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

This standard is issued under the fixed designation D 5195; 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.

1.2 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 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.

1.4 *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 6, "Hazards."

2. Referenced Documents

2.1 *ASTM Standards:*

D 1452 Practice for Soil Investigation and Sampling by Auger Borings[2,3]

D 1587 Practice for Thin Walled Tube Sampling of Soils[2]

D 2113 Practice for Diamond Core Drilling for Site Investigation[2]

D 2216 Method for Laboratory Determination of Water (Moisture) Content of Soil, Rock, and Soil-Aggregate Mixtures[2]

D 2922 Test Methods for Density of Soil and Soil-Aggregate In-Place by Nuclear Methods (Shallow Depth)[2]

D 2937 Test Method for Density of Soil In-Place by the Drive-Cylinder Method[2]

D 4428/D4428M Test Method for Crosshole Seismic Testing[2]

D 5220 Test Method for Water Content of Soil and Rock In-Place by Downhole Neutron Probe Method[4]

3. Significance and Use

3.1 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 D 2922.

3.2 With proper calibration in accordance with Annex A1, this test method can be used for quality control and acceptance testing for construction and for research and development applications.

3.3 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.

3.4 The fundamental assumptions inherent in this test method are that Compton scattering and photoelectric absorption are the dominant interactions of the gammas and the material under test.

4. Interferences

4.1 The chemical composition of the sample may effect 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 value.

4.2 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.

4.2.1 Voids around the access tube can affect the measurement (see 8.1.2.1).

4.3 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.

5. Apparatus (See Fig. 1)

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

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

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

5.1.3 *Suitable Timed Scaler and Power Source.*

5.2 *Cylindrical Probe*—The apparatus shall be equipped with a cylindrical probe, containing the gamma source and

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

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

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

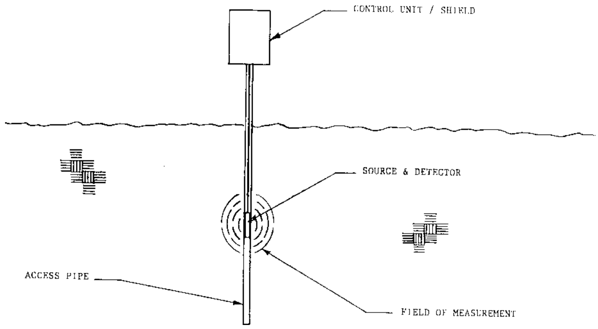

FIG. 1 Schematic Diagram: Depth Density by Nuclear Method

detector, connected by a cable of sufficient design and length, that is capable of being lowered down a cased hole to desired test depths.

5.3 *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.

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

5.5 *Accessories*:

5.5.1 *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.

5.5.2 *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 undisturbed 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.

6. Hazards

6.1 This equipment utilizes radioactive materials that may be hazardous to the health of the users unless proper precautions are taken. Users of this equipment must become completely familiar with possible safety hazards and with all applicable regulations concerning the handling and use of radioactive materials. Effective user instructions together with routine safety procedures are a recommended part of the operation of this apparatus.

7. Calibration, Standardization, and Reference Check

7.1 Calibrate the instrument in accordance with Annex A1.

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

7.3 *Standardization and Reference Check*:

7.3.1 Nuclear apparatus are subject to the long-term decay of the radioactive source and aging of detectors and electronic systems that may change the relationship between count rate and material density. To offset these changes, the apparatus may be calibrated as the ratio of the measured count rate to a count rate made on a reference standard. The reference count rate should be in the same or a higher order of magnitude than the range of measurement count rates over the useful density range of the apparatus.

7.3.2 Standardization of equipment should be performed at the start of each day's work, and a permanent record of these data retained. Perform the standardization with the apparatus located at least 10 m (30 ft) away from other apparatus containing radioactive sources and clear of large masses or other items which may affect the reference count rate.

7.3.2.1 If recommended by the apparatus manufacturer to provide more stable and consistent results: turn on the apparatus prior to use to allow it to stabilize, and leave the power on during the day's testing.

7.3.2.2 Using the reference standard, take at least four repetitive readings at the normal measurement period and determine the mean. If available on the apparatus, one measurement at a period of four or more times the normal period is acceptable. These measurements constitute one standardization check.

7.3.2.3 If the value obtained above is within the limits stated below, the apparatus is considered to be in satisfactory condition and the value may be used to determine the count ratios for the day of use. If the value is outside these limits, allow additional time for the apparatus to stabilize, make sure the area is clear of sources of interference and then conduct another standardization check. If the second standardization check is within the limits, the apparatus may be used, but if it also fails the test, the apparatus shall be adjusted or repaired as recommended by the manufacturer. The limits are as follows:

$$Ns \leq No + \frac{2.0\sqrt{No}}{\sqrt{F}} \tag{1}$$

and:

$$Ns \geq No - \frac{2.0\sqrt{No}}{\sqrt{F}}$$

where:

Ns = value of current standardization check,
No = average of the past four values of Ns taken previously, and
F = value of prescale (see A3.2.1).

7.3.3 If the apparatus standardization has not been checked within the previous three months, perform at least four new standardization checks and use the mean as the value for No.

7.3.4 Use the value of Ns to determine the count ratios for the current day's use of the apparatus. If for any reason the measured density becomes suspect during the day's use, perform another standardization check.

8. Procedure

8.1 *Installation of Access Tubing (Casing)*:

8.1.1 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.

8.1.2 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.

8.1.2.1 If voids are suspected to be caused by the drilling process they can be grouted using the procedures in Test Method D 4428. The only method to determine the presence of voids is to perform field calibrations provided in A1.3.

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

8.1.3.1 If ground water is encountered or saturated conditions are expected to develop, seal the tube using procedures given in Test Method D 4428 at the bottom to prevent water seepage into the tube. This will prevent erroneous readings and possible damage to the probe.

8.1.4 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.

8.1.4.1 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.

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

8.3 Standardize the apparatus.

8.4 Proceed with the test as follows:

8.4.1 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).

8.4.2 Take a measurement count at the selected timing period.

NOTE 1—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.

9. Calculation

9.1 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 2—Some instruments have built-in provisions to compute and display the ratio and corrected bulk or wet density per unit volume.

9.1.1 If the dry density is required determine the in-place water content using either gravimetric samples and laboratory determination of water content (see Method D 2216), or the same apparatus or a different apparatus which determines water content by the neutron probe method (Method D 5220). The dry density is calculated by either of the following equations:

$$pd = \frac{pw}{1 + M/100} \tag{2}$$

or:

$$pd = pw - Mm$$

where:

pd = dry density in kg/m^3 (lbf/ft^3),
pw = wet density in kg/m^3 (lbf/ft^3),
Mm = water density in kg/m^3 (lbf/ft^3) from apparatus, and
M = water as a percent of the dry density from lab.

10. Report

10.1 Report the following information:

10.1.1 Make, model, and serial number of the apparatus,

10.1.2 Date of calibration,

10.1.3 Method of calibration, such as field, factory, etc.

10.1.4 Calibration adjustments,

10.1.5 Date of test,

10.1.6 Standard count for the day of the test,

10.1.7 Any adjustment data for the day of the test,

10.1.8 Test site identification including; tube location(s) and tube number(s),

10.1.9 Tube type and tube installation methods (methods of drilling, installing and any initial gravimetric and count data),

10.1.10 Geologic log of the borehole, and

10.1.11 Depth, measurement count data, and calculated density of each measurement.

11. Precision and Bias

11.1 *Precision*—The precision of this test method has not been determined. While the apparatus precision (repeatability of the same sample) can be defined (see Annex A3), no data are presently available to determine true test precision.

11.2 *Bias*—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.

12. Keywords

12.1 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 undisturbed samples from each access hole over the measurement intervals to be tested. As the access hole is drilled, take undisturbed samples from the soil or rock samples taken by any suitable drilling and sampling method appropriate for the material (see Practices D 1452, D 1587, and D 2113, 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 undisturbed 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 8 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 undisturbed 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 D 2937) 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 The precision of the apparatus on a sample of approximately 2000 kg/m^3 (125 lbf/ft^3) shall be better than 8 kg/m^3 (0.5 lbf/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 lbf/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 lbf/ft^3) divided by the change in density (kg/m^3 or lbf/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 lbf/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 lbf/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 lbf/ft^3). In order to perform this procedure, the resolution of the count display, calibration response, or other method of displaying water content must be equal to or better than ± 1 kg/m^3 (± 0.1 lbf/ft^3).