Designation: D5220/D5220M – 21

Standard Test Method for Water Mass per Unit Volume of Soil and Rock In-Place by the Neutron Depth Probe Method[1]

This standard is issued under the fixed designation D5220/D5220M; 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 measurement of the water mass per unit volume of soil and rock by thermalization or slowing of fast neutrons, where the neutron source and the thermal neutron detector are placed at the desired depth in the bored hole lined by an access tube.

1.1.1 For limitations see Section 6 on Interferences.

1.2 The water mass per unit volume, expressed as mass per unit volume of the material under test, is determined by comparing the thermal neutron count rate with previously established calibration data (see Annex A1).

1.3 *Units*—The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in 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 of 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 guidelines 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 hazards are given in Section 8.

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 Practice for Soil Exploration and Sampling by Auger Borings
D1586 Test Method for Standard Penetration Test (SPT) and Split-Barrel Sampling of Soils
D1587 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
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
D5195 Test Method for Density of Soil and Rock In-Place at Depths Below Surface by Nuclear Methods
D6026 Practice for Using Significant Digits in Geotechnical Data

[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.

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

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 *neutron probe*—a cylindrical device containing a fast neutron source and a thermal neutron detector.

4. Summary of Test Method

4.1 This test method uses thermalization of neutron radiation to determine the in-place water mass per unit volume of soil and rock at various depths by placing a probe containing a neutron source and a thermal neutron detector at desired depths in a bored hole lined by an access tube as opposed to surface measurements in accordance with Test Method D6938.

4.2 Neutrons emitted by the source are thermalized (slowed) by collisions with materials of low atomic numbers. Hydrogenous materials, such as water and other compounds containing hydrogen, are most effective in thermalizing neutrons. In this apparatus the neutrons thermalized by the material under test are detected by the thermal neutron detector.

4.3 In the absence of interference elements as discussed in Section 6, the number of thermalized neutrons is a function of the hydrogen content of the material under test and the water content is proportional to the hydrogen content.

4.4 By the use of a calibration process the water mass per unit volume is determined by correlating the count rate to known water mass per unit volume values.

5. Significance and Use

5.1 This test method is useful as a rapid, nondestructive technique for the measurement of the in-place water mass per unit volume of soil and rock at desired depths below the surface.

5.2 This test method is useful for informational and research purposes. The information acquired from this test method is best used for quality control and acceptance testing when correlated to actual water mass per unit volume using procedures and methods described in A1.2.3.

5.3 The non-destructive nature of this 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 the material under test is homogeneous and hydrogen present is in the form of water as defined by Test Method D2216.

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 standard 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 sample heterogeneity, density, and chemical composition of the material under test will affect the measurements. The apparatus must be calibrated to the material under test or adjustments made in accordance with Annex A2.

6.1.1 Hydrogen, in forms other than water, as defined by Test Method D6938 and carbon, present in organic soils, will cause measurements in excess of the true water value. 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 water value.

6.2 This test method exhibits spatial bias in that it is more sensitive to water contained in the material closest to the access tube. The measurement is not necessarily an average water content of the total sample involved.

6.2.1 Voids around the access tube can affect the measurement (see 10.1.2).

6.3 The actual sample volume that the instrument measures is indeterminate and varies with the apparatus and the water content of the material. In general, the greater the water content of the material, the smaller the volume involved in the measurement. For example, the sample volume is approximately 0.048 m^3 [1.7 ft^3] for a soil with a water content of 200 kg/m^3 [12.5 lbm/ft^3].

7. Apparatus (See Fig. 1)

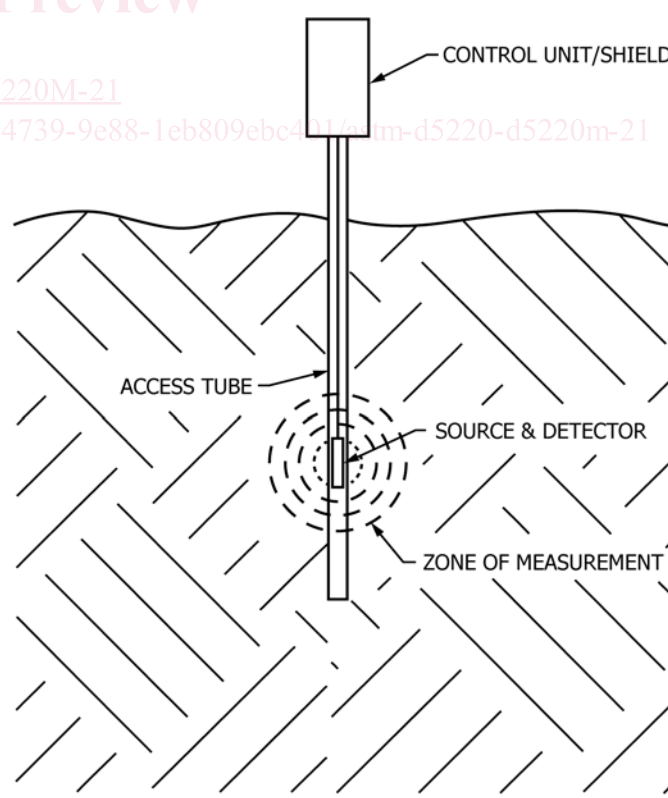

FIG. 1 Schematic Diagram; Water Content by Neutron Depth Probe Method

7.1 The apparatus shall consist of a nuclear instrument capable of measuring water mass per unit volume at various depths below the surface containing the following:

7.1.1 A sealed mixture of a radioactive material such as americium or radium with a target element such as beryllium, and a suitable thermal neutron detector, and

7.1.2 A suitable timed scaler and power source.

7.2 The apparatus shall be equipped with a cylindrical probe containing the neutron source and detector, connected by a cable of sufficient design and length, that is capable of being lowered down the 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 75 mm [3 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 The apparatus shall be equipped with a reference standard, a fixed shape of hydrogenous 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, the tubing shall be of a material such as aluminum, steel, or polyvinyl chloride, having an interior diameter large enough to permit probe access without binding. The tubing shall be as thin-walled as possible to provide close proximity of the probe to the material under test. The same type of tubing shall be used in the field as is used in calibration.

7.5.2 *Drilling Tool(s)*—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 shall be acceptable. The equipment used shall be capable of maintaining constant borehole diameter to ensure that the measurements are performed on undisturbed soil and rock. The type of equipment and methods of advancing the access hole shall be reported.

7.5.3 *Dummy Probe*—A cylindrical probe the same size as the probe containing the neutron source and a chain or cable of sufficient design and length to permit lowering the dummy probe down the cased hole to desired test depths.

8. Hazards

8.1 These instruments utilize radioactive materials that may be hazardous to the health of the users unless proper precautions are taken. Users of these instruments must 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, are a mandatory part of the operation and storage of these 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 Perform and evaluate standardization and reference check on a daily basis, prior to taking field measurements, in accordance with Annex A4.

10. Procedure

10.1 *Installation of Access Tubing (Casing):*

10.1.1 Drill the access tube hole and install the access tubing 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 shall be clear enough to allow installing the tubing while still providing a snug fit. Voids along the sides of the tubing may cause erroneous readings.

10.1.2.1 If voids are suspected to be caused by the drilling process they may be grouted using procedures in Test Method D4428/D4428M.

10.1.2.2 The only method to determine the presence of voids is to perform field calibrations provided in A1.2.3.

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 at the bottom to prevent water seepage into the tube using procedures given in Test Method D4428/D4428M or the manufacturer's recommended procedures. This will prevent erroneous readings and possible damage to the probe.

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

10.1.4.1 Install all tubes at the same height above the 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.

10.3 Standardize the apparatus (see Annex A4).

10.4 Proceed with the test as follows:

10.4.1 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).

10.4.2 Take a measurement count at the selected timing period.

10.4.3 If the water content as a percentage of dry density is required, the in-place density may be determined by using a different apparatus that determines density at depths below the surface by the nuclear method. Such methods include, but are not limited to, Test Method D5195, Test Method D2937 (depths not more than 1 m [3 ft]), or Test Method D1587 (fine-grained soils only.)

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 1.3 through 1.5 and in Practice D6026.

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 Date of calibration,

11.2.3 Name of operator/test technician,

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(s) 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), tube number(s),

11.2.10 Tube type and tube installation methods (method 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 water mass per unit volume of each measurement.

12. Precision and Bias

12.1 *Precision*—It is not possible to specify the precision of the procedure in Test Method D5220/D5220M for measuring water mass per unit volume of soil and rock in-place at depths below the surface by nuclear method because it is not feasible and too costly at this time to have ten or more agencies participate in an in situ testing program at a given site.

12.1.1 Subcommittee D18.08 is seeking any data from the users of this test method that might be used to make a limited statement on precision.

12.2 *Bias*—No information can be presented on the bias of the procedure in Test Method D5220/D5220M for measuring water mass per unit volume of soil and rock in-place at depths below the surface by nuclear method because it is not feasible and too costly at this time to have ten or more agencies participate in an in situ testing program at a given site.

13. Keywords

13.1 depth probe; in-place water content; in situ water content; neutron probe; nuclear methods; water mass per unit volume

ANNEXES

(Mandatory Information)

A1. CALIBRATION

A1.1 At least once each year, establish or verify calibration curves, tables, or equations by determining the count rate of at least three samples of different known water mass per unit volume. These 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 water mass per unit volume. 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 water mass per unit volume of materials used to establish the calibration must vary through a range to include the water mass per unit volume of materials to be tested and be of a similar density.

A1.2 Calibration standards may be established using one of the following methods. The standards must be verified to 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 homogeneous standards of hydrogenous materials having a water mass per unit volume determined by comparison (using a nuclear instrument) to a saturated silica sand standard with a known water mass per unit volume. As an alternate, determine the equivalent water mass per unit volume by calculation if the hydrogen, carbon, and oxygen content is known or can be calculated from the specific gravity and chemical composition. A zero water content standard can be prepared by using a non-hydrogenous material, such as magnesium, as the standard.

A1.2.2 Prepare containers of soil and rock compacted to uniform densities with a range of water mass per unit volumes. Determine the percent water content of the materials by oven drying (see Test Method D2216) and a wet density determined from the mass of the material and the inside dimensions of the container. Whenever possible, use soil and rock obtained from the test site for this calibration.

A1.2.3 Where neither of the previous calibration standards are available or a higher accuracy of calibration is required, the apparatus may be calibrated in the field by using the following methods:

A1.2.3.1 Using a minimum of three selected test sites containing a homogeneous material with as wide a range of water mass per unit volumes as possible among the selected sites, obtain intact specimens from each access hold over the measurement intervals to be tested. As the access hole is drilled, take intact specimens 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)).

A1.2.3.2 Determine the specimen wet density by trimming and measuring the mass and volume of the specimen. At a minimum, obtain intact specimens at 2 m [79 in.] intervals and at changes in strata. When sampling with a hand auger, determine the mass of the soil recovered over given sampling intervals and use the hole diameter for computation of the specimen volume.

A1.2.3.3 Determine the percent water content by oven drying the specimens (see Test Method D2216). Note the sampling intervals for the intact sample(s). (See Note A1.1.)

NOTE A1.1—For agricultural purposes it is highly practical to obtain the intact sample(s) (see Practice D1452) above the water table in shallow installations. The intact sample(s) will represent a mixture of materials over the interval samples. For a higher level of calibration accuracy it is recommended to obtain samples directly in the measurement interval by other referenced methods such as Test Method D7263.

A1.2.3.4 Calculate the water mass per unit volume of the specimen using Eq A1.1:

$$\rho_{wm} = \frac{\rho \times w}{100 + w} \qquad (A1.1)$$

where:

ρ_{wm} = water mass per unit volume, kg/m^3 [lbm/ft^3],
w = water content, percent of dry mass, and
ρ = in-place (wet) density, kg/m^3 [lbm/ft^3].

A1.2.3.5 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 water mass per unit volume based upon laboratory determinations.

A1.2.3.6 Take the test measurement counts at approximate depths that will correspond to the depth location of the intact samples.

A1.2.4 Record all sample data and any anomalous values, such as voids, grout plugs, changes in strata, or perched water layers. The initial count profile and adjusted water mass per unit volume data shall be reported with later readings to review changes in water mass per unit volume 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. Also check the calibration response on newly acquired or repaired apparatus.

A2.2 Take sufficient measurements and compare them to samples obtained by other accepted methods such as a 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.

NOTE A2.1—Some apparatus utilizing a microprocessor may have provision to input a correction factor that is established by determining the correlation between the apparatus measurement and oven drying (see Test Method D2216).

A3. PRECISION OF THE APPARATUS

A3.1 Instrument precision is defined as the change in measured water mass per unit volume that occurs corresponding to a one standard deviation change in the count due to the random decay of the radioactive source. The water mass per unit volume of the material and time period of the count must be stated. The precision of the apparatus at a water mass per unit volume of 200 kg/m^3 (12.5 lbm/ft^3) shall be better than 5 kg/m^3 (0.3 lbm/ft^3) at the manufacturer's stated period of time for the measurement (see Note A3.1). 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.

NOTE A3.1—While 30 s is the usual timing period and may be used for comparison of various apparatus, the intent of this test method is to require a measurement period that produces the stated precision for all acceptance testing.

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

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

where:

P = apparatus precision in water mass per unit volume (kg/m^3 or lbm/ft^3),
σ = standard deviation in counts per measurement period, and