Designation: ~~D5195 – 14ε1~~ D5195 – 21

Standard Test Method for Density of Soil and Rock In-Place at Depths Below Surface by Nuclear Methods[1]

This standard is issued under the fixed designation D5195; 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.

~~ε1 NOTE—Editorially corrected units of measurement statement in June 2021.~~

1. Scope*

1.1 This test method covers the calculation of the wet density of soil and rock by the attenuation of gamma radiation, where the gamma source and the gamma detector are placed at the desired depth in a bored ~~hole~~ hole, typically lined by an access tube.

1.1.1 For limitations see Section ~~5~~6 ~~on Interference.~~, "Interference."

1.2 The wet density, in mass per unit volume of the material under test, is calculated by comparing the detected rate of gamma radiation with previously established calibration data (see Annex A1).

~~1.3 A precision statement has not been developed for this standard at this time. Therefore, this standard should not be used for acceptance or rejection of a material for purchasing purposes unless correlated to other accepted ASTM standards.~~

1.3 *Units*—The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values ~~given~~stated in ~~parentheses are provided for information only and are not considered standard.~~each system are not necessarily exact equivalents; therefore, to ensure conformance with the standard, each system shall be used independently of the other, and values from the two systems shall not be combined. Within the text of this standard, SI units appear first followed by the inch-pound (or other non-SI) units in brackets.

1.3.1 Reporting the test results in units other than SI shall not be regarded as nonconformance with this standard.

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

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

1.5 *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.* Specific precautionary statements are given in Section ~~7~~8, "Hazards."

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

1.6 *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
D1452/D1452M Practice for Soil Exploration and Sampling by Auger Borings[3]
D1587/D1587M Practice for Thin-Walled Tube Sampling of Fine-Grained Soils for Geotechnical Purposes
D2113 Practice for Rock Core Drilling and Sampling of Rock for Site Exploration
D2216 Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass
D2937 Test Method for Density of Soil in Place by the Drive-Cylinder Method
D3441 Test Method for Mechanical Cone Penetration Testing of Soils
D3740 Practice for Minimum Requirements for Agencies Engaged in Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction
D4428/D4428M Test Methods for Crosshole Seismic Testing
D5220/D5220M Test Method for Water Mass per Unit Volume of Soil and Rock In-Place by the Neutron Depth Probe Method
D5778 Test Method for Electronic Friction Cone and Piezocone Penetration Testing of Soils
D6026 Practice for Using Significant Digits and Data Records in Geotechnical Data
D6938 Test Methods for In-Place Density and Water Content of Soil and Soil-Aggregate by Nuclear Methods (Shallow Depth)
D7263 Test Methods for Laboratory Determination of Density and Unit Weight of Soil Specimens

3. Terminology

3.1 *Definitions*—For definitions of common technical terms in this standard, refer to Terminology D653.

~~3.2 *Definitions of Terms Specific to This Standard:*~~

~~3.2.1 *wet density*—same as bulk density (as defined in Terminology D653); the total mass (solids plus water) per total volume.~~

~~3.2.2 *gamma (radiation) source*—a sealed, radioactive material that emits gamma radiation as it decays.~~

~~3.2.3 *gamma detector*—a device to observe and measure gamma radiation.~~

~~3.2.4 *Compton scattering*—the interaction between a gamma ray (photon) and an orbital electron where the gamma ray loses energy and rebounds in a different direction.~~

~~3.2.5 *volumetric water content*—the volume of water as a percent of the total volume of soil or rock material.~~

4. Summary of the Test Method

4.1 The test method is as follows:

4.1.1 A vertical hole is bored or driven into the site where the test is to be performed. The depth of the hole shall be at least 300 mm [1 ft] lower than the bottom of the probe when it is in its deepest measurement position.

4.1.2 An access tube is typically installed in the hole, with any soil or rock falling back into the hole removed. Alternate methods of drilling the hole and placing the probe are described in 10.2 and 10.3.

4.1.3 The probe containing the source and detector are positioned at the desired measurement depth, and a measurement is taken.

5. Significance and Use

5.1 This test method is useful as a rapid, nondestructive technique for the calculation of the in-place density of soil and rock at

[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] Replace with continuous flight and hollowstream methods when available.

desired depths below the surface as opposed to surface measurements in accordance with Test Method D6938. Alternative destructive methods are likewise described in this test method.

5.2 This test method is useful for informational and research purposes. It should only purposes, only to be used for quality control and acceptance testing when correlated to other accepted methods such as Test Method D2937.

5.3 The non-destructive nature of the test method allows repetitive measurements to be made at a single test location for statistical analysis and to monitor changes over time.

5.4 The fundamental assumptions inherent in this test method are that Compton scattering and photoelectric absorption are the dominant interactions of the gamma rays with the material under test.

NOTE 1—The quality of the result produced by this standard test method 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 D3740 are generally considered capable of competent and objective testing/sampling/inspection, and the like. Users of this test method 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 those factors.

5.5 The probe response, in counts, may be converted to wet density by comparing the detected rate of gamma radiation with previously established calibration data (see Annex A1).

5.6 The probe count response may also be utilized directly for unitless, relative comparison with other probe readings

5.6.1 For materials of densities higher than that of about the density of water, higher count rates within the same soil type relate to lower densities and, conversely, lower count rates within the same soil type relate to higher densities.

5.6.2 For materials of densities lower than the density of water, higher count rates within the same soil type relate to higher densities and, conversely, lower count rates within the same soil type relate to lower densities.

5.6.3 Because of the functional inflection of probe response for densities near the density of water, exercise great care when drawing conclusions from probe response in this density range.

NOTE 1—The quality of the result produced by this standard test method 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 D3740 are generally considered capable of competent and objective testing/sampling/inspection, and the like. Users of this test method 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 those factors.

6. Interferences

6.1 The chemical composition of the sample may affect the measurement and adjustments may be necessary. Some elements with atomic numbers greater than 20 such as iron (Fe) or other heavy metals may cause measurements higher than the true density value.

6.2 The sample heterogeneity affects the measurements. This test method also exhibits spatial bias in that it is more sensitive to material closest to the access tube.

6.2.1 Voids around the access tube can affect the measurement (see 9.1.2.1Annex A2).

6.3 The sample volume is approximately 0.028 m^3 (0.8[0.8 ft^3).]. The actual sample volume is indeterminate and varies with the apparatus and the density of the material. In general, the greater the density the smaller the volume.

7. Apparatus (See Fig. 1Figs. 1-3)

7.1 The apparatus shall consist of a nuclear instrument capable of measuring density of materials at various depths below the surface and contain the following:

7.1.1 *Sealed Source of High Energy Gamma Radiation,* such as cesium-137, cobalt-60, or radium-226.

7.1.2 *Gamma Detector*—Any type of gamma detector such as a Geiger-Mueller tube.

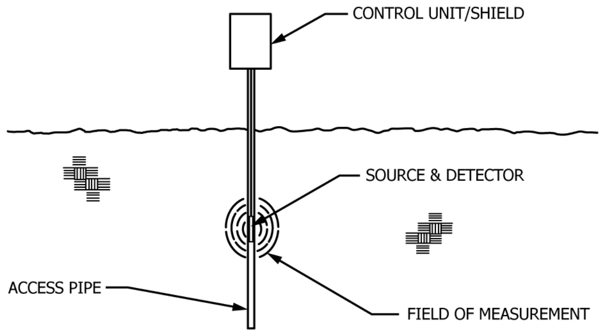

FIG. 1 Schematic Diagram: Depth Density by Nuclear ~~Method~~Method, Expanded View

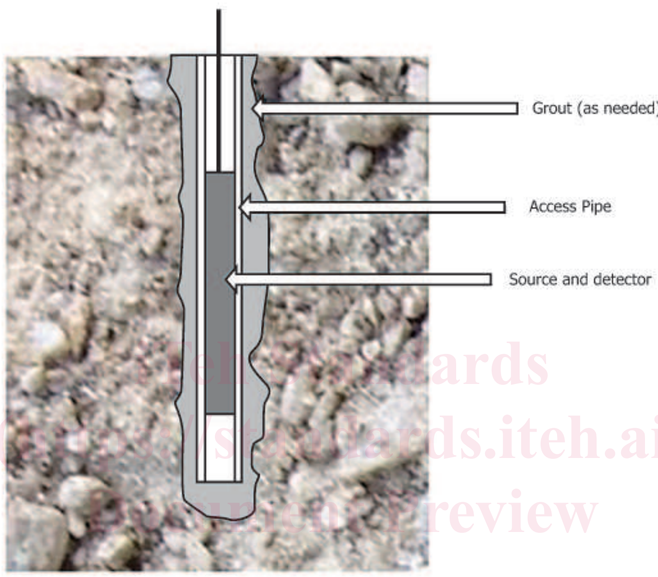

FIG. 2 Schematic Diagram: Depth Density by Nuclear Method, Detail View, Voids Due to the Drilling Process Filled with Grout (Not to Scale)

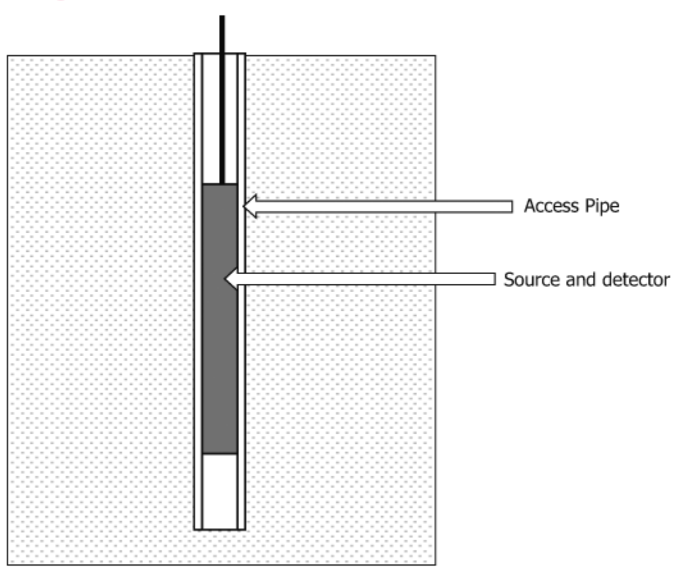

FIG. 3 Schematic Diagram: Depth Density by Nuclear Method, Detail View, Negligible Voids Due to the Drilling Process (Not to Scale)

7.1.3 *Suitable Timed Scaler and Power Source.*

7.2 *Cylindrical Probe*—The apparatus shall be equipped with a cylindrical probe, containing the gamma source and detector, connected by a cable of sufficient design and length, that is capable of being lowered down a cased hole to desired test depths.

7.2.1 The dimensions of the probe vary among manufacturers and models, but are generally between 25 mm [1 in.] and 100 mm [4 in.] in diameter and 20 mm [8 in.] and 1 m [39 in.] in length. Probe diameters are generally designed by the manufacturer to be commensurate with the internal diameter of commonly used access tubing, or drill hole sizes.

7.3 *Reference Standard*—The apparatus shall be equipped with a reference standard, a fixed shape of dense material used for checking apparatus operation and to establish conditions for a reproducible reference count rate. It may also serve as a radiation shield.

7.4 *Apparatus Precision*—See Annex A3 for the precision of the apparatus.

7.5 *Accessories:*

7.5.1 *Access Tubing*—The access tubing (casing) is required for all access holes in nonlithified materials (soils and poorly consolidated rock) that cannot maintain constant borehole diameter with repeated measurements. If access tubing is required it ~~must~~shall be of a material such as aluminum, steel, or polyvinyl chloride, having an interior diameter large enough to permit probe access without binding, and an exterior diameter as small as possible to provide close proximity of the material under test. The same type of tubing ~~must~~shall be used in the field as is used in calibration.

7.5.2 *Hand Auger or Power Drilling Equipment,* that can be used to establish the access hole. Any drilling equipment that provides a suitable clean open hole for installation of access tubing and insertion of the probe that ensures the measurements are performed on intact soil and rock while maintaining constant borehole diameter ~~shall be~~ is acceptable. The type of equipment and methods of advancing the access hole ~~should~~shall be reported.

7.5.3 *Cone Penetrometer Rig Drill,* if the probe readings are to be taken in conjunction with cone penetrometer soundings.

8. Hazards

8.1 These ~~gauges~~instruments utilize radioactive materials that may be hazardous to the health of the users unless proper precautions are taken. Users of these ~~gauges must~~instruments shall become familiar with applicable safety procedures and government regulations.

8.2 Effective user instructions, together with routine safety procedures and knowledge of and compliance with ~~Regulatory Requirements,~~regulatory requirements, are a mandatory part of the operation and storage of these ~~gauges.~~instruments.

9. Calibration, Standardization, and Reference Check

9.1 Calibrate the instrument in accordance with Annex A1.

9.2 Adjust the calibration in accordance with Annex A2 if adjustments are necessary.

9.3 ~~*Standardization and Reference Check:*~~ Perform and evaluate standardization and reference check on a daily basis, prior to taking field measurements, in accordance with Annex A4.

~~8.3.1 Nuclear density gauges are subject to long-term aging of the radioactive sources, which may change the relationship between count rates and the material density. To correct for this aging effect, gauges are calibrated as a ratio of the measurement count rate to a count rate made on a reference standard.~~

~~8.3.2 Standardization of the gauge shall be performed at the start of each day's use, and a record of these data should be retained for the amount of time required to ensure compliance with either 8.3.4 or 8.3.5, whichever is applicable. Perform the standardization with the gauge far enough away from other apparatus containing radioactive sources to prevent interference due to radiation from the other apparatus. In addition, perform the standardization far enough away from large masses or other items which can affect the reference count rates due to reflections from these masses or items.~~

~~NOTE 2—Separation of nuclear gauges by a distance of 9 m (30 ft) from one another has typically proven sufficient in preventing radiation from one gauge from being detected by another gauge and potentially causing an incorrect standardization count. This separation can be reduced by the proper use of shielding. With regards to reflections from large masses or other items potentially causing incorrect standardization counts, a separation of 1 m (3 ft) between the gauge and the mass or item in question has typically proven sufficient to prevent such reflections from influencing the standardization counts.~~

~~8.3.3 Turn on the gauge and allow for stabilization according to the manufacturer's recommendations.~~

~~8.3.4 Using the reference standard, take at least four repetitive readings at the normal measurement period and obtain the mean. If available on the gauge, one measurement at four or more times the normal measurement period is acceptable. This constitutes one standardization check. Use the procedure recommended by the gauge manufacturer to establish the compliance of the standard measurement to the accepted range. Without specific recommendations from the gauge manufacturer, use the procedure in 8.3.5.~~

~~8.3.5 If the value of the current standardization count is outside the limits set by Eq 1, repeat the standardization check. If the second standardization check satisfies Eq 1, the gauge is considered in satisfactory operating condition.~~

$$0.99(N_c)e^{\frac{-ln(2)t}{T_{1/2}}} \le N_0 \le 1.01(N_c)e^{\frac{-ln(2)t}{T_{1/2}}} \qquad (1)$$

~~*where:*~~

~~$T_{1/2}$ = the half-life of the isotope that is used for the density or moisture determination in the gauge. For example, ^{137}Cs, the isotope most commonly used for density determination in these gauges, $T_{1/2}$ is 11 023 days,~~
~~N_c = the standardization count acquired at the time of the last calibration or verification,~~
~~N_0 = the current standardization count,~~
~~t = the time that has elapsed between the current standardization test and the date of the last calibration or verification. The units selected for t and $T_{1/2}$ should be consistent, that is, if $T_{1/2}$ is expressed in days, then t should also be expressed in days,~~
~~$ln(\ )$ = the natural logarithm function, and~~
~~e = the positive real number for which the natural logarithm value is equal to one. e itself is equal to 2.71828182845904.~~

~~8.3.6 *Example*—A nuclear gauge containing a ^{137}Cs source for density determination (half-life = 11 023 days) is calibrated on March 1 of a specific year. At the time of calibration, the density standard count was 2800 counts per minute (prescaled). According to Eq 1, what is the allowed range of standard counts for November 1 of the same year? For this example, a total of 245 days have elapsed between the date of calibration or verification (March 1) and the date of the gauge standardization (November 1).~~

~~*Therefore:*~~

~~t = 245 days~~
~~$T_{1/2}$ = 11 023 days~~
~~N_c = 2800 counts~~

~~According to Eq 1, therefore, the lower limit for the density standard count taken on November 1, denoted by N_0, is~~

$$0.99(N_c)e^{\frac{-(ln(2))t}{T_{1/2}}} = 0.99(2800)e^{\frac{-(ln(2))\cdot 245}{11\,023}} = 2772e^{-0.01541} = 2730\ counts$$

~~Likewise, the upper limit for the density standard count taken on November 1, denoted by N_0, is~~

$$1.01(N_c)e^{\frac{-(ln(2))t}{T_{1/2}}} = 1.01(2800)e^{\frac{-(ln(2))\cdot 245}{11\,023}} = 2828e^{-0.01541} = 2785\ counts$$

~~Therefore, the density standard count acquired on November 1 should lie somewhere between 2730 and 2785 counts, or $2730 \le N_0 \le 2785$.~~

~~8.3.7 If for any reason the measured density becomes suspect during the day's use, perform another standardization check.~~

10. Procedure

10.1 *Installation of Access Tubing ~~(Casing):~~ (Casing) with a Drill Allowing Repeated, In-Place Readings:*

10.1.1 Drill the access tube hole and install access tube in a manner dependent upon the material to be tested, the depth to be tested, and the available drilling equipment.

10.1.2 The access hole ~~must~~shall be clear enough to allow installing the tube yet ~~must~~ provide a snug fit. Voids along side the tube will cause erroneous readings.

10.1.2.1 If voids are suspected to be caused by the drilling process they can be grouted using the procedures in Test Method D4428/D4428M. The only method to determine the presence of voids is to perform field calibrations ~~provided~~ as described in A1.3.

10.1.3 Record and note the position of the ground water table, perched water tables, and changes in strata as drilling progresses.

10.1.3.1 If ground water is encountered or saturated conditions are expected to develop, seal the tube using procedures given in Test Method D4428/D4428M at the bottom to prevent water seepage into the tube. This will prevent erroneous readings and possible damage to the probe.

10.1.4 The tube ~~should~~shall project above the ground and be capped to prevent foreign material from entering. The access tube ~~should~~shall not project above the ground so high as it might be damaged by equipment passing over it.

10.1.4.1 Install all tubes at the same height above ground as this enables marking the cable to indicate the measured depth to be used for all tubes.

10.2 ~~Lower a dummy probe down the access tube to verify proper clearance before lowering the probe containing the radioactive source.~~*Destructive Access Hole Drilling without Repeated, In-Place Readings:*

10.2.1 In some field situations it may be more appropriate to use a drilling technique involving alternating between a large diameter hollow-stem auger, a split-spoon sampler, or thin-walled volumetric sampler and access tubing.

10.2.2 This technique is destructive and only one measurement can be made at each depth per hole.

10.3 ~~Standardize the apparatus.~~*Probe Placement with Cone Penetrometer (CPT) Rig:*

10.3.1 Sufficiently robust probes can be placed with a CTP rig. Whether the probe is durable enough to withstand this treatment shall be confirmed with the probe manufacturer.

10.3.2 Connect the probe to the top of the CPT probe.

10.3.3 With the probe mounted on the top of the CPT probe, proceed with the CPT soundings as described in either Method D3441 or Method D5778, acquiring probe readings in conjunction with the CPT soundings.

10.3.4 If the probe is mounted to the top of a dummy CPT tip, push the probe into the soil with the CPT rig.

10.4 ~~Proceed with the test as follows:~~*Probe Placement (for Drilling Procedures Described in 10.1 and 10.2):*

10.4.1 When the drilling procedures described in 10.1 or 10.2 are complete, lower a dummy probe down the access tube to verify proper clearance before lowering the probe containing the radioactive source.

10.4.2 Seat the apparatus firmly over the access tube, then lower the probe into the tube to the desired depth. Secure the probe by cable clamps (usually provided by the apparatus manufacturer).

~~9.4.2 Take a measurement count at the selected timing period.~~

~~NOTE 3—The above procedure is performed in an installed access tube that will allow repeated in-place measurements. In some field situations it may be more appropriate to use a drilling technique involving alternating between a large diameter hollow-stem auger, a split-spoon sampler, or thin-walled volumetric sampler and access tubing. This technique is destructive and only one measurement can be made at each depth per hole.~~

10.5 *Data Acquisition and Evaluation:*

10.5.1 Standardize the apparatus.

10.5.2 Proceed with the test as follows:

10.5.3 Take a measurement count at the selected timing period.