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Standard Guide for Nuclear Surface Moisture and Density Gauge Calibration[1]

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1. Scope*

1.1 *Procedure A*—This guide describes the process and objective of formulating the mathematical relationship between the density system count of a nuclear surface moisture and density gauge and the corresponding wet density value of the density standard upon which the density system response was observed.

1.2 *Procedure B*—This guide describes the process and objective of comparing the wet density measured by a nuclear surface moisture and density gauge and the corresponding density value of the density standard upon which the density system response was observed.

1.3 This guide describes the process and objective of the verification of the measurements of a nuclear surface moisture and density gauge.

1.4 *Procedure A*—This guide describes the process and objective of formulating the mathematical relationship between the water content system count of a nuclear surface moisture and density gauge and the corresponding water mass per unit volume value of the water content standard upon which the water content system response was observed.

1.5 *Procedure B*—This guide describes the process and objective of comparing the water mass per unit volume measured by a nuclear surface moisture and density gauge and the corresponding water mass per unit volume of the corresponding water content standard upon which the water content system response was observed.

1.6 This guide describes the process and objective of the verification of the measurements of a nuclear surface moisture and density gauge.

1.7 This guide describes two mathematical processes by which the gauge measurement precision may be computed or measured.

1.8 This guide offers guidance for developing and reporting estimates of uncertainties in measurements made with gauges that have undergone calibration and verification.

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

1.10 *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.

1.10.1 Reporting of test results in units other than SI shall not be regarded as nonconformance with this guide.

1.11 *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.*

1.12 This guide offers an organized collection of information or a series of options and does not recommend specific course of action. This document cannot replace education or experience and should be used in conjunction with professional judgment. Not all aspects of this guide may be applicable in all circumstances. This ASTM standard is not intended to represent or replace the standard of care by which the adequacy of a given professional service must be judged, nor should this document be applied without consideration of a project's many unique aspects. The word "Standard" in the title of this document means only that the document has been approved through the ASTM consensus process.

[1] This practice 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**

1.13 *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

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

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

D6026 Practice for Using Significant Digits 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

D8167/D8167M Test Method for In-Place Bulk Density of Soil and Soil-Aggregate by a Low-Activity Nuclear Method (Shallow Depth)

3. Terminology

3.1 *Definitions*—See Terminology D653 for general definitions. For definitions of common metrology terms used in this standard, refer to the VIM—International Vocabulary of Metrology.[3]

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *density system calibration, n*—a set of processes by which, for each density standard used in the process, a density indication (gauge count or gauge density response) is obtained by the nuclear gauge on the density standard, and a relationship is established between the indications of the gauge and the density of the standard; the uncertainty of the standard and the indication must be established.

3.2.2 *density calibration equation, n*—the mathematical function that relates the density of the medium under measurement by the gauge (the independent variable) to the density system count response of the gauge (the dependent variable).

3.2.3 *density system verification, n*—a set of processes by which the acceptability of the associated density calibration equation of a gauge is determined.

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

3.2.5 *prepared standards, n*—density or water content measurement standards prepared of soil, solid rock, concrete, and engineered materials, that have density or water content values, or both, that are established and known to a specified uncertainty.

3.2.6 *soil-equivalent density, n*—the density of an average soil (where an "average soil" is defined herein to have a Z/A value of 0.5) that yields the same gauge density count response as a metallic calibration standard; Z is the average atomic number of a material and A is the average atomic mass number of that same material.

3.2.7 *water content system calibration, n*— a set of processes by which, for each water content standard used in the process, a water mass per unit volume indication (gauge count or water mass per unit volume value) is obtained by the nuclear gauge on the water content standard, and a relationship is established between the indication of the gauge and the water mass per unit volume value of the standard; the uncertainty of the standard and the indications must be established.

3.2.8 *water mass per unit volume calibration equation, n*—the mathematical function that relates the water mass per unit volume of the medium under measurement by the gauge (the independent variable) to the water content system count response of the gauge (the dependent variable).

3.2.9 *water content system verification, n*—a set of processes by which the acceptability of the water mass per unit volume calibration equation of a gauge is determined.

4. Summary of Practice

4.1 The summary of the practice is as follows:

4.1.1 *Procedure A*—For new gauges and gauges that fail to meet the required density system verification criteria, for each affected index rod position one must perform a **density calibration** in which one relates the gauge density system response (the gauge counts) to the soil-equivalent density of the standard(s) on which the response is elicited and, in a second step, uses this information to establish a **calibration equation**.

4.1.1.1 The measurement uncertainties of the density standard(s) and the gauge density system counts must be known.

4.1.1.2 The standard(s) used for the determination of uncertainty shall be representative of the range of densities for which the gauge will be used.

4.1.1.3 The mode of density calibration just described is not limited to new gauges or gauges that fail to meet the required density system verification criteria.

4.1.2 *Procedure B*—For gauge index rod positions for which a density calibration equation has been formulated, one has the option of performing a **density calibration** in which one establishes the relation between the soil-equivalent density values of the necessary number of soil-equivalent density standard(s) and the corresponding soil-equivalent density measured by the gauge when used to measure the standards and, in a second step, uses this information to establish the relationship between these two density values.

4.1.2.1 The measurement uncertainties of the density standards and the density measured by the gauge must be known.

[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] *International vocabulary of metrology—Basic and general concepts and associated terms (VIM)*, 3rd Edition. Joint Committee for Guides in Metrology, 2012. https://www.bipm.org/utils/common/documents/jcgm/JCGM_200_2012.pdf

4.1.2.2 The standard(s) used for the determination of uncertainty shall be representative of the range of densities for which the gauge will be used.

4.1.3 The objective of density system **verification** is to evaluate the current density calibration equation for the gauge and determine if new calibration constants are required.

4.1.4 *Procedure A*—For new gauges and gauges that fail to meet the required water content system verification criteria, one must perform a **water content calibration** in which one establishes the relation between the water mass per unit volume of the necessary number of water content standard(s) and the corresponding water system gauge counts elicited from the gauge when used to measure these standards and, in a second step, uses this information to establish a **calibration equation**.

4.1.4.1 The measurement uncertainties of the water content standard(s) and the gauge counts must be known.

4.1.4.2 The standard(s) used for the determination of uncertainty shall be representative of the range of water mass per unit volume for which the gauge will be used.

4.1.4.3 The mode of water content system calibration just described is not limited to new gauges or gauges that fail to meet the required water content system verification criteria.

4.1.5 *Procedure B*—For gauges for which the calibration constants of a water mass per unit volume calibration equation have been formulated, one may perform a **water content calibration** in which one establishes the relation between the water mass per unit volume value of the necessary number of water content standard(s) and the corresponding water mass per unit volume measured by the gauge when used to measure these standard(s) and, in a second step, uses this information to establish the relationship between these two water mass per unit volume values.

4.1.5.1 The measurement uncertainties of the water content standards and the water mass per unit volume measured by the gauge must be known.

4.1.5.2 The standards used for the determination of uncertainty shall be representative of the range of water mass per unit volume values for which the gauge will be used.

4.1.6 The objective of water content system **verification** is to evaluate the current water content calibration equation for the gauge and determine if new calibration constants are required.

4.2 The density calibration equation relates the wet density value measured by the gauge on a test site (the "independent variable") with the density test count measured by the gauge on the test site (the "dependent variable") and is typically exponential or polynomial in form, with three fit coefficients.

4.2.1 Historically, the most successful methods for computing the density calibration equation for the density system of a gauge is done by taking gauge density readings on three or more density standards, combining the independent and dependent variables into data pairs, and using a least-squares or Newton-Raphson fitting algorithm with these data pairs to compute the fit coefficients. These density standards have unique density values that span the range of densities for which the gauge will be used.

4.2.2 The computation of the density calibration equation is not necessarily limited to the process described in 4.2.1. However, for any method that is used in the density system calibration process, one must know the uncertainties of the wet density readings measured by devices calibrated in this manner over the range of density values for which the gauge will be used.

4.2.3 The water content calibration equation that relates the water mass per unit volume value measured by the gauge on a test site (the "independent variable") with the water mass per unit volume test count measured by the gauge on the test site (the "dependent variable") is typically linear in form, with two fit coefficients.

4.3 Historically, the most successful method for computing the water content calibration equation of a gauge is by taking readings on two water content standards (one of which is a zero water content standard), combining the independent and dependent variables into data pairs, and computing the fit coefficients.

4.3.1 The computation of the water content calibration equation is not necessarily limited to the process described in 4.3. However, for any method that is used in the water content system calibration process, one must know the uncertainties of the water mass per unit volume readings measured by devices calibrated in this manner over the range of water mass per unit volume values for which the gauge will be used.

4.4 See Appendix X1 for a flowchart of the calibration and verification processes.

5. Significance and Use

5.1 Gauge calibration is performed for the following purposes:

5.1.1 When necessary, to compute the calibration constants of a density calibration equation that relates the gauge density system response (the "density count") to the soil-equivalent density of the standard on which this response is elicited.

5.1.2 When necessary, to compute the calibration constants of a water content calibration equation that relates the gauge water content system response (the "water content count") to the water mass per unit volume value of the standard on which this response is elicited.

5.1.3 To establish the relationship between the density measured by the gauge to the soil-equivalent density of the standard on which this response is elicited.

5.1.4 To establish the relationship between the water mass per unit volume measured by the gauge to the water mass per unit volume of the standard on which this response is elicited.

5.1.5 To ensure that the gauge has an in-place density gauge precision level that is consistent with typical gauge response.

5.1.6 To ensure that the gauge has an in-place water mass per unit volume gauge precision level that is consistent with typical gauge response.

5.2 Gauge verification is performed for the following purposes:

5.2.1 To indicate to the party or agency performing the verification when the mathematical relationship between the in-place density reading indicated by the gauge and the corresponding gauge density test count needs to be adjusted so