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

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1. Scope*

1.1 This guide describes the process and objective of calibrating the density system of a nuclear surface moisture and density gauge, or formulating the mathematical relationship between the density system response (the "density count") of a nuclear surface moisture and density gauge and the corresponding density value of the density standard upon which the density system response was observed.

1.2 This guide describes the process and objective of calibrating the water content system of a nuclear surface moisture and density gauge, or formulating the mathematical relationship between the water content system response (the "water content 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.

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

1.4 This guide describes the process and objective of verifying the water content system of a nuclear surface moisture and density gauge.

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

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

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

1.8 *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; therefore, each system shall be used independently of the other. Combining values from the two systems may result in nonconformance with the standard.

1.9 *This guide 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 guide to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

1.10 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.

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

D7013 Guide for Nuclear Surface Moisture and Density Gauge Calibration Facility Setup

3. Terminology

3.1 *Definitions*—See Terminology D653 for general definitions.

[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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[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**

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *coverage factor*[3], *n*—a number larger than one by which a combined standard measurement uncertainty is multiplied to obtain an expanded measurement uncertainty.

3.2.2 *definitional uncertainty*[3], *n*—the component of measurement uncertainty resulting from the finite amount of detail in the definition of the measurand. The "measurand" in the case of a nuclear surface moisture density gauge, is typically either in-place density or water mass per unit volume.

3.2.3 *density system calibration, n*—the method by which the values of the fit parameters in the equation that relates the density system response (the "density count") of a nuclear gauge and the corresponding density value of the density standard upon which that density system response was observed are computed. In addition, the uncertainty of measurements taken with gauges calibrated by the specific method must be known at representative density values that span the range of densities for which the calibration is valid.

3.2.4 *density system verification, n*—a set of operations or processes, or both, by which, for each density standard used in the process, the in-place density value(s) measured by the nuclear gauge on the density standard is related to the corresponding value(s) of the standard or standards. In addition, the uncertainty of measurements taken with gauges that meets the established verification criterion or criteria must be known at representative densities that span the range of densities for which the verification is valid.

3.2.5 *detector, n*—a device to detect and measure radiation.

3.2.6 *expanded measurement uncertainty*[3], *n*—product of a combined standard measurement uncertainty and a coverage factor larger than one.

3.2.7 *gamma (radiation) source, n*—a sealed source of radioactive material that emits gamma radiation as it decays.

3.2.8 *in-place density, n*—the total mass (solids plus water) per total volume of soil or soil-aggregates measured in place.

3.2.9 *measurement uncertainty*[3], *n*—non-negative parameter characterizing the dispersion of the quantity values being attributed to a measurand. The "measurand" in the case of a nuclear surface moisture density gauge, is typically either in-place density or water mass per unit volume.

3.2.10 *neutron (radiation) source, n*—a sealed source of radioactive material that emits neutron radiation as it decays.

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

3.2.12 *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.

3.2.13 *standard measurement uncertainty*[3], *n*—measurement uncertainty expressed as a standard deviation.

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

3.2.15 *Type A Uncertainty Evaluation*[3], *n*—evaluation of a component of measurement uncertainty by a statistical analysis of measured quantity values obtained under defined measurement conditions.

3.2.16 *Type B Uncertainty Evaluation*[3], *n*—evaluation of a component of measurement uncertainty by means other than a Type A Evaluation.

3.2.17 *volumetric water content, n*—the volume of water as a percent of the total volume of soil or rock material.

3.2.18 *water content, n*—the ratio of the mass of water contained in the pore spaces of soil or soil-aggregate, to the solid mass of particles in that material, expressed as a percentage (*this is sometimes referred to in some scientific fields as gravimetric water content to differentiate it from volumetric water content*).

3.2.19 *water content system calibration, n*—the method by which the values of the fit parameters in the equation that relates the water content system response (the "water content count") of a nuclear gauge and the corresponding water mass per unit volume value of the water content standard upon which that water content system response was observed are computed. In addition, the uncertainty of measurements taken with the gauges calibrated by the specific method must be known at representative water mass per unit volume values that span the range of water mass per unit volume values for which the calibration is valid.

3.2.20 *water content system verification, n*—a set of operations or processes, or both, by which, for each water content standard used in the process, the in-place water mass per unit volume value(s) measured by the nuclear gauge on water content standard is related to the corresponding value(s) of these standards. In addition, the uncertainty of measurements taken with gauges that meets the established verification criterion or criteria must be known at representative water mass per unit volume values that span the range of water mass per unit volume values for which the verification is valid.

3.2.21 *water mass per unit volume, n*—the ratio of the mass of water contained in the pore spaces of a soil or soil-aggregate to the total volume occupied by that soil or rock material.

4. Summary of Practice

4.1 The objectives of the practice are as follows:

4.1.1 The objective of density system **calibration** is to formulate a mathematical equation, or *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. The maximum uncertainties of subsequent gauge density readings shall be determined for the calibration process that is used. The standards used for the determination of uncertainty shall be representative of the range of densities for which the gauge will be used.

4.1.2 The objective of density system **verification** is to evaluate the current density calibration equation for the gauge and determine if a new calibration is required. The verification method will be based upon relating, at the pertinent density or

[3] JCGM 200:2008: International Vocabulary of Metrology—Basic and General Concepts and Associated Terms (VIM). 2008: Joint Document Committee for Guides in Metrology.

densities for the specific method, the density value of a known density standard to the density measured by the gauge. The maximum uncertainties of subsequent gauge density readings shall be determined for the verification method used. The standards 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 water content system **calibration** is to formulate a mathematical equation, or *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. The uncertainties of subsequent gauge water mass per unit volume readings shall be known for, at a minimum, a water mass per unit volume level within 32 kg/m^3 [2.0 lbm/ft^3] of the upper extreme of the water mass per unit volume calibration range (typically 300 kg/m^3 [18.7 lbm/ft^3] or higher).

4.1.4 The objective of water content system verification is to evaluate the current water content system calibration equation for the gauge and determine if a new calibration is required. This evaluation will be based upon relating, at the pertinent water mass per unit volume values for the specific method, the water mass per unit volume value of a known water mass per unit volume standard to the water mass per unit volume value measured by the gauge. The uncertainties of subsequent gauge water mass per unit volume readings shall be known for, at a minimum, a water mass per unit volume level within 32 kg/m^3 [2.0 lbm/ft^3] of the upper extreme of the water mass per unit volume calibration range (typically 300 kg/m^3 [18.7 lbm/ft^3] or higher).

4.1.5 The density calibration equation relates the in-place 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") is typically exponential or polynomial in form, with three fit coefficients.

4.2 Historically, the most successful methods for calibrating 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-Rafson 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.

4.2.1 The density system calibration of a gauge is not necessarily limited to the process described in 4.2. However, for any method that is used in the density system calibration process, one must know the uncertainties of the in-place density readings measured by devices calibrated in this manner over the range of density values for which the gauge will be used.

4.2.2 For any method that is used in the density system verification process, one must know the uncertainties of the in-place 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 in-place water mass per unit volume value measured by the gauge on a test site (the "independent variable") with the water content 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 calibrating the water content system 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 using a least-squares or fitting algorithm with these data pairs to compute the fit coefficients.

4.3.1 The water content system calibration of a gauge 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 mass per unit volume values for which the gauge will be used.

4.3.2 For any method that is used in the water content system verification 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 mass per unit volume values for which the gauge will be used.

5. Significance and Use

5.1 Gauge calibration is performed for the following purposes:

5.1.1 To formulate a mathematical equation, or 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 To formulate a mathematical equation, or 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 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 that the gauge calibration meets the required level of measurement uncertainty.

5.2.2 To indicate to the party or agency performing the verification when the mathematical relationship between the water mass per unit volume indicated by the gauge and the corresponding gauge water content test count needs to be adjusted so that the gauge calibration meets the required level of measurement uncertainty.

5.2.3 Gauge verification and calibration require specialized training and equipment. Gauge calibration and verification should only be conducted by those trained in the proper operation of the gauge, the calibration or verification standards, and any tables, charts, graphs, or computer programs required for the proper execution of these operations.