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Standard Test Method for Logging In Situ Moisture Content and Density of Soil and Rock by the Nuclear Method in Horizontal, Slanted, and Vertical Access Tubes[1]

This standard is issued under the fixed designation D6031/D6031M; 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~~ Scope*

1.1 This test method covers collection and comparison of logs of thermalized-neutron counts and back-scattered gamma counts along horizontal or vertical air-filled access tubes.

1.2 For limitations, see Section 6, "Interferences."

1.3 The in situ water content in mass per unit volume and the density in mass per unit volume of soil and rock at positions or in intervals along the length of an access tube are calculated by comparing the thermal neutron count rate and gamma count rates respectively to previously established calibration data.

1.4 *Units*—The values stated in either ~~inch-pound~~SI units or ~~SI units [presented in brackets]~~ inch-pound units are to be regarded separately as standard. The values stated in each system ~~may not be~~are not necessarily exact equivalents; therefore, to ensure conformance with the standard, each system shall be used independently of the ~~other. Combining~~other, and values from the two systems ~~may result in non-conformance with the standard.~~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

1.4.1 ~~The gravitational system of inch-pound units is used when dealing with inch-pound units. In this system, the pound (lbf) represents a unit of force (weight), while the unit for mass is slugs. The rationalized slug unit is not given, unless dynamic (F = ma) calculations are involved.~~Reporting the test results in units other than SI shall not be regarded as nonconformance with the standard.

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] This test method is under the jurisdiction of ASTM Committee D18 on Soil and Rock and is the direct responsibility of Subcommittee D18.21 on Groundwater and Vadose Zone Investigations.

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

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~~safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.* For specific hazards, see Section ~~6~~8.

1.7 *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~~D1452/D1452M Practice for Soil Exploration and Sampling by Auger Borings
~~D1586~~D1586/D1586M Test Method for Standard Penetration Test (SPT) and Split-Barrel Sampling of Soils
~~D1587~~D1587/D1587M Practice for Thin-Walled Tube Sampling of Fine-Grained Soils for Geotechnical Purposes (Withdrawn 2024)[3]
D2113 Practice for Rock Core Drilling and Sampling of Rock for Site Exploration (Withdrawn 2023)[3]
D2216 Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass
~~D2922 Test Methods for Density of Soil and Soil-Aggregate in Place by Nuclear Methods (Shallow Depth) (Withdrawn 2007)~~[3]
D2937 Test Method for Density of Soil in Place by the Drive-Cylinder Method
~~D3017 Test Method for Water Content of Soil and Rock in Place by Nuclear Methods (Shallow Depth)~~
~~D3550~~D3550/D3550M Practice for Thick Wall, Ring-Lined, Split Barrel, Drive Sampling of Soils
D4428/D4428M Test Methods for Crosshole Seismic Testing (Withdrawn 2023)[3]
D4564 Test Method for Density and Unit Weight of Soil in Place by the Sleeve Method (Withdrawn 2013)[3]
D5195 Test Method for Density of Soil and Rock In-Place at Depths Below Surface by Nuclear Methods
~~D5220~~D5220/D5220M 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 and Data Records in Geotechnical Data

3. Terminology

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

4. Summary of the Test Method

4.1 The test method is as follows:

4.1.1 A horizontal, slanted, or 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 installed in the hole, with any soil or rock falling back into the hole removed.

4.1.3 The probe containing the source(s) and detector(s) 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 repeatable, nondestructive technique to monitor in-place density and moisture of soil and rock along lengthy sections of horizontal, slanted, and vertical access holes or tubes. With proper calibration in accordance with Annex A1, this test method can be used to quantify changes in density and moisture content of soil and rock.

5.2 This test method is used in vadose zone monitoring, for performance assessment of engineered barriers at waste facilities, and for research related to monitoring the movement of liquids (water solutions and hydrocarbons) through soil and rock. The nondestructive nature of the test allows repetitive measurements at a site and statistical analysis of results.

[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] The last approved version of this historical standard is referenced on www.astm.org.

5.3 The fundamental assumptions inherent in the density measurement portion of this test method are that the dry bulk density of the test material is constant and that the response to fast neutrons and gammaray energy associated with soil and liquid chemistry is constant.Compton scattering and photoelectric absorption are the dominant interactions of the gamma rays with the material under test.

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

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

5.5.1 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.

5.5.2 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.

5.5.3 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.

5.6 The fundamental assumption inherent in the moisture measurement portion of this test is that the hydrogen contained in the water molecules within the soil and rock is the dominant neutron thermalizing media, so increased water content of the soil and rock results in higher count rates of the moisture content system of the instrument.

6. Interferences

6.1 The sample heterogeneity and chemicalelemental composition of the material under test willmay affect the measurement of both moisture and density. water content, density, or both. The apparatus should be calibrated to the material under test at a similar density of dry soil or rock and in the similar type and orientation of access tube, or adjustments must be made in accordance with Annex A2.

6.2 Hydrogen, in forms other than water, as defined by Test Method D2216, will cause measurements in excess of the true moisture content. Some elements such as boron, chlorine, and minute quantities of cadmium, if present in the material under test, will cause measurements lower than the true moisture content. 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.

6.3 The measurement of moisture and density using this test method exhibits spatial bias in that it is more sensitive to the material closest to the access tube. The density and moisture measurements are necessarily an average of the total sample involved.

6.4 The sample volume for a moisture measurement is approximately 3.8 ft0.11 m^3 [0.11 m[3.8 ft^3] at a moisture content of 12.5 lbf/ftwater mass per unit volume of 200 kg/m^3 [200 kg/m[12.5 lbm/ft^3]. The actual sample volume for moisture is indeterminate and varies with the apparatus and the moisture content of the material. In general the greater the moisture content of the material, the smaller the measurement volume.

6.5 A density measurement has a sample volume of approximately 0.8 ft0.003 m^3 [0.028 m[0.8 ft^3]. The actual sample volume for density is indeterminate and varies with the apparatus and the density of the material. In general, the greater the density of the material, the smaller the measurement volume.

6.6 Air gaps between the probe and the access tube or voids around the access tube willmay cause the indicated moisture content and density to be less than the calibrated values.

6.7 Condensed moisture inside the access tube may cause the indicated moisture content to be greater than the true moisture content of material outside the access tube.

7. Apparatus

7.1 While exact details of construction of the apparatus may vary, the system shall consist of:

7.1.1 *Fast Neutron Source*—A sealed mixture of a radioactive material such as americium or radium and a target material such as beryllium, or other fast neutron sources such as californium that do not require a target.

7.1.2 *Slow Neutron Detector*—Any type of slow neutron detector, such as boron trifluoride or helium-3 proportional counters.

7.1.3 *High-Energy Gamma-Radiation Source*—A sealed source of radioactive material, such as cesium-137, cobalt-60, or radium-226.

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

7.1.5 *Suitable Readout ~~Device:~~Device.*

7.1.6 *Cylindrical Probe*—The apparatus shall be equipped with a cylindrical probe, containing the neutron and gamma sources and the detectors, connected by a cable or cables of sufficient design and length, that are capable of raising and lowering the probe in vertical applications and pulling it in horizontal applications, to the desired measurement location.

7.1.7 *Reference Standard*—A device containing dense, hydrogenous material for checking equipment operation and to establish conditions for a reproducible reference count rate. It also may serve as a radiation shield.

7.2 Accessories shall include:

7.2.1 *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 plastic, 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.

7.2.2 *Hand Auger or Power Drilling/Trenching Equipment*—Equipment that can be used to establish the access hole or position the access tube when required (see ~~5.2.1~~10.1.1). Any 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 a constant diameter per width shall be acceptable. The type of equipment and methods of advancing the access hole ~~should~~shall be reported.

7.2.3 *Winching Equipment or Other Motive Devices*—Equipment that can be used to move the probe through the access tubing. The type of such equipment is dependent upon the orientation of the access tubing and the distance over which the probe must be moved.

8. Hazards

8.1 ~~Warning~~This~~—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 all 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.~~

8.2 Effective user instructions together with routine safety procedures are a recommended part of the operation of this apparatus.

8.3 ~~Warning~~When~~—When~~ using winching or other motive equipment, the user ~~should~~shall take additional care to learn its proper use in conjunction with measurement apparatus. Known safety hazards such as cutting and pinching exist when using such equipment.

8.4 This test method does not cover all safety precautions. It is the responsibility of the users to familiarize themselves with all safety precautions.

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.

~~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 either the material density or the moisture content of the material, or both. To correct for these changes, the apparatus may be calibrated periodically. To minimize error, moisture and density measurements commonly are reported as count ratios, the ratio of the measured count rate to a count rate made in a reference standard. The reference count rate should be similar or higher than the count rates over the useful measurement range of the apparatus.~~

~~7.3.2 Standardization of equipment on the reference standard is required at the start of each day's use and a permanent record of these data shall be retained. The standardization shall be performed with the equipment located at least 33 ft [10 m] away from other radioactive sources and large masses or other items that may affect the reference count rate.~~

~~7.3.3 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.~~

~~7.3.4 Using the reference standard, take at least four repetitive readings at the manufacturer's recommended measurement period of 20 or more at some shorter period and obtain the mean. If available on the instrument, one measurement at a period of four or more times the normal test measurement period is acceptable. This constitutes one standardization check.~~

~~7.3.5 If the value obtained in 7.3.4 is within the following limits, the equipment 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 obtained is outside these limits, another standardization check should be made. If the second standardization check is within the limits, the equipment may be used. If it also fails the test, however, the equipment shall be adjusted or repaired as recommended by the manufacturer.~~

$$No+2F\sqrt{\frac{No}{F}}>Ns>No-2F\sqrt{\frac{No}{F}}$$

~~where:~~

~~*Ns* = value of current standardization check (7.3.4) on the reference standard,~~
~~*No* = average of the past values of *Ns* taken for prior usage, and~~
~~*F* = value of prescale, a multiplier that alters the count value for the purpose of display (see A3.1.1.1).~~

~~7.3.6 If the apparatus standardization has not been checked within the previous three months, perform at lest four new standardization checks and use the mean as the value for *No*.~~

~~7.3.7 The value of *Ns* will be used to determine the count ratios for the current day's use of the equipment. If, for any reason, either the measured density or moisture content become suspect during the day's use, perform another standardization to ensure that the equipment is stable.~~

10. Procedure

10.1 *Installation of Access Tubing (Casing):*

10.1.1 Drill the access hole or excavate a trench at the desired location and install the access tube in a manner to maximize contact with test material and minimize voids. The access tubes ~~should~~shall fit snugly into the access hole or trench. Unstable conditions in fill material around the access tube may result in redistribution of solids over time, piping, or other phenomena that will degrade precision. Voids caused during drilling, tube installation, or backfilling, or a combination thereof, may cause erroneously low results. Excessive compaction of clay-rich backfill material will limit the effectiveness of moisture monitoring for leak detection. ~~Backfill should approximate~~ Select backfill that approximates the composition, water content, and bulk density of test material as nearly as possible.

10.1.2 Grouting of annular spaces, if required, ~~should~~shall be of minimum functional thickness, and grout mixtures ~~should~~shall not contain excessive water. Grouts thicker than ~~2 in. [5 cm]~~5 cm [2 in.] create high background counts that will obscure moisture content changes in fine-textured soils and severely limit meaningful density measurements in all soil types. ~~Grouting should not be used~~Do not use grout unless it is required to seal off flow pathways along the access tube, such as in some vertical borings and where trenches cross engineered barriers. Grouting can be accomplished using procedures described in Test Methods D4428/D4428M.

10.1.3 Record and note the position of the groundwater table, perched water tables, and changes in soil texture as drilling or trenching progresses.

10.1.4 If groundwater is encountered or saturated conditions are expected to develop, seal the tube at seams and open ends to prevent water seepage into the tube. This will prevent erroneous measurements and possible damage to the probe.

10.1.5 The access tube ~~should~~shall project above the ground and be capped to prevent foreign material from entering. The access tube ~~should~~shall not project out of the test material far enough to be damaged by equipment traffic.

10.2 Pass a dummy probe through the access tube to verify proper clearance before deploying the radioactive sources.

10.3 Standardize the apparatus (see ~~7.3~~Annex A4).

10.4 Proceed with the test run in a continuous logging mode or in a noncontinuous logging mode as follows:

10.4.1 Set up the winching equipment or other motive devices (see ~~5.2.3~~7.2.3) to begin a logging run by stationing the probe at one end of the access tube to be logged.

10.4.2 Select a timing period for collecting measurement counts based on desired precision (see Annex A3), anticipated measurement response, or site-specific logistical criteria.

10.4.3 For testing in continuous logging mode, advance the probe continuously through the access tube while recording data that relate gamma ray counts and thermal neutron counts to position intervals or time (for constant logging speed), or both.

10.4.4 For testing in noncontinuous logging mode, advance the probe through the access tube to the desired position and stop, record counts while probe is stationary, advance the probe to the next desired position, and repeat. Record data relating gamma counts and thermal neutron counts to discrete positions along the access tube.

11. Calculation

11.1 Calculations related to reporting density as calibrated units are provided in Test Method D5195. For moisture content, these same calculations are provided in Test Method ~~D3017~~D5220/D5220M.

11.2 Data can be used in a comparative mode, as in graphs or charts. For example, measurements from repeated logging events can be compared directly at each position (or interval) and analyzed to detect statistically significant changes from background.

11.2.1 For data reported as uncalibrated ~~counts,~~ counts that have not been prescaled (see A3.1.2.2), the accepted estimator of the standard deviation of a population of nuclear count measurements is equal to the square root of the mean.[4] Standard deviation estimated from more than one background measurement at any given position (or over any specific interval) can be used to define tolerance levels. The tolerance level defines a threshold neutron count above which there is a defined probability that the count is higher than background.

12. ~~Report~~Report: Test Data Sheet(s)/Form(s)

12.1 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 and Practice D6026.

[4] Kramer, J. H., Everett, L. G., and Cullen, S. J., 1992. "Vadose Zone Monitoring with Neutron Moisture Probe," *Ground Water Monitoring Review*, Vol 12, No. 2, 1992, pp. 177–187.