 *Vertical Pressure Application System*—The system for applying vertical pressure on the TDA specimen in the permeameter (if used) shall allow for applying and controlling the pressure to within ±5 % or better accuracy. The vertical pressure application system may include a dead-weight load application setup; a hydraulic load application system; or any other system that allows for application of the desired level of pressure to a specimen via the top of the specimen.

5.5 *Permeameter*—The permeameter shall consist of a permeameter cell and attached equipment that allow for connecting the permeameter to the hydraulic system, the flow-measurement system, and the pressure application system, as well as provisions to support a specimen and to permeate the specimen. The permeameter cell shall consist of a rigid mold, 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 nominal size (defined as the average particle size that comprises more than 50 % of a TDA sample per Practice D6270) of the TDA to be tested. A permeameter diameter at least 6 times the nominal particle size has been shown to be adequate (**1**). A permeameter with a diameter of 0.30 m and a height of 0.12 m was demonstrated to be effective for testing tire chips with dimensions of 38 × 76 mm (**2**).

5.5.1 *Rigid Permeameter Mold*—The permeameter cell shall consist of a rigid-wall mold into which the tire specimen to be tested is placed and in which the test specimen is permeated. The mold shall be constructed of a rigid material such as steel, aluminum, brass, or plastic that will not be damaged during placement/compression of the specimen in the mold. The mold shall be cylindrical in shape. The cross-sectional area along the direction of flow shall not vary by

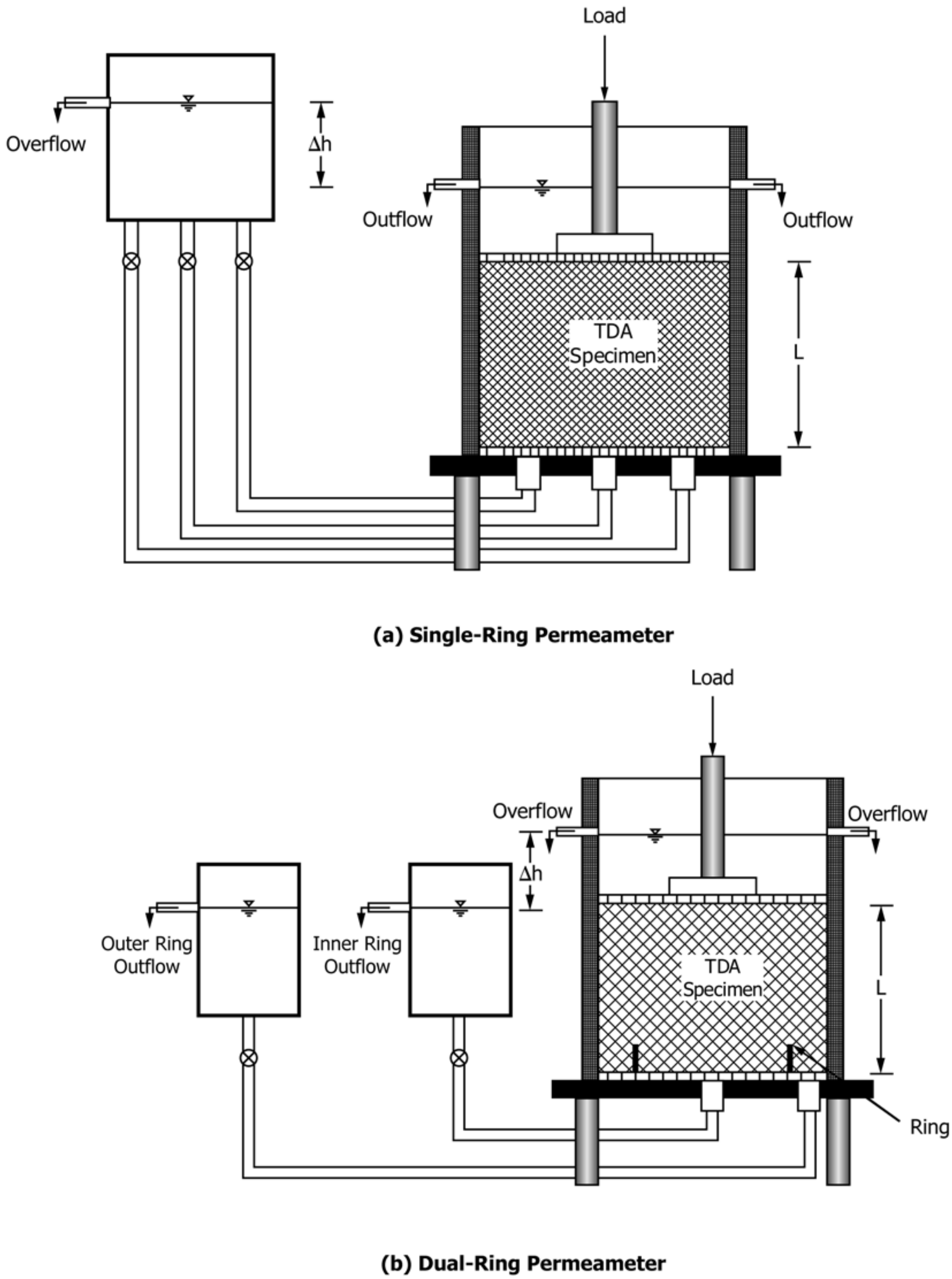

FIG. 1 Example Test Setups

more than ±2 % and the height shall not vary by more than ±1 %. The permeameter shall be designed and operated such that permeant water flows downward through the test specimen, although upward flow may be used if the top of the specimen is protected from upward movement by a rigid porous element. Provisions may be included along the sidewall of the permeameter to directly attach the mold to the constant-head hydraulic system or the flow-measurement system or both. Hydraulic gradient measurements may be made using the stand pipe piezometer attachments on the sidewall.

5.5.2 *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 systems 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 top plate shall be designed to ensure that flow through the test specimen is one-dimensional.

5.5.3 *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 ensure that flow through the test specimen is one-dimensional. If a dual-ring permeameter is used, the diameter of the inner ring shall be 80 % of the diameter of the permeameter mold and the inner ring shall be concentric to the mold. The height of the inner ring shall be 5 % of the height of the mold.

5.5.4 *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). Porous end pieces shall be constructed of a material that does not react with the specimen or the permeant liquid. Geosynthetic materials such as geonets and drainage geocomposites may be used when high flow through the system is required. The end pieces shall have plane and smooth surfaces and be free of cracks, chips, and discontinuities. The top porous end piece shall have the same diameter (±5 % or better accuracy) as the specimen, and shall have sufficient thickness to prevent breaking. If a dual-ring permeameter is used, two porous end pieces are required under the specimen due to the use of the dual-ring base plate. 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 disc shape shall have a width within -5 % of the width of the annular space between the inner collector ring and the permeameter mold. The end pieces shall be free from clogging. The hydraulic conductivity of the porous end pieces shall be significantly greater than that of the specimen to be tested. The requirements outlined in 6.1 below ensure that this criterion is satisfied.

5.6 *Deformation Measurement*—The permeameter may be equipped for determination of axial deformation of a specimen during placement or during a test. The deformation of a specimen shall be determined to the nearest 1 mm. The height 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 required for the determination of deformation as prescribed above. The height of a specimen also may be monitored using a deformation gauge connected to the top plate above a specimen or a deformation gauge attached to a loading piston connected to the top plate above a specimen. The deformation can be determined using a dial gauge, LVDT, or other device that has the resolution required for the determination of deformation as prescribed above.

5.7 *Balances*—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 between 100 g and 999 g shall be determined to the nearest 0.1 g. The mass of specimens greater than 999 g shall be determined to the nearest g.

5.8 *Time Measurement Devices*—Devices to measure the duration of each permeation trial, such as a clock with second hand or stop watch (or equivalent), or both.

5.9 *Vacuum Pump*—A vacuum pump may be used to assist with de-airing of permeant water or saturation of specimens.

6. Procedure

6.1 *Determination of Head Losses*—Excessive head losses in the tubes, valves, and porous end pieces may limit flow in the test system and lead to errors in measurements in the tests. Head losses shall be determined using the actual permeant water that will be used in a test program. The permeameter shall be assembled without a specimen and then water shall be passed through the system to determine head losses in 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 % or better accuracy. This rate of flow shall be at least ten times greater than the rate of flow that is measured when a specimen is placed inside the permeameter and the same hydraulic heads are applied.

6.2 *Specimen Setup:*

6.2.1 Soak the porous end pieces in a container of permeant water.

6.2.2 Place the porous end piece on the base plate. If a dual-ring permeameter is used, place the two (or the single in case of geosynthetics) porous end pieces on the base plate. Place the permeameter mold over the base plate and place the predetermined mass of TDA specimen in the permeameter. Place the top porous end piece and top plate over the specimen. Secure all components in place and fully assemble the permeameter cell.

6.2.3 Attach the pressure application system to the permeameter. If required, apply pressure to compress the specimen to reach the desired dry unit weight at the onset of a test and maintain this pressure during the test.

6.2.4 Attach the hydraulic system to the influent and effluent lines of the permeameter.

6.2.5 Attach the flow measurement system to the influent and effluent lines and the permeameter.

6.3 *Initial Vacuum Saturation (Optional)*—To aid in saturation, a specimen may be inundated with permeant water under partial vacuum applied to the top of the specimen. Water under atmospheric pressure shall be applied to the specimen base through the effluent lines. The magnitude of the vacuum shall be adjusted to generate a hydraulic gradient across the specimen less than the gradient that will be used during hydraulic conductivity measurements. The direction of flow in this initial step may be opposite of the flow direction during permeation. It is easier to drive air out of a specimen if the flow is from bottom to top of the specimen.

6.4 *Permeation*—Specimens shall be permeated using at least three hydraulic gradients to ensure that permeation is done under laminar flow conditions and that Darcy's law is valid and can be used to calculate hydraulic conductivity, *k*. Low gradients may be used to achieve laminar flow conditions for specimens with high k. Measurements during permeation may be made by reading water levels directly from reservoirs containing the water in a test setup. These measurements include head and flow determinations. In the case of flow, the measured liquid level is multiplied with the area of the reservoir that holds the liquid to determine flow volumes. The last digit may be estimated when directly reading liquid levels from graduated reservoirs. The use of estimated digits for such measurements is provided in Practice D6026. When the last digit is estimated in a measurement where the reading is a function of the elevation/location of the eye, a mirror or another device is required to reduce the reading error caused by parallax.

6.4.1 Adjust/apply desired overburden pressure to the specimen in accordance with the testing requirements.

6.4.2 Adjust/set up the constant-head hydraulic system to apply the desired hydraulic gradient in the test.

6.4.3 Open the influent valves and allow the flow of water through the specimen. Measure and record the heads applied to the specimen at the inflow and outflow ends to the resolution stated in 5.2 at the start and end of each permeation trial (as a minimum). Determine the head loss across the specimen using measured heads. The head loss across the permeameter shall be kept constant to within ±5 % or better during permeation. The volumes of inflow and outflow shall be measured and recorded to the resolution stated in 5.3 at the start and end of each permeation trial (as a minimum). If monitored, the height of the test specimen shall be measured and recorded at the start and end of each trial (as a minimum) and changes in height shall be determined using the measured heights.

6.4.4 Continue permeation with consideration to criteria regarding steadiness of hydraulic conductivity and pore volumes of flow. The hydraulic conductivity shall be considered steady if four or more consecutive hydraulic conductivity determinations fall within ±25 % or better of the mean value and a plot or tabulation of the hydraulic conductivity versus time shows no significant upward or downward trend. In addition, at least 4 pore volumes of flow shall occur through the specimen.

6.4.5 The time at the start and end of each permeation trial shall be measured and recorded. The permeation duration shall be measured to the nearest second.

6.4.6 At the start (t_1) and end (t_2) of each permeation trial, the test temperature shall be measured and recorded to the nearest 0.1 °C.

6.4.7 Repeat permeation at the next level of hydraulic gradient.

7. Calculation

7.1 Calculate the hydraulic conductivity, k, as follows:

$$k = -\frac{\Delta Q \cdot L}{A \cdot \Delta h \cdot \Delta t} \tag{1}$$

where:

k = hydraulic conductivity (cm/s),
ΔQ = quantity of flow for given time interval, Δt ($t_2 - t_1$), (cm^3); if a dual-ring permeameter is used, this is the quantity of flow through the inner ring (cm^3),
L = length of specimen across which the hydraulic gradient is applied (cm),
A = cross-sectional area of specimen (cm^2); if a dual-ring permeameter is used, this is the area of the inner ring (cm^2),
Δh = constant head loss across the specimen length, L (cm), and
Δt = interval of time ($t_2 - t_1$) associated with the flow quantity, ΔQ, T (s).

7.2 Calculate the pore volumes of flow, PVF, as follows:

$$PVF = \frac{\Sigma V_{outflow}}{V_v} \tag{2}$$

where:

PVF = pore volumes of flow,
$\Sigma V_{outflow}$ = cumulative amount of effluent collected during test (m^3), and
V_v = volume of voids in the specimen (m^3).

8. Report: Test Data Sheet(s)/Form(s)

8.1 Record as a minimum the following general information (data): Sample/specimen identifying information, such as project number, TDA source/characteristics, etc., and information on permeant water.

8.2 Record as a minimum the following test specimen data: size and gradation of TDA and initial dry unit weight (or void ratio).

8.3 Record as a minimum the following test conditions and permeation data: overburden stress; the length and area of the test specimen during permeation; hydraulic head and gradient; for each permeation trial, the start and end time and elapsed duration (nearest second); the start and end temperature (nearest 0.1 °C).

8.4 Generate a plot of the discharge velocity ($v = k \times i$) vs. the applied hydraulic gradient ($i = \Delta h/L$).

8.5 The calculated hydraulic conductivity to two or more significant digits in units of cm/s or other units.

9. Precision and Bias

9.1 *Precision*—Test data on precision are not presented due to the nature of the TDA materials tested by this test method. Producing multiple specimens for testing by ten or more laboratories in a round-robin testing program that have uniform physical properties is considered infeasible. Any variation observed in the data is essentially equally likely to be due to specimen variation as to operator or laboratory testing variation.

9.2 *Bias*—Subcommittee D18.14 on Geotechnics of Sustainable Construction is seeking data from the users of this test method that might be used to make a limited statement on precision.

10. Keywords

10.1 constant head; hydraulic conductivity; scrap tire; shredded tires; tire chips; tire derived aggregate

REFERNCES

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