Designation: D5195 – 14

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.

1. Scope*

1.1 This test method covers the calculation of the 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 lined by an access tube.

1.1.1 For limitations see Section 5 on Interference.

1.2 The 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.

1.4 *Units*—The values stated in SI units are regarded as the standard. The inch-pound units given in parentheses are for information only and may be approximate.

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

1.5.1 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.

1.6 *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.* Specific precautionary statements are given in Section 7, "Hazards."

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D653 Terminology Relating to Soil, Rock, and Contained Fluids

D1452 Practice for Soil Exploration and Sampling by Auger Borings[3]

D1587 Practice for Thin-Walled Tube Sampling of Soils for Geotechnical Purposes

D2113 Practice for Rock Core Drilling and Sampling of Rock for Site Investigation

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

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 Test Method for Water Mass per Unit Volume of Soil and Rock In-Place by the Neutron Depth Probe Method

D6026 Practice for Using Significant Digits in Geotechnical Data

D6938 Test Method for In-Place Density and Water Content of Soil and Soil-Aggregate by Nuclear Methods (Shallow Depth)

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:*

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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 D18.08 on Special and Construction Control Tests.

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[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.

***A Summary of Changes section appears at the end of 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. Significance and Use

4.1 This test method is useful as a rapid, nondestructive technique for the calculation of the in-place density of soil and rock at desired depths below the surface as opposed to surface measurements in accordance with Test Method D6938.

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

4.3 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.

4.4 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. Interferences

5.1 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.

5.2 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.

5.2.1 Voids around the access tube can affect the measurement (see 9.1.2.1).

5.3 The sample volume is approximately 0.028 m^3 (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.

6. Apparatus (See Fig. 1)

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

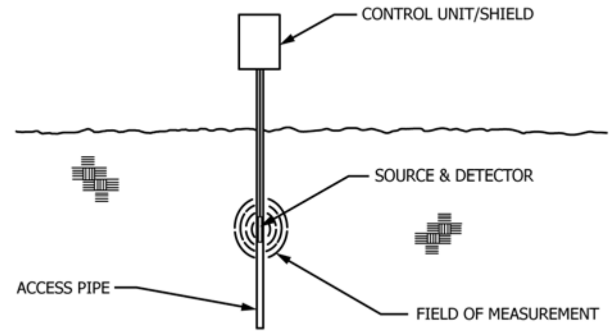

FIG. 1 Schematic Diagram: Depth Density by Nuclear Method

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

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

6.1.3 *Suitable Timed Scaler and Power Source.*

6.2 *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.

6.3 *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.

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

6.5 *Accessories:*

6.5.1 *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 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 be used in the field as is used in calibration.

6.5.2 *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 acceptable. The type of equipment and methods of advancing the access hole should be reported.

7. Hazards

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

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

8. Calibration, Standardization, and Reference Check

8.1 Calibrate the instrument in accordance with Annex A1.

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

8.3 *Standardization and Reference Check:*

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.

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

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 $2730 \leq N_0 \leq 2785$.

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

9. Procedure

9.1 *Installation of Access Tubing (Casing):*

9.1.1 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.

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

9.1.2.1 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 in A1.3.

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

9.1.3.1 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.

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

9.1.4.1 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.

9.2 Lower a dummy probe down the access tube to verify proper clearance before lowering the probe containing the radioactive source.

9.3 Standardize the apparatus.

9.4 Proceed with the test as follows:

9.4.1 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. Calculation

10.1 Determine the ratio of the reading obtained compared to the standard count. Then using the calibration data combined with appropriate calibration adjustments, or apparatus direct readout feature, determine the in-place density. This is the bulk or wet density.

NOTE 4—Some instruments have built-in provisions to compute and display the ratio and corrected bulk or wet density per unit volume.

10.1.1 If the dry density is required determine the in-place water content using either gravimetric samples and laboratory determination of water content (see Method D2216), or the same apparatus or a different apparatus which determines water mass per unit volume by the neutron probe method (Method D5220). The dry density is calculated by either of the following equations:

$$\rho_d = \frac{100 \times \rho}{100 + w} \tag{2}$$

or:

$$\rho_d = \rho - M_m$$

where:

ρ_d = dry density in kg/m^3 (or lbm/ft^3),
ρ = wet density in kg/m^3 (or lbm/ft^3),
M_m = water mass per unit volume in kg/m^3 (lbm/ft^3) from apparatus, and
w = water content as a percent of the dry density from lab.

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

11.1 The methodology used to specify how data are recorded on the test data sheet(s)/form(s) as given below is covered in 1.5.

11.2 Record at a minimum the following general information (data):

11.2.1 Make, model, and serial number of the apparatus,
11.2.2 Name of operator/technician
11.2.3 Date of calibration,
11.2.4 Method of calibration, such as field, factory, etc.
11.2.5 Calibration adjustments,
11.2.6 Date of test,
11.2.7 Standard count for the day of the test,
11.2.8 Any adjustment data for the day of the test,
11.2.9 Test site identification including; tube location(s) and tube number(s),
11.2.10 Tube type and tube installation methods (methods of drilling, installing and any initial gravimetric and count data),
11.2.11 Geologic log of the borehole, and
11.2.12 Depth, measurement count data, and calculated density of each measurement.

12. Precision and Bias

12.1 *Precision*—It is not possible to specify the precision of the procedure in this standard for measuring density of soil and rock in-place at depths below the surface because the precision of this test method is operator dependent and a function of the care exercised in installing the access tubing and performing the steps of the procedures properly. Interferences as described in Section 4, such as voids, large rocks, and varying densities at different depths of the access tube would also prevent developing a meaningful precision statement.

12.2 *Bias*—No information can be presented on the bias of the procedure in this standard for measuring density of soil and rock in-place at depths below the surface because no methods are presently available that provide sufficiently accurate values of density of soil and rock in-place against which this test method can be compared.

13. Keywords

13.1 depth probe; in-place density; in situ density; nuclear methods

ANNEXES

(Mandatory Information)

A1. CALIBRATION

A1.1 At least once each year, establish or verify calibration curves, tables, or equation coefficients by determining by test the count rate of at least three samples of different known densities. This data may be presented in the form of a graph, table, equation coefficients, or stored in the apparatus, to allow converting the count rate data to material density. The method and test procedures used in establishing these count ratios must be the same as those used for obtaining the count ratios for in-place material. The densities of materials used to establish the calibration must vary through a range to include the density of the in-place materials to be tested and be of an equivalent material.

A1.2 Calibration standards may be established using one of the following methods. The standards must be of sufficient size to not change the count rate if enlarged in any dimension. Access tubing used in the standards must be the same type and size as that to be used for in-place measurements.

A1.2.1 Prepare containers of soil and rock compacted to a range of densities. Place the material in the containers in lifts whose thickness depends upon the compaction equipment available. Each lift is to receive equal compactive effort. Calculate the density of each container of material based on the measured volume and mass (weight) of the material.

A1.2.2 Prepare containers of poured concrete using different aggregates and aggregate mixes to obtain a range of densities. Place the concrete in the containers in a way that will ensure a uniform mixture and uniform densities.

A1.2.3 Prepare containers of non-soil materials. Calculate the soil and rock equivalent density of each container of material based on the measured volume and mass (weight) of the material.

A1.3 *Field Calibrations*—When a check of laboratory calibration to field materials is required for a check of accuracy of calibration, the apparatus may be calibrated in the field by using the following methods.

A1.3.1 Obtain intact samples from each access hole over the measurement intervals to be tested. As the access hole is drilled, take intact samples from the soil or rock samples taken by any suitable drilling and sampling method appropriate for the material (see Practices D1452, D1587, and D2113, double tube or triple tube core samplers, piston samplers or double tube hollow (stem samplers) and determine the average tube density by trimming and measuring the mass and volume of the sample. At a minimum, obtain intact samples at 2 m intervals and at changes in strata. When sampling with a hand auger, determine the mass of soil recovered over given sample intervals and use the hole diameter for computation of sample volume.

A1.3.2 As soon as possible after the access tubing has been installed, take sufficient measurements at the desired depths in accordance with Section 9 and calculate the count ratio and density based upon laboratory calibrations. Take the test measurement counts at approximate depths that will correspond to the depth location of the intact samples.

A1.3.3 Report all sample data and anomalous data (such as voids, grout plugs, and changes in strata) obtained. The initial count profile and adjusted density data should be reported with later readings to review changes in density with subsequent readings.

A2. CALIBRATION ADJUSTMENTS

A2.1 Check the calibration response prior to performing tests on materials that are distinctly different from the material types used in establishing the calibration. The calibration response shall also be checked on newly acquired or repaired apparatus.

A2.2 Take sufficient measurements and compare them to other accepted methods such as volumetric sampling (see Test Method D2937) to establish a correlation between the apparatus calibration and the other method.

A2.2.1 Adjust the existing calibration to correct for the difference or establish a new calibration in accordance with Annex A1.

A3. PRECISION OF APPARATUS

A3.1 Gauge precision is defined as the change in measured density that occurs corresponding to a one standard deviation change in the count due to the random decay of the radioactive source. The density of the material and time period of the count must be stated. The precision of the apparatus on a sample of approximately 2000 kg/m^3 (125 lbm/ft^3) shall be better than 8 kg/m^3 (0.5 lbm/ft^3) at the manufacturer's stated period of time for the measurement. Other timing periods may be available that may be used where higher or lower precisions are desired for statistical purposes. The precision shall be determined by the procedure defined in A3.2 or A3.3.

A3.2 The precision of the apparatus is determined from the slope of the calibration response and the statistical deviation of the count (detected gamma radiation) for the period of measurement:

$$P = \sigma\sqrt{S} \quad \text{(A3.1)}$$

where:

P = apparatus precision in density (kg/m^3 or lbm/ft^3),
σ = standard deviation in counts per measurement period, and
S = slope of change in counts per measurement period at a density of 2000 kg/m^3 (125 lbm/ft^3) divided by the change in density (kg/m^3 or lbm/ft^3).

A3.2.1 The count per measurement period shall be the total number of gammas detected during the time period. The displayed value must be corrected for any prescaling which is built into the apparatus. The prescale value (*F*) is a divisor that reduces the actual value for the purpose of display. The manufacturer will supply this value if other than 1.0.

A3.2.2 The standard deviation in counts per measurement period shall be obtained by:

$$\sigma = \sqrt{C/F} \quad \text{(A3.2)}$$

where:

σ = standard deviation in counts per measurement period,
C = counts per measurement period (before prescale correction) at a density of 2000 kg/m^3 (125 lbm/ft^3), and
F = value of prescale (see A3.2.1).

A3.2.3 The counts per measurement period (before prescale correction) may be obtained from the calibration curve, tables, or equation by multiplying the count ratio by the instrument standard count.

A3.2.4 The slope of calibration response in counts per measurement period (before prescale correction) at a density of 2000 kg/m^3 (125 lbm/ft^3) shall be determined from the calibration curve, tables, or equation.

A3.3 Compute the precision by determining the standard deviation of at least 20 repetitive measurements (apparatus not moved after the first measurement) on material having a density of 1600 to 2400 kg/m^3 (100 to 150 lbm/ft^3). In order to perform this procedure, the resolution of the count display, calibration response, or other method of displaying density must be equal to or better than ±1 kg/m ^{3} (±0.1 lbm/ft^3).

SUMMARY OF CHANGES

Committee D18 has identified the location of selected changes to this standard since the last issue (D5195 – 08) that may impact the use of this standard. (Approved July 1, 2014.)

(1) Added "Units" before 1.4.
(2) Deleted 3.2.5 as this term is already defined in Terminology D653.
(3) Section 11, Report, now makes an indirect reference to D6026, has the proper title and instructions.
(4) Fixed circular term references in 3.2.2 and 3.2.3.
(5) Updated 3.1 to standard language.
(6) Used standard language in precision and bias statements.