ASTM INTERNATIONAL

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Standard Test Method for
Field Measurement of Hydraulic Conductivity Using Borehole Infiltration[1]

This standard is issued under the fixed designation D6391; 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 field measurement of hydraulic conductivity (also referred to as *coefficient of permeability*) of porous materials using a cased borehole technique. When isotropic conditions can be assumed and a flush borehole is employed, the method yields the hydraulic conductivity of the porous material. When isotropic conditions cannot be assumed, the method yields limiting values of the hydraulic conductivity in the vertical direction (upper limit) if a single stage is conducted and the horizontal direction (lower limit) if a second stage is conducted. For anisotropic conditions, determination of the actual hydraulic conductivity requires further analysis by qualified personnel.

1.2 This test method may be used for compacted fills or natural deposits, above or below the water table, that have a mean hydraulic conductivity less than or equal to 1×10^{-5} m/s (1×10^{-3} cm/s).

1.3 Hydraulic conductivity greater than 1×10^{-5} m/s may be determined by ordinary borehole tests, for example, U.S. Bureau of Reclamation 7310 (**1**)[2]; however, the resulting value is an apparent conductivity.

1.4 For this test method, a distinction must be made between "saturated" (K_s) and "field-saturated" (K_{fs}) hydraulic conductivity. True saturated conditions seldom occur in the vadose zone except where impermeable layers result in the presence of perched water tables. During infiltration events or in the event of a leak from a lined pond, a "field-saturated" condition develops. True saturation does not occur due to entrapped air (**2**). The entrapped air prevents water from moving in air-filled pores, which may reduce the hydraulic conductivity measured in the field by as much as a factor of two compared with conditions when trapped air is not present (**3**). This test method develops the "field-saturated" condition.

1.5 Experience with this test method has been predominantly in materials having a degree of saturation of 70 % or more, and where the stratification or plane of compaction is relatively horizontal. Its use in other situations should be considered experimental.

1.6 As in the case of all tests for hydraulic conductivity, the results of this test pertain only to the volume of soil permeated. Extending the results to the surrounding area requires both multiple tests and the judgment of qualified personnel. The number of tests required depends on among other things: the size of the area, the uniformity of the material in that area, and the variation in data from multiple tests.

1.7 The values stated in SI units are to be regarded as standard. The values given in parentheses are provided for information only and are not considered standard.

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

1.8.1 The procedures in this standard that are used to specify how data are collected, recorded, and calculated are regarded as the industry standard. In addition, they are representative of the significant digits that should generally be retained. The procedures do not consider material variation, purpose for obtaining the data, special purpose studies, or any considerations for the objectives of the user. Increasing or reducing the significant digits of reported data to be commensurate with these considerations is common practice. Consideration of the significant digits to be used in analysis methods for engineering design is beyond the scope of this standard.

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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.* This test method does not purport to address environmental protection problems, as well.

1.10 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the*

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

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:*[3]

D653 Terminology Relating to Soil, Rock, and Contained Fluids

D1452/D1452M Practice for Soil Exploration and Sampling by Auger Borings

D1587/D1587M Practice for Thin-Walled Tube Sampling of Fine-Grained Soils for Geotechnical Purposes

D2937 Test Method for Density of Soil in Place by the Drive-Cylinder Method

D3740 Practice for Minimum Requirements for Agencies Engaged in Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction

D5084 Test Methods for Measurement of Hydraulic Conductivity of Saturated Porous Materials Using a Flexible Wall Permeameter

D5092/D5092M Practice for Design and Installation of Groundwater Monitoring Wells

D6026 Practice for Using Significant Digits in Geotechnical Data

3. Terminology

3.1 *Definitions:*

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

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *horizontal conductivity, k_h, n*—the hydraulic conductivity in (approximately) the horizontal direction.

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

3.2.2.1 *Discussion*—The term *coefficient of permeability* often is used instead of *hydraulic conductivity*, but *hydraulic conductivity* is used exclusively in this test method. A more complete discussion of the terminology associated with Darcy's law is given in the literature (**4**). It should be noted that both natural soils and recompacted soils usually are not isotropic with respect to hydraulic conductivity. Except for unusual materials, $k_h > k_v$.

3.2.3 *limiting horizontal conductivity, K2, n*—the hydraulic conductivity as determined in Stage 2 of this test method, assuming the tested medium to be isotropic. For ordinary soils, both compacted and natural, this is the minimum possible value for k_h.

3.2.4 *limiting vertical conductivity, K1, n*—the hydraulic conductivity as determined in Stage 1 of this test method,

assuming the tested medium to be isotropic. For ordinary soils, both compacted and natural, this is the maximum possible value for k_v.

3.2.5 *test diameter, n*—the inside diameter (ID) of the casing.

3.2.6 *vertical conductivity, k_v, n*—the hydraulic conductivity in (approximately) the vertical direction.

4. Summary of Test Method

4.1 The rate of flow of water into soil through the bottom of a sealed and cased borehole is measured in one or two stages, normally with a standpipe using a falling-head or constant-head procedure. The standpipe is refilled as necessary. A schematic of the test apparatus is shown in Fig. 1 with the dimensions to be recorded.

4.2 *Method A*—Method A is used when the soil being tested is treated as anisotropic. A falling-head test is conducted in two stages with the bottom of the borehole flush with the bottom of the casing in Stage 1 and extended below the bottom of the casing as a right circular cylinder in Stage 2 (Fig. 1). The borehole is extended for Stage 2 after Stage 1 is completed. A limiting hydraulic conductivity is computed from the falling head data in both stages. These limiting hydraulic conductivities are *K1* and *K2*, respectively.

Stages 1 and 2 are continued until the limiting conductivity for each stage is relatively constant.

Methods to calculate actual vertical and horizontal hydraulic conductivities (k_v and k_h) from *K1* and *K2* are described in (**5**) and (**6**).

4.3 *Method B*—Method B employs a falling head and is used when the soil being tested is treated as isotropic. A falling head test is conducted in a borehole flush with the bottom of the casing (Fig. 1). Hydraulic conductivity of the soil is computed from the falling head data. The test is continued until the hydraulic conductivity becomes essentially constant.

4.4 *Method C*—Method C employs a Mariotte tube to apply a constant head and is also used when the soil being tested is treated as isotropic. A constant head test is conducted in a borehole flush with the bottom of the casing. Hydraulic conductivity of the soil is computed from the steady flow rate measured during the test. The same apparatus and test set up is used for Methods B and C, except the falling-head standpipe used in Method B (Fig. 2a) is replaced by a constant-head Mariotte tube (Fig. 2b).

5. Significance and Use

5.1 This test method provides a means to measure the hydraulic conductivity of isotropic materials and the maximum vertical and minimum horizontal hydraulic conductivities of anisotropic materials, especially in the low ranges associated with fine-grained clayey soils, 1×10^{-7} m/s to 1×10^{-11} m/s.

5.2 This test method is useful for measuring liquid flow through soil hydraulic barriers, such as compacted clay barriers used at waste containment facilities, for canal and reservoir liners, for seepage blankets, and for amended soil liners, such as those used for retention ponds or storage tanks. Due to the boundary condition assumptions used in deriving the equations
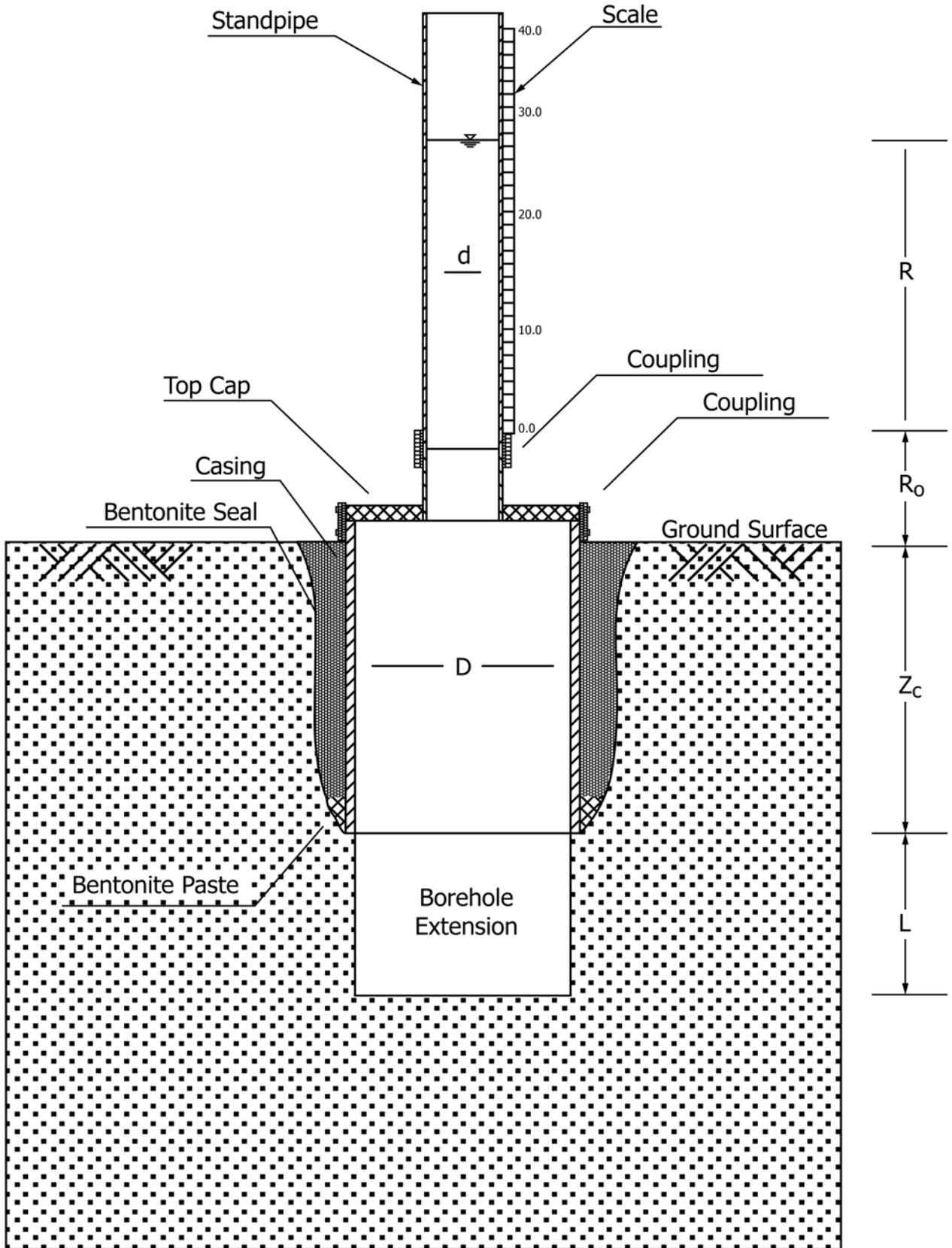
FIG. 1 Schematic of Borehole Test Showing Borehole Flush with Base (Methods B and C, Stage 1 of Method A) and with Extension for Stage 2 of Method A