



Designation: D 6780 – 02

Standard Test Method for Water Content and Density of Soil in Place by Time Domain Reflectometry (TDR)¹

This standard is issued under the fixed designation D 6780; 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 may be used to determine the water content of soils and the in-place density of soils using a TDR apparatus.

1.2 This test method applies to soils that have 30 % or less by weight of their particles retained on the 19.0-mm (¾-in.) sieve.

1.3 This test method is suitable for use as a means of acceptance for compacted fill or embankments.

1.4 This test method may not be suitable for organic and highly plastic soils.

1.5 All observed and calculated values shall conform to the guidelines for significant digits and rounding established in Practice D 6026.

1.5.1 The method used to specify how data are collected, calculated, or recorded in this standard is not directly related to the accuracy to which the data can be applied in design or other uses, or both. How one applies the results obtained using this standard is beyond its scope.

1.6 The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in non-conformance with the standard.

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:

D 653 Terminology Relating to Soil, Rock, and Contained Fluids²

D 698 Test Methods for Moisture-Density Relations of Soils and Soil-Aggregate Mixtures, Using 5.5 lb (2.49 kg) Rammer and 12-in. (305-mm) Drop²

D 1556 Test Method for Moisture-Density of Soil In-Place by the Sand-Cone Method²

D 1557 Test Methods for Moisture-Density Relations of Soils and Soil-Aggregate Mixtures, Using 10 lb (4.54 kg) Rammer and 18-in. (457-mm) Drop²

D 2167 Test Method for Density of Soil In-Place by the Rubber-Balloon Method²

D 2216 Method for Laboratory Determination of Water (Moisture) Content of Soil, Rock, and Soil-Aggregate Mixtures²

D 2922 Test Methods for Density of Soil and Soil Aggregate and Rock in Place by Nuclear Methods (Shallow Depth)²

D 2937 Test Method for Density of Soil In-Place by the Drive-Cylinder Method²

D 3017 Test Method for Water Content of Soil and Rock In-Place by Nuclear Methods (Shallow Depth)²

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 Construction²

D 4643 Method for Determination of Water (Moisture) Content of Soil by the Microwave Oven Method

D 4718 Practice for Correction of Unit Weight and Water Content for Soils Containing Oversize Particles²

D 4753 Specification for Evaluating, Selecting, and Specifying Balances and Scales for Use in Soil and Rock Testing²

D 4914 Test Method for Density and Unit Weight of Soil and Rock in Place by the Sand Replacement Method²

D 4944 Test Method for Field Determination of Water (Moisture) Content of Soil by the Calcium Carbide Gas Pressure Tester Method²

D 4959 Test Method for Determination of Water (Moisture) Content of Soil by Direct Heating Method²

D 5030 Test Methods for Density and Unit Weight of Soil and Rock in Place by the Water Replacement Method²

D 5080 Test Method for Rapid Determination of Percent Compaction²

¹ This test method is under the jurisdiction of ASTM Committee D18 on Soil and Rock and is the direct responsibility of Subcommittee D18.08 on Special and Construction Control Tests.

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² Annual Book of ASTM Standards, Vol 04.08.

D 6026 Practice for Using Significant Digits in Geotechnical Data³

D 6565 Test Method for Determination of Water (Moisture) Content of Soil by the Time Domain Reflectometry Method³

E 1 Specification for ASTM Thermometers⁴

E 11 Specification for Wire-Cloth Sieves for Testing Purposes⁴

SI 10 Standard for Use of the International System of Units (SI): The Modern Metric System⁵

3. Terminology

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

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *apparent dielectric constant*, K_{insitu} , K_{mold} —the squared ratio of the velocity of light in air to the apparent velocity of electromagnetic wave propagation in the soil measured by a TDR apparatus in place and in the cylindrical mold, respectively.

3.2.2 *apparent length*, l_a —on a plot of electromagnetic wave signal versus scaled distance measured by a TDR apparatus as shown in Fig. 1, it is the horizontal distance between the point on the waveform due to the reflection from the surface of the soil where the probe is inserted into the soil to the point on the waveform due to the reflection from the end of the probe.

3.2.3 *coaxial head*, CH^6 —a device that forms a transition from the coaxial cable connected to the TDR apparatus to the Multiple Rod Probe or to a Cylindrical Mold Probe.

3.2.4 *cylindrical mold probe*, CMP^6 —a probe formed by a cylindrical metal mold as the outer conductor having a non-

metallic end plate, filled with compacted soil, and with an inner conductor consisting of a rod driven into the soil along the axis of the mold.

3.2.5 *multiple rod probe*, MRP^6 —a probe formed by driving four rods of equal length into the soil in a pattern where three of the rods define the outer conductor of a “coaxial cable” and one of the rods is the inner conductor.

3.2.6 *probe length*, L —the length of the TDR probe that is below the surface of the soil.

3.2.7 *scaled distance*, l —the product of the velocity of light in air and electromagnetic wave travel time in the soil divided by two.

4. Summary of Test Method

4.1 The dielectric constant of the soil in-place is determined using a multiple rod probe (MRP), a coaxial head (CH), and TDR apparatus. The soil at the location of the in-situ measurement is then excavated and compacted in a mold. By measurement of the mass of the mold and soil and with the mass and volume of the mold known, the wet density of the soil in the mold is determined. A rod driven into the soil along the axis of the mold creates a cylindrical mold probe (CMP). Using the same coaxial head (CH), an adapter ring, and the TDR apparatus the dielectric constant of the soil in the mold is measured. The water content of the soil in the mold is determined using a correlation between the dielectric constant, moisture content and soil density. The correlation requires two constants that are somewhat soil specific. It is assumed that the water content of the soil in place is the same as the water content in the mold. The density of the soil in place is determined from the density of the soil in the mold and the dielectric constants measured in the mold and in place.

5. Significance and Use

5.1 This test method can be used to determine the density and water content of naturally occurring soils and of soils placed during the construction of earth embankments, road fills, and structural backfills.

5.2 Time domain reflectometry (TDR) measures the apparent dielectric constant of soil. The dielectric constant is affected

³ Annual Book of ASTM Standards, Vol 04.08.

⁴ Annual Book of ASTM Standards, Vol 14.02.

⁵ Annual Book of ASTM Standards, Vol 14.04.

⁶ The apparatus is covered by patents. Interested parties are invited to submit information regarding the identification of alternative(s) to this patented item to the ASTM Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee, which you may attend.

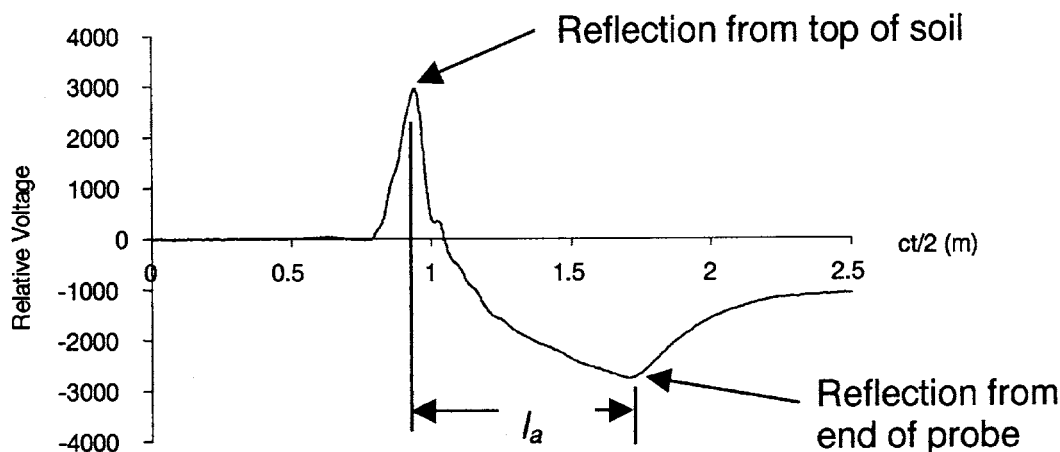


FIG. 1 Typical TDR Curve Showing Reflection Points and Apparent Length, l_a

significantly by the water content and density of soil, and to a lesser extent by the chemical composition of soil and pore water and by temperature. The water content determined in this standard makes use of a different relationship between apparent dielectric constant and water content from that used in Test Method D 6565.

5.3 Soil and porewater characteristics are accounted for in this method with two calibration constants that are determined for a given soil by performing compaction tests as described in Annex A2 where water content also is measured by use of Method D 2216.

5.4 The water content is the average value over the length of the cylindrical mold and the density is the average value over the length of the multiple-rod probe embedded in the soil.

NOTE 1—The quality of the result produced by this standard is dependent on the competence of the personnel performing it, and the suitability of the equipment and facilities used. Agencies that meet the criteria of Practice D 3740 are generally considered capable of competent and objective testing/sampling/inspection/etc. Users of this standard are cautioned that compliance with Practice D 3740 does not in itself assure reliable results. Reliable results depend on many factors; Practice D 3740 provides a means of evaluating some of those factors.

6. Interferences

6.1 Quality and accuracy of the test results significantly depend on soil having contact with the inner conductor of the probes. To assist this, when installing the rods of the MRP, the rod that forms the inner conductor must be the last rod installed. If in the installation process, the rod hits upon a large particle that causes it to drift from vertical alignment, all rods should be removed and the test conducted in a new location at least 0.2-m (8-in.) from the previous test location.

6.2 The quality of the signal read by the TDR apparatus depends on having clean contacts between the CH and the MRP and the CMP. The contacting surfaces should be wiped with a clean cloth prior to placing the CH on the MRP and the CMP. Once placed, observe the signal on the TDR apparatus. If the characteristic signal is not present, the CH may have to be slightly rotated about its axis to make better contact.

6.3 This test method only applies to non-frozen soil. The apparent dielectric constant is slightly temperature dependent for soils and depends on soil type. For soil temperatures between 15°C and 25°C (59°F and 77°F), no temperature corrections are needed for most soils. A simple temperature adjustment for water content determination is part of the test method.

7. Apparatus

7.1 *TDR Apparatus*, a Metallic Time Domain Reflectometer with a scaled length resolution of at least 2.4-mm (0.10-in.) (this corresponds approximately to a time between data points less than or equal to sixteen picoseconds (16×10^{-12} s)). A portable computer with a serial communication port to the TDR is suggested for controlling the apparatus, acquiring and saving the data, and for making the calculations as the test proceeds.

7.2 *Multiple Rod Probe (MRP)⁶ with Coaxial Head (CH)³*

7.2.1 The MRP consists of four common steel spikes, typically 250-mm (10-in.) in length and uniform diameters of

9.5-mm ($\frac{3}{8}$ -in.). (Other length spikes, but with the same diameter, may be used but in no case should they have lengths less than 150-mm (6-in.). For lengths longer than 250-mm (10-in.), drift in the alignment of the spikes and loss of reflected signal from the end of the MRP may occur.)

7.2.2 A MRP guide template (see Fig. 2) is used to guide the spikes as they are driven into the soil. The template must allow for its removal after the spikes are driven and before a TDR measurement is made. (The radius from the central spike to the outer spikes must be within the range of 5 to 7.5 times the diameter of the central spike.)

7.2.3 The Coaxial Head (CH)⁶ (see Fig. 3) forms a transition from the coaxial cable coming from the TDR apparatus to the MRP.

7.3 *Cylindrical Mold Probe (CMP)⁶*, the CMP consists of a cylindrical mold, a guide template, a central rod, and a ring collar. Details for these items are shown in Fig. 4.

7.3.1 The central rod is a stainless steel rod with a diameter of 8.0-mm ($\frac{5}{16}$ -in.) and a length of 264-mm (10.4-in.) in length.

7.4 *Balances or Scales*, meeting Specification GP10 of Specification D 4753 to determine the mass of the soil and the cylindrical mold. A battery-operated balance or scale having a minimum capacity of 10 kg is suitable when an apparatus with the dimension given in Fig. 3 is used.

7.5 *Driving Tools*, a brass-headed hammer for driving spikes for the MRP and the central rod into the cylindrical mold. A resin-headed hammer also may be used for driving the central rod into the cylindrical mold. (Use of these hammers prevents peening of the driving end of the steel rods from repeated use.)

7.6 *Tamping Rod*, an aluminum rod with flat ends, a diameter of 37-mm (1.5-in.), and a length of 380-mm (15-in.).

7.7 *Thermometer*, 0 to 50°C range, 0.5°C graduations, conforming to requirements of Specification E 1.

7.8 *Vernier or Dial Caliper*, having a measuring range of at least 0 to 250-mm (0 to 10-in.) and readable to at least 0.02-mm (0.001-in.).

7.9 *Miscellaneous Tools*, a battery-powered hand drill with a spare battery and charger and with a 25-mm (1-in.) diameter auger bit (alternatively, a small pick will work), straight edge for smoothing the surface of the soil for the in-place test and for smoothing the surface of the soil in the cylindrical mold, pliers for removing the spikes and central rod, small scoop or spoon for removal of the loosened soil and for placement in the cylindrical mold, and a brush for removing excess soil from around the base of the cylindrical mold prior to determining its mass.

8. Preparation of Apparatus

8.1 Charge or replace, as appropriate batteries in the TDR apparatus, the hand drill, and the balance.

9. Calibration and Standardization

9.1 Determine the average length of the spikes that will penetrate into the soil surface in the in-place test, L_{insitu} , m (in.), by inserting each spike into the MRP guide template and measuring the length that each spike protrudes from the