
Standard Method of Test for In-Place Density and Moisture Content of Soil and Soil–Aggregate by Nuclear Methods (Shallow Depth)

AASHTO Designation: T 310-22

Technically Revised: 2022

**Technical Subcommittee: 1b, Geotechnical Exploration,
Instrumentation, Stabilization, and Field Testing**



**American Association of State Highway and Transportation Officials
555 12th Street NW, Suite 1000
Washington, D.C. 20004**

In-Place Density and Moisture Content of Soil and Soil–Aggregate by Nuclear Methods (Shallow Depth)

AASHTO Designation: T 310-122

AASHTO

Technically Revised: 2022

Technical Subcommittee: 1b, Geotechnical Exploration, Instrumentation, Stabilization, and Field Testing

1. SCOPE

- 1.1. This test method describes the procedure for determining the in-place density and moisture of soil and soil–aggregate by use of nuclear gauge. The density of the material may be determined by either Direct Transmission, Backscatter, or Backscatter/Air-Gap Ratio Method. The moisture of the material is determined only from measurements taken at the surface of the soil (i.e., backscatter).
- 1.2. *Density*—The total or wet density of soil and soil–rock mixtures is determined by the attenuation of gamma radiation where the source or detector is placed at a known depth up to 300 mm (12 in.) while the detector(s) or source remains on the surface (Direct Transmission Method) or the source and detector(s) remain on the surface (Backscatter Method).
 - 1.2.1. The density in mass per unit volume of the material under test is determined by comparing the detected rate of gamma radiation with previously established calibration data.
- 1.3. *Moisture*—The moisture content of the soil and soil–rock mixtures is determined by thermalization or slowing of fast neutrons where the neutron source and the thermal neutron detector both remain at the surface.
 - 1.3.1. The water content in mass per unit volume of the material under test is determined by comparing the detection rate of thermalized or slow neutrons with previously established calibration data.
- 1.4. *SI Units*—The values stated in SI units are to be regarded as the standard. The inch-pound equivalents may be approximate. It is common practice in the engineering profession to concurrently use pounds to represent both a unit of mass (lbm) and of force (lbf). This implicitly combines two systems of units, that is, the absolute system and the gravitational system.
 - 1.4.1. This standard has been written using the absolute system for water content (kilograms per cubic meter) in SI units. Conversion to the gravitational system of unit weight in lbf/ft³ may be made. The recording of water content in pound-force per cubic foot should not be regarded as nonconformance with this standard, although the use is scientifically incorrect.
 - 1.4.2. In the U.S. Customary units system, the pound (lbf) represents a unit of force (weight). However, the use of balances or scales recording pounds of mass (lbm) or recording of density (lbm/ft³) should not be regarded as nonconformance with this standard.

- 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 and health practices and determine the applicability of regulatory limitations prior to use.*
See Section 6, Hazards.
- 1.6. *The quality of the results produced by this standard are dependent on the competence of the personnel performing the procedure and the capability, calibration, and maintenance of the equipment used. Agencies that meet the criteria of R 18 are generally considered capable of competent and objective testing/sampling/inspection/etc. Users of this standard are cautioned that compliance with R 18 alone does not completely assure reliable results. Reliable results depend on many factors; following the suggestions of R 18 or some similar acceptable guideline provides a means of evaluating and controlling some of those factors.*

2. REFERENCED DOCUMENTS

- 2.1. *AASHTO Standards:*
- R 18, Establishing and Implementing a Quality Management System for Construction Materials Testing Laboratories
 - T 99, Moisture–Density Relations of Soils Using a 2.5-kg (5.5-lb) Rammer and a 305-mm (12-in.) Drop
 - T 180, Moisture–Density Relations of Soils Using a 4.54-kg (10-lb) Rammer and a 457-mm (18-in.) Drop
 - T 191, Density of Soil In-Place by the Sand-Cone Method
 - T 265, Laboratory Determination of Moisture Content of Soils
 - T 272, One-Point Method for Determining Maximum Dry Density and Optimum Moisture
- 2.2. *ASTM Standards:*
- D4253, Standard Test Methods for Maximum Index Density and Unit Weight of Soils Using a Vibratory Table
 - D4254, Standard Test Methods for Minimum Index Density and Unit Weight of Soils and Calculation of Relative Density
 - D7013/D7013M, Standard Guide for Calibration Facility Setup for Nuclear Surface Gauges

3. SIGNIFICANCE

- 3.1. The test method described is useful as a rapid, nondestructive technique for the in-place determination of the wet density and water content of soil and soil–aggregate.
- 3.2. The test method is used for quality control and acceptance testing of compacted soil and rock for construction and for research and development. The nondestructive nature allows for repetitive measurements at a single test location and statistical analysis of the results.
- 3.3. *Density*—The fundamental assumptions inherent in the methods are that Compton scattering is the dominant interaction and that the material under test is homogeneous.
- 3.4. *Moisture*—The fundamental assumptions inherent in the test method are that the hydrogen present is in the form of water as defined by T 265 and that the material under test is homogeneous.
- 3.5. Test results may be affected by chemical composition, sample heterogeneity, and to a lesser degree, material density and the surface texture of the material being tested. The technique also

exhibits spatial bias in that the gauge is more sensitive to water contained in the material in close proximity to the surface and less sensitive to water at deeper levels.

4. INTERFERENCES

4.1. *In-Place Density Interferences:*

4.1.1. The chemical composition of the sample may affect the measurement, and adjustments may be necessary.

4.1.2. The gauge is more sensitive to the density of the material in close proximity to the surface in the Backscatter Method.

Note 1—The nuclear gauge density measurements are somewhat biased to the surface layers of the soil being tested. This bias has largely been corrected out of the Direct Transmission Method, and any remaining bias is insignificant. The Backscatter Method is still more sensitive to the material within the first several inches from the surface. Density measurements with direct transmission is the preferred method.

4.1.3. Oversize rocks or large voids in the source-detector path may cause higher or lower density determination, respectively. Where lack of uniformity in the soil due to layering, rock, or voids is suspected, excavate and visually examine the test site to determine if the test material is representative of the full material in general, and if rock correction is required.

4.1.4. The sample volume is approximately 0.0028 m³ (0.10 ft³) for the Backscatter Method and 0.0057 m³ (0.20 ft³) for the Direct Transmission Method when the test depth is 150 mm (6 in.). The actual sample volume is indeterminate and varies with the gauge and the density of the material. In general, the higher the density, the smaller the volume.

4.1.5. Other radioactive sources must not be within 10 m (30 ft) of the gauge in operation.

4.2. *In-Place Moisture Content Interferences:*

4.2.1. The chemical composition of the sample may dramatically affect the measurement and adjustments may be necessary. Hydrogen in forms other than water will cause measurements in excess of the true value. Some chemical elements, such as boron, chlorine, and minute quantities of cadmium, will cause measurements lower than the true value.

4.2.2. The water content determined by this test method is not necessarily the average water within the volume of the sample involved in the measurement. The measurement is heavily influenced by the water content of the material closest to the surface. The volume of soil and rock represented in the measurement is indeterminate and will vary with the water content of the material. In general, the greater the water content of the material, the smaller the volume involved in the measurement. At 160 kg/m³ (10 lb/ft³), approximately 50 percent of the typical measurement results from the water content of the upper 50 to 75 mm (2 to 3 in.).

4.2.3. Other neutron sources must not be within 10 m (30 ft) of the gauge in operation.

5. APPARATUS

5.1. *Nuclear Density/Moisture Gauge*—Although exact details of construction of the gauge may vary, the system consists of:

5.1.1. A sealed source of high-energy gamma radiation, such as cesium or radium.

- 5.2. *Gamma Detector*—Any type of gamma detector, such as a Geiger-Mueller tube(s).
- 5.3. *Fast Neutron Source*—A sealed mixture of a radioactive material, such as americium, radium, or californium-252, and a target material such as beryllium.
- 5.4. *Slow Neutron Detector*—Any type of slow neutron detector, such as boron trifluoride or helium-3 proportional counter.
- 5.5. *Reference Standard*—A block of material used for checking gauge operation, correction of source decay, and to establish conditions for a reproducible reference count rate.
- 5.6. *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 in the Direct Transmission Method, guiding the drive pin to prepare a perpendicular hole.
- 5.7. *Drive Pin*—A pin not to exceed the diameter of the rod in the Direct Transmission gauge by more than 6 mm ($\frac{1}{4}$ in.), or as recommended by the gauge manufacturer, used to prepare a hole in the material under test for inserting the rod.
- 5.7.1. A slide hammer, with a drive pin attached, may also be used both to prepare a hole in the material to be tested and to extract the pin without distortion to the hole.
- 5.8. *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 in the extraction process.

6. HAZARDS

- 6.1. The gauge utilizes radioactive materials that may be hazardous to the health of the users unless proper precautions are taken. Users of the gauge must become familiar with applicable safety procedures and government regulations.
- 6.2. Effective user instructions together with routine safety procedures, such as source leak tests, recording and evaluation of film badge data, etc., are a recommended part of the operation and storage of this gauge.

7. CALIBRATION

- 7.1. Calibration of the gauge will be in accordance with Annexes A1 and A2. (See also ASTM D7013/D7013M.)

8. STANDARDIZATION

- 8.1. All nuclear density/moisture gauges are subject to long-term aging of the radioactive sources, detectors, and electronic systems, which may change the relationship between count rates and the material density and water content. To offset this aging, gauges are calibrated as a ratio of the measurement count rate to a count rate made on a reference standard or to an air-gap count (for the backscatter/air-gap ratio method). The reference count rate should be in the same or higher order of magnitude than the range of measurement count rates over the useful range of the gauge.
- 8.2. Standardization of the gauge on the reference standard is required at the start of each day's use. Retain a permanent record of these data. Perform the standardization with the gauge at least 10 m (30 ft) away from other nuclear density/moisture gauges and clear of large masses of water or