Designation: D8167/D8167M – 23$^{\varepsilon 1}$

Standard Test Method for In-Place Bulk Density of Soil and Soil-Aggregate by a Low-Activity Nuclear Method (Shallow Depth)[1]

This standard is issued under the fixed designation D8167/D8167M; 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.

ε^1 NOTE—Minor editorial correction was made in May 2023.

1. Scope*

1.1 This test method describes the procedures for measuring in-place bulk density of soil and soil-aggregate using nuclear equipment with radioactive sources (hereafter referred to simply as "gauges"). These gauges are distinct from those described in Test Method D6938 insofar as:

1.1.1 These gauges do not contain a system (nuclear or otherwise) for the determination of the water content of the material under measurement.

1.1.2 These gauges have photon yields sufficiently low as to require the inclusion of background radiation effects on the response during normal operation.

1.1.2.1 For the devices described in Test Method D6938, the contribution of gamma rays detected from the naturally-occurring radioisotopes in most soils (hereafter referred to as "background") compared to the contribution of gamma rays used by the device to measure in-place bulk density is typically small enough to be negligible in terms of their effect on measurement accuracy. However, for these low-activity gauges, the gamma ray yield from the gauge is low enough that the background contribution from most soils compared to the contribution of gamma rays from the gauge is no longer negligible, and changes in this background can adversely affect the accuracy of the bulk density reading.

1.1.2.2 In order to compensate for potentially differing background contribution to low-activity gauge measurements at different test sites, a background reading must be taken in conjunction with gauge measurements obtained at a given test site. This background reading is utilized in the bulk density calculation performed by the gauge with the goal of minimizing these background effects on the density measurement accuracy.

1.2 For limitations see Section 5 on Interferences.

1.3 The bulk density of soil and soil-aggregate is measured by the attenuation of gamma radiation where the source is placed at a known depth up to 300 mm [12 in.] and the detector(s) remains on the surface (some gauges may reverse this orientation).

1.3.1 The bulk density of the test sample in mass per unit volume is calculated by comparing the detected rate of gamma radiation with previously established calibration data.

1.3.2 Neither the dry density nor the water content of the test sample is measured by this device. However, the results of this test can be used with the water content or water mass per unit volume value determined by alternative methods to determine the dry density of the test sample.

1.4 The gauge is calibrated to read the bulk density of soil or soil-aggregate.

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

1.5.1 For purposes of comparing, a measured or calculated value(s) with specified limits, the measured or calculated value(s) shall be rounded to the nearest decimal or significant digits in the specified limits.

1.5.2 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 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 *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 may not be exact equivalents;

[1] This test method is under the jurisdiction of ASTM Committee D18 on Soil and Rock and is the direct responsibility of Subcommittee D18.08 on Special and Construction Control Tests.

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*A Summary of Changes section appears at the end of this standard therefore, each system shall be used independently of the other. Combining values from the two systems may result in nonconformance with the standard. Reporting test results in units other than SI shall not be regarded as nonconformance with this standard.

1.7 *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.*

NOTE 1—Nuclear density gauge manuals and reference materials, as well as the gauge displays themselves, typically refer to bulk density as "wet density" or "WD."

NOTE 2—The term "bulk density" is used throughout this standard. This term has different definitions in Terminology D653, depending on the context of its use. For this standard, however, "bulk density" refers to, as defined in Terminology D653, "the total mass of partially saturated or saturated soil or rock per unit total volume."

1.8 *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

D698 Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (12,400 ft-lbf/ft^3 (600 kN-m/m^3))

D1557 Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort (56,000 ft-lbf/ft^3 (2,700 kN-m/m^3))

D2216 Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass

D2487 Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)

D2488 Practice for Description and Identification of Soils (Visual-Manual Procedures)

D3740 Practice for Minimum Requirements for Agencies Engaged in Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction

D4253 Test Methods for Maximum Index Density and Unit Weight of Soils Using a Vibratory Table

D4254 Test Methods for Minimum Index Density and Unit Weight of Soils and Calculation of Relative Density

D4643 Test Method for Determination of Water Content of Soil and Rock by Microwave Oven Heating

D4718/D4718M Practice for Correction of Unit Weight and Water Content for Soils Containing Oversize Particles

D4944 Test Method for Field Determination of Water (Moisture) Content of Soil by the Calcium Carbide Gas Pressure Tester

D4959 Test Method for Determination of Water Content of Soil By Direct Heating

D6026 Practice for Using Significant Digits and Data Records in Geotechnical Data

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

D7013/D7013M Guide for Calibration Facility Setup for Nuclear Surface Gauges

D7382 Test Methods for Determination of Maximum Dry Unit Weight of Granular Soils Using a Vibrating Hammer

D7759/D7759M Guide for Nuclear Surface Moisture and Density Gauge Calibration

E177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods

E691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method

3. Terminology

3.1 *Definitions:*

3.1.1 For definitions of common technical terms used in this standard, refer to Terminology D653.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *nuclear gauge, n*—a device containing one or more radioactive sources used to measure certain properties of soil and soil-aggregates.

3.2.2 *probe, n*—aslender, elongated device, part of the gauge, that is inserted into the soil being measured by the gauge. This device may contain either a radioactive source, a radiation detection device, or both. Probes containing only a radioactive source are commonly referred to as "source rods."

3.2.3 *test count, n*—the measured output of a detector for a specific type of radiation for a given test.

3.2.4 *standardization count, n*—the measured output of a detector taken for the purposes of evaluating gauge stability and accounting for long-term aging of the radioactive sources. This output is frequently referred to as the "standard count" as well.

3.2.5 *background count, n*—the counts measured by the gauge to evaluate the ambient radiation in the proximity where a test measurement is to be taken rather than the radiation emitted by the gauge itself.

3.2.6 *background position, n*—the orientation of the gauge source rod when the background count is acquired.

4. Significance and Use

4.1 The test method described is useful as a rapid, nondestructive technique for in-place measurements of bulk density of soil and soil-aggregate. Test results may be used for the determination of dry density if the water content of the soil or soil-aggregate is determined by separate means, such as those methods described in Test Methods D2216, D4643, D4944, and D4959.

4.2 The test method is used for quality control and acceptance testing of compacted soil and soil-aggregate mixtures as

[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.

used in construction and also for research and development. The nondestructive nature allows repetitive measurements at a single test location and statistical analysis of the results.

4.3 *Density*—The fundamental assumptions inherent in the method is that Compton scattering is the dominant interaction and that the material is homogeneous.

NOTE 3—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.

5. Interferences

5.1 *In-Place Density Interferences:*

5.1.1 Measurements may be affected by the chemical composition of the material being tested.

5.1.2 Measurements may be affected by non-homogeneous soils and surface texture (see 10.2). Excessive voids in the prepared test surface beneath the gauge can cause density measurements that are lower than the actual soil density. Excessive use of fill material to compensate for these voids may likewise cause biased density measurements.

5.1.3 The measurement volume of the gauge in a given probe orientation extends from near the tip of the probe (which can be placed at a known depth up to 300 mm [12 in.]) to the detector at the surface of the in situ material under measurement. This volume is similar to that described by the volume bounded by an elliptic paraboloid surface. This volume varies for different depths of the probe within the material under measurement. Large particles near the probe tip may also distort the volume of measurement of the gauge.

5.1.4 Gravel particles or large voids in the source-detector path may cause higher or lower density measurements. Where lack of uniformity in the soil due to layering, aggregate or voids is suspected, the test site should be excavated and visually examined to determine whether the test material is representative of the in situ material in general and whether an oversize correction is required in accordance with Practice D4718/D4718M.

5.1.5 The measured volume is approximately 0.0057 m^3 [0.20 ft^3] when the test depth is 150 mm [6 in.]. The actual measured volume is indeterminate and varies with the apparatus and the density of the material.

5.1.6 Perform gauge measurements with the gauge far enough away from other apparatus containing radioactive sources to prevent interference due to radiation from the other apparatus. (See Note 4.)

5.1.7 For gauges with low source activity, variations in ambient background radiation from one test site to another may significantly influence test results. In such instances this ambient background radiation must be measured at the test site in conjunction with the test measurement and used in the calculation of the measured bulk density.

5.1.8 The gamma radiation response for any detector is typically influenced by the environmental testing temperature.

5.1.8.1 For scintillation detectors, changing temperatures may cause variations in the resulting light output distribution from the crystal—both in magnitude and shape of the spectrum. These variations may result in corresponding variations in the number of counted photons and, consequently, the wet density determined from the measurement.

5.1.8.2 The changes to the detector response due to temperature changes are compensated by various detector stabilization methods that compare current detector response to a standardized response and correct for energy spectrum changes accordingly.

5.1.8.3 The working temperature range of the gauge at which the aforementioned temperature variations are compensated is provided in the gauge specifications. In general, for a gauge using a sodium iodide scintillation detector, the working temperature range is similar to that of a nuclear gauge using Geiger-Mueller gas detectors: –10 to 70 °C [14 to 158 °F]. Please refer to the operator's manual to find the operating temperature range of the gauge.

5.1.8.4 For special applications where the gauge is used outside the operating temperature range, please consult the gauge manufacturer.

NOTE 4—Separation of the gauge described in this standard by a distance of 9 m [30 ft] from one another, or from the gauges described in Test Method D6938, has typically proven sufficient in preventing radiation from one gauge from being detected by another gauge and potentially causing an incorrect standardization or test measurement reading. 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.

6. Apparatus

6.1 *Nuclear Density Gauge*—While exact details of construction of the apparatus may vary, the system shall consist of:

6.1.1 *Gamma Source*—A sealed source of high-energy gamma radiation such as cesium, cobalt, or radium.

6.1.2 *Gamma Detector*—Any type of gamma detector, but typically a scintillation detector or semiconductor based detector.

6.2 *Site Preparation Device*—A plate, straightedge, or other suitable leveling tool that may be used for planing the test site to the required smoothness and guiding the drive pin to prepare a perpendicular hole.

6.3 *Drive Pin*—A pin of slightly larger diameter than the probe in the instrument, used to prepare a hole in the test site for inserting the probe.

6.3.1 *Drive Pin Guide*—A fixture that keeps the drive pin perpendicular to the test site. Generally part of the site preparation device.

6.4 *Hammer*—Heavy enough to drive the pin to the required depth without undue distortion of the hole.

6.5 *Drive Pin Extractor*—A tool that may be used to remove the drive pin in a vertical direction so that the pin will not distort the hole during the extraction process.

6.6 *Slide Hammer, with a Drive Pin Attached*—As an alternative to 6.3 through 6.5, may also be used both to prepare a hole in the material to be tested and to extract the pin without distortion of the hole.

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 and follow these standards when using the gauge.

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

8. Calibration

8.1 Gauge calibration shall be performed in accordance with Guides D7759/D7759M and D7013/D7013M.

9. Standardization

9.1 Nuclear density gauges are subject to long-term aging of the radioactive sources, which will change the relationship between test count rates and the material bulk density. To correct for this aging effect, gauges are calibrated as a ratio of the test count rate to a reference count rate.

9.2 Standardization of the gauge must be performed at the start of each day's use, and a record of these data must be retained for the amount of time required to ensure compliance with either 9.2.8 or 9.2.8.1, whichever is applicable.

9.2.1 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. (See Note 4.)

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

9.2.3 Prepare the site where the standardization measurement will be made as described in 10.2.

9.2.4 If the site where the standardization measurement will be made will also be used as a test site immediately after the standardization measurement, then make a hole perpendicular to the prepared surface using either a hammer and a drive pin or a slide hammer, using the rod guide to ensure the integrity of the hole. The hole should be a minimum of 50 mm [2 in.] deeper than the desired measurement depth of the test that follows the standardization process, and of an alignment that insertion of the probe will not cause the gauge to tilt from the plane of the prepared area. If the site where the standardization measurement will be made will not be used as a test site, then simply make a 50 mm [2 in.] hole perpendicular to the prepared surface using either a hammer and a drive pin or a slide hammer, using the rod guide to ensure the integrity of the hole.

9.2.5 Remove the hole-forming device carefully, using a drive pin extractor when needed, to prevent the distortion of the hole, damage to the surface, or loose material from falling into the hole.

9.2.6 With the gauge placed over the prepared hole and the probe in safe position, take a reading that is the duration of a normal measurement period (where a normal measurement period is typically two minutes).

9.2.7 Immediately after the preceding count is complete, lower the probe to background position, into the hole that was formed in 9.2.4, and take a two minute background count. The difference between the count acquired in 9.2.6 and this background constitutes one standardization count.

9.2.8 Use the procedure recommended by the gauge manufacturer to establish the compliance of the standard measurement to the accepted range. Otherwise, without specific recommendations from the gauge manufacturer, use the procedure in 9.2.8.1.

9.2.8.1 If the values of the current standardization count are 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. If the second standardization check does not satisfy Eq 1, then the gauge must be removed from service until such time that the gauge can pass this standardization test.

$$0.98(N_{dc})e^{\frac{-(\ln\ (2))t}{T_{d(1/2)}}} \leq N_{d0} \leq 1.02(N_{dc})e^{\frac{-(\ln\ (2))t}{T_{d(1/2)}}} \quad (1)$$

where:

$T_{d(1/2)}$ = the half-life of the isotope that is used for the density determination in the gauge. For example, for ^{137}Cs, the radioactive isotope most commonly used for density determination in these gauges, $T_{d(1/2)}$, is 11,023 days,
N_{dc} = the density system standardization count acquired at the time of the last calibration or verification,
N_{d0} = the current density system 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 $T_{d(1/2)}$ should be consistent, that is, if $T_{d(1/2)}$ is expressed in days, then t should also be expressed in days.

and N_{dc} and N_{d0} are corrected for background effects as described in 11.1.1.

9.2.8.2 *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 from 9.2.7, what is the allowed range of standard counts for November 1 of the same year?

(1) 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:

$$t = 245 \ \text{days}$$
$$T_{d(1/2)} = 11023 \ \text{days}$$
$$N_{dc} = 2800 \ \text{counts}$$

(2) According to Eq 1, therefore, the lower limit for the density standard count taken on November 1, denoted by N_{d0}, is:

$$0.98(N_{dc})e^{\frac{-(\ln\ (2))t}{T_{d(1/2)}}} = 0.98(2800)e^{\frac{-(\ln\ (2))\times 245}{11023}} = 2744e^{-0.01541}$$
$$= 2702 \ \text{counts}$$

(3) Likewise, the upper limit for the density standard count taken on November 1, denoted by N_{d0}, is:

$$1.02(N_{dc})e^{\frac{-(\ln\ (2))t}{T_{d(1/2)}}} = 1.02(2800)e^{\frac{-(\ln\ (2))\times 245}{11023}} = 2856e^{-0.01541}$$
$$= 2812 \ \text{counts}$$

9.2.9 If for any reason the measured bulk density becomes suspect during the day's use, perform another standardization count.

10. Procedure

10.1 When possible, select a test location where the gauge will be placed at least 600 mm [24.0 in.] away from any object sitting on or projecting above the surface of the test location, where the presence of this object has the potential to modify gauge response. Any time a measurement must be made at a specific location and the aforementioned clearance cannot be achieved, such as in a trench, follow the gauge manufacturer's correction procedure(s).

10.2 *Prepare the test site in the following manner:*

10.2.1 Remove all loose and disturbed material and additional material as necessary to expose the true surface of the material to be tested.

10.2.2 Prepare an area sufficient in size to accommodate the gauge by grading or scraping the area to a smooth condition so as to obtain maximum contact between the gauge and material being tested.

10.2.3 The depth of the maximum void beneath the gauge must not exceed 3 mm [⅛ in.]. Use either native material that does not contain gravel, or use fine sand, to fill the voids, and then smooth the surface with the site preparation device or other suitable tool. The depth of the filler should not exceed approximately 3 mm [⅛ in.].

10.2.4 The placement of the gauge on the surface of the material to be tested is critical to accurate density measurements. The optimum condition is total contact between the bottom surface of the gauge and the surface of the material being tested. The total area filled should not exceed approximately 10 percent of the bottom area of the gauge.

10.3 Turn on and allow the gauge to stabilize (warm up) according to the manufacturer's recommendations (see 9.2.2).

10.4 *The Measurement Procedure:*

10.4.1 When possible, select a test location where the gauge will be placed at least 600 mm [24.0 in.] away from any object sitting on or projecting above the surface of the test location, when the presence of this object has the potential to modify gauge response. Any time a measurement must be made at a specific location and the aforementioned clearance cannot be achieved, such as in a trench, follow the gauge manufacturer's correction procedure(s).

10.4.2 Make a hole perpendicular to the prepared surface using either a hammer and a drive pin or a slide hammer, using the rod guide to ensure the integrity of the hole. The hole should be a minimum of 50 mm [2 in.] deeper than the desired measurement depth and of an alignment that insertion of the probe will not cause the gauge to tilt from the plane of the prepared area.

10.4.3 Mark the test area to allow the placement of the gauge over the test site and to align the probe to the hole. Follow the manufacturer's recommendations.

10.4.4 Remove the hole-forming device carefully, using a drive pin extractor when needed, to prevent the distortion of the hole, damage to the surface, or loose material falling into the hole.

NOTE 5—Care must be taken in the preparation of the access hole in uniform cohesionless granular soils. Measurements can be affected by damage to the density of surrounding materials when forming the hole by potentially creating air voids what would not ordinarily be in the undisturbed material.

10.4.5 Place the gauge on the material to be tested, ensuring maximum surface contact as described previously in 10.2.4.

10.4.6 Lower the probe into the hole to the desired test depth. Pull the gauge gently toward the back, or detector end, so that the back side of the probe is in intimate contact with the side of the hole in the gamma measurement path.

NOTE 6—As a safety measure, it is recommended that a probe containing radioactive sources not be extended out of its shielded position prior to placing it into the test site. When possible, align the gauge to allow placing the probe directly into the test hole from the shielded position.

10.4.7 Ensure that the gauge is far enough away from other apparatus containing radioactive sources to prevent interference due to radiation from the other apparatus. (See Note 4.)

10.4.8 If the gauge requires the probe depth to be entered into the gauge or otherwise selected by the user prior to a test measurement, then set the depth selector to the same depth as the probe.

10.4.9 Secure and record one or more bulk density readings, where the duration of the reading corresponds with the desired gauge measurement precision level (see Annex A1). Read the in-place bulk density directly or determine one by use of the calibration curve or table previously established.

10.4.10 If this is the first reading in a new job site or a new in situ material, move the source rod to background position and take a one-minute background count.

10.4.11 If desired, using a separate method or device, make a water content or water mass per unit volume measurement. Use the data collected in this manner with the bulk density measured by the nuclear gauge to determine the dry density and water content of the test site.

10.5 *Oversize Particle Correction:*

10.5.1 When oversize particles are present, the gauge can be rotated about the axis of the probe to obtain additional readings as a check. When there is any uncertainty as to the presence of these particles it is advisable to sample the material beneath the gauge to verify the presence and the relative proportion of the oversize particles. A rock correction can then be made for bulk density by the method in Practice D4718/D4718M.

11. Calculation of Results

11.1 *Determine the Bulk Density:*

11.1.1 On most gauges, read the value directly in kg/m^3 [lbm/ft^3]. If the bulk density reading is in test counts, determine