Designation: D 6035 – 02

Standard Test Method for Determining the Effect of Freeze-Thaw on Hydraulic Conductivity of Compacted or Undisturbed Soil Specimens Using a Flexible Wall Permeameter[1]

This standard is issued under the fixed designation D 6035; 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 effect of freeze-thaw on the hydraulic conductivity of compacted or undisturbed soil specimens (using Test Method D 5084 and a flexible wall permeameter to determine hydraulic conductivity). This test method does not provide steps to perform sampling of, or testing on, in situ soils that have already been subjected to freeze-thaw conditions.

1.2 This test method may be used with undisturbed specimens (block or thin-walled) or laboratory compacted specimens and shall be used for soils that have an initial hydraulic conductivity less than or equal to 1E-5 m/s (1E-3 cm/s) (Note 1).

NOTE 1—The maximum initial hydraulic conductivity is given as 1 E-3 cm/s. This should also apply to the final hydraulic conductivity. It is expected that if the initial hydraulic conductivity is 1 E-3 cm/s, than the final hydraulic conductivity will not change (increase) significantly (that is, greater than 1 E-3 cm/s).

1.3 Soil specimens tested using this test method can be subjected to three-dimensional freeze-thaw (herein referred to as 3-d) or one-dimensional freeze-thaw (herein referred to as 1-d). (For a discussion of one-dimensional freezing versus three-dimensional freezing, refer to Zimmie[2] or Othman.[3])

1.4 Soil specimens tested using this test method can be tested in a closed system (that is, no access to an external supply of water during freezing) or an open system.

1.5 The values stated in SI units are to be regarded as the standard, unless other units are specifically given. By tradition, it is U.S. practice to report hydraulic conductivity in centimetres per second, although the common SI units for hydraulic conductivity are metres per second. The values are to be calculated and reported in accordance with Practice D 6026.

1.6 *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:*

D 653 Terminology Relating to Soil, Rock, and Contained Fluids[4]

D 1587 Practice for Thin-Walled Tube Geotechnical Sampling of Soils[4]

D 2113 Practice for Diamond Core Drilling for Site Investigation[4]

D 2216 Test Method for Laboratory Determination of Water (Moisture) Content of Soil and Rock[4]

D 3740 Practice for Minimum Requirements for Agencies Engaged in the Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction[4]

D 4220 Practice for Preserving and Transporting Soil Samples[4]

D 4753 Specification for Evaluating, Selecting, and Specifying Balances and Scales for Use in Testing Soil, Rock, and Related Construction Materials[4]

D 5084 Test Method for Measurement of Hydraulic Conductivity of Saturated Porous Materials Using a Flexible Wall Permeameter[4]

D 6026 Practice for Using Significant Digits in Geotechnical Data[5]

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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 D18.19 on Frozen Soil and Rock.

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[2] Zimmie, T. F., and La Plante, C., "The Effect of Freeze/Thaw Cycles on the Permeability of a Fine-Grained Soil," *Hazardous and Industrial Wastes, Proceedings of the Twenty-Second Mid-Atlantic Industrial Waste Conference*, Joseph P. Martin, Shi-Chieh Cheng, and Mary Ann Susavidge, eds., Drexel University, 1990, pp. 580–593.

[3] Othman, M. A., Benson, C. H., Chamberlain, E. J., and Zimmie, T. F.," Laboratory Testing to Evaluate Changes in Hydraulic Conductivity of Compacted Clays Caused by Freeze-Thaw: State-of-the-Art," *Hydraulic Conductivity and Waste Contaminant Transport in Soils, ASTM STP 1142*, David E. Daniel, and Stephen J. Trautwein, eds., American Society for Testing and Materials, Conshohocken, PA, pp. 227–254.

[4] *Annual Book of ASTM Standards*, Vol 04.08.

[5] *Annual Book of ASTM Standards*, Vol 04.09.

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

E 145 Specification for Gravity-Convection and Forced-Ventilation Ovens[6]

3. Terminology

3.1 Refer to Terminology D 653 for standard definitions of terms.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *freeze-thaw cycle*, *n*—a loop from room temperature to the ambient temperature of the freezing cabinet, and back to room temperature.

3.2.2 *freezing, closed system*, *n*—freezing that occurs under conditions that preclude the gain or loss of any water in the system.

3.2.3 *freezing, open system*, *n*—freezing that occurs under conditions that allow the gain or loss of water in the system by movement of pore water from or to an external source to growing ice lenses.

3.2.4 *hydraulic conductivity, 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).

4. Significance and Use

4.1 This test method identifies the changes in hydraulic conductivity as a result of freeze-thaw on natural soils only.

4.2 In using this test method the user shall both conduct the tests and provide the supervision required in accordance with Practice D 3740. Test values shall be calculated and recorded in accordance with Practice D 6026

4.3 It is the user's responsibility when using this test method to determine the appropriate moisture content of the laboratory-compacted specimens (that is, dry, wet, or at optimum moisture content) (Note 2).

NOTE 2—It is common practice to construct clay liners and covers at optimum or greater than optimum moisture content. Specimens compacted dry of optimum moisture content typically do not contain larger pore sizes as a result of freeze-thaw because the effects of freeze-thaw are minimized by the lack of water in the sample. Therefore, the effect of freeze-thaw on the hydraulic conductivity is minimal, or the hydraulic conductivity may increase slightly.[3,7]

4.4 The requestor must provide information regarding the effective stresses to be applied during testing, especially for determining the final hydraulic conductivity. Using high effective stresses (that is, 35 kPa (5 psi) as allowed by Test Method D 5084) can decrease an already increased hydraulic conductivity resulting in lower final hydraulic conductivity values. The long-term effect of freeze-thaw on the hydraulic conductivity of compacted soils is unknown. The increased hydraulic conductivity caused by freeze-thaw may be temporary. For example, the overburden pressure imparted by the waste placed on a soil liner in a landfill after being subjected to freeze-thaw may reduce the size of the cracks and pores that cause the increase in hydraulic conductivity. It is not known if the pressure would overcome the macroscopically increased hydraulic conductivity sufficiently to return the soil to its original hydraulic conductivity (prior to freeze-thaw). For cases such as landfill covers, where the overburden pressure is low, the increase in hydraulic conductivity due to freeze-thaw will likely be permanent. Thus, the requestor must take the application of the test method into account when establishing the effective stress.

4.5 The specimen shall be frozen to −15°C unless the requestor specifically dictates otherwise. It has been documented in the literature that the initial (that is, 0 to −15°C) freezing condition causes the most significant effects[3] in hydraulic conductivity. Freezing rate and ultimate temperature should mimic the field conditions. It has been shown that superfreezing (that is, freezing the specimen at very cold temperatures and very short time periods) produces erroneous results.

4.6 The thawed specimen temperature and thaw rate shall mimic field conditions. Thawing specimens in an oven (that is, overheating) will produce erroneous results.

4.7 Literature relating to this subject indicates that the effects of freeze-thaw usually occur by Cycle 10, thus it is recommended that at least 10 freeze-thaw cycles shall be performed to ensure that the full effects of freeze-thaw are measured. If the hydraulic conductivity values are still increasing after 10 freeze-thaw cycles, the test method shall be continued (that is, more freeze-thaw cycles shall be performed).

5. Apparatus

5.1 *Freezing Cabinet*, capable of maintaining at least −15 ±1°C.

5.2 The apparatus listed in Test Method D 5084 (see 5.1 through section 5.18).

6. Reagents

6.1 *Deaired Water*—To aid in removing as much air from the specimen as possible during the hydraulic conductivity portion of the test, deaired water shall be used.

6.2 *Optional*—If the specimen is frozen/thawed in the flexiwall permeameter, a mixture of propylene glycol and tap water can be placed in the flexi-wall permeameter cell. The compatibility of the mixture and membrane used shall be determined. Membranes may degrade and cause cell leakage. This mixture should have a freezing point lower than the ambient temperature of the freezing cabinet. The specimen will freeze, but the cell fluid will not. This allows the total stress on the specimen to remain unchanged during the freeze-thaw procedures.

7. Test Specimens

7.1 *Size*—The size of the specimen depends on the type and size of permeameter being used for the hydraulic conductivity testing. The specimen shall have a minimum diameter of 71.1 mm (2.80 in.) or greater and a minimum height of 71.1 mm. The height and diameter of the specimen shall be measured to the nearest 0.3 mm (0.01 in.) or better. The length and diameter shall not vary by more than ±5 %. For specimen diameters of 71.1 mm, clods less than 12.7 mm (0.5 in.) shall not be

[6] *Annual Book of ASTM Standards*, Vol 14.02.

[7] McManus, A. C., Werthman, P. H., and McManus, K. R., "Evaluation of the Effects of Frost Action on the Permeability of a Compacted Soil," presented at the New York State Association of Solid Waste Management Fall Program, Lake Luzerne, NY, October 1989.

reduced. For specimen diameters of 101.6 mm (4.00 in.), clod sizes less than 17.0 mm (0.67 in.) shall not be reduced. The surface of the test specimen may be uneven, but indentations must not be so deep that the length or diameter of the specimen varies by more than ±5 %. The diameter and height of the specimen shall each be at least 6 times greater than the largest particle size within the specimen. After completion of the test method, if oversized particles are found, it should be noted in the report.

7.2 Undisturbed or laboratory-compacted specimens can be used with this methodology. Test Method D 5084 shall be followed to prepare undisturbed or laboratory-compacted specimens.

7.3 *Number of Test Specimens*—This test method provides Test Method A and Test Method B for performing the test.

7.3.1 *Test Method A*—A specimen shall be prepared for each hydraulic conductivity determination performed. For example, if the hydraulic conductivity is performed initially, after 5 cycles and finally after 10 freeze-thaw cycles, a total of 3 specimens would be required. One specimen would be used for the initial hydraulic conductivity, the second specimen hydraulic conductivity would be determined after subjecting the specimen to 5 freeze-thaw cycles and the third specimen hydraulic conductivity would be determined after subjecting the specimen to 10 freeze-thaw cycles. This test method requires similar specimen preparation methods to ensure that representative samples are used (see Note 3).

7.3.2 *Test Method B*—One specimen can be used for the entire test method. This is not recommended for specimens with initial moisture contents significantly lower than 100 % saturation of the soil (Note 3).

NOTE 3—Using more than one specimen offers the advantage of comparison of hydraulic conductivities at an unchanging moisture content. When using one specimen for the entire test, the initial hydraulic conductivity test saturates the specimen producing a specimen for the freeze-thaw cycles that has a moisture content increased from the original compacted moisture content. This test method allows either procedure; however cautions the user about the moisture content. The results should not be significantly different if the initial moisture content is almost at saturation, which is the case if soils are compacted well above optimum moisture content. Using more than one specimen for the test method, specifically undisturbed specimens, has the disadvantage of potential nonrepresentative specimens and test results that are not comparable.

7.3.3 *Undisturbed Specimens*—Undisturbed test specimens shall be prepared from a representative portion of undisturbed specimens secured in accordance with Practice D 1587 or Practice D 2113, and preserved and transported in accordance with requirements for Group C materials in Practice D 4220 (refer to Test Method D 5084 for further discussion).

7.3.4 *Laboratory Compacted Specimens*— Refer to Test Method D 5084. Specimens shall be compacted in a mold or piece of PVC pipe or any other suitable apparatus so that the samples are confined during the freeze-thaw cycles. The user of the test method can perform 1-d freeze-thaw by placing insulation around the pipe and using a control sample with a thermocouple (see Note 4) or can perform 3-d freezing by placing the pipe in the freezer without insulation.

7.4 Other preparation test methods can be followed if specified and if identified in the report.

7.5 Determine the water content (Test Method D 2216), height, diameter, and mass of each test specimen and calculate the dry unit weight. The initial degree of saturation can be estimated.

8. Procedure

8.1 Determine the initial hydraulic conductivity of the specimen following Test Method D 5084.

8.2 Place the specimen in the freezing cabinet for approximately 24 h (Note 4). The water content of the specimen should not be allowed to change during the freeze-thaw cycles. This can be accomplished by placing each specimen in a plastic bag, or wrapping the specimens in saran wrap.

8.3 After 24 h, remove the specimen from the freezing cabinet and place it in an environment with an ambient temperature between 16°C (60°F) and 27°C (80°F) for 24 h (Note 4).

NOTE 4—The time of freezing or thawing the specimen can be reduced if a direct measurement of the temperature of the specimen can be monitored using a thermocouple in a control specimen.

8.4 Steps 8.2 and 8.3 combined shall constitute one freeze-thaw cycle.

8.5 Perform at least 10 freeze-thaw cycles. The hydraulic conductivity value determined after the final freeze-thaw cycle shall be compared with the previous hydraulic conductivity value (that is, at 5 freeze-thaw cycles). Additional freeze-thaw cycles shall be performed (that is, 15 or 20 cycles) if the hydraulic conductivity values are exhibiting an upward trend from freeze-thaw Cycle 5 to freeze-thaw Cycle 10.

8.6 The hydraulic conductivity shall be determined following Test Method D 5084 initially, during an intermediate cycle, and finally (that is, initial, 5, and 10). The hydraulic conductivity can be determined more than 3 times if desired.

9. Hydraulic Conductivity Determination

9.1 Perform each hydraulic conductivity following Test Method D 5084 using an effective stress of 14 to 35 kPa (2 to 5 psi). In addition, when performing the hydraulic conductivity at any point during the test following Test Method D 5084, the effective stress used should at no time exceed the expected minimum in-situ effective stress of the application being used (Note 5).

NOTE 5—It has been documented in literature that high effective stresses used on specimens that have been subjected to freeze-thaw will reduce the increased hydraulic conductivity due to freeze-thaw. Fig. 1[8] illustrates the relationship of effective stress versus hydraulic conductivity. The effective stress used should mimic the expected field effective stress. For example: in landfill covers, typically the effective stress does not exceed 14 kPa (2 psi). It has been shown that 35 kPa (5 psi) effective stress will reduce the increased hydraulic conductivity due to freeze-thaw to one half of its original value.

9.2 Perform final measurements and note any cracks, or other visible effects of freeze-thaw on the integrity of the

[8] Erickson, A. E., Chamberlain, E. J., and Benson, C. H., "Effects of Frost Action on Covers and Liners Constructed in Cold Environments," presented at the Seventeenth International Madison Waste Conference, Sept. 21–22, 1994, Department of Engineering Professional Development, University of Wisconsin-Madison.