FLORIDA DEPARTMENT OF TRANSPORTATION
State Materials Office
5007 NE 39th Avenue
Gainesville, Florida 32609

February 12, 2024

Florida Method of Test for In-Place Density of Soils and Soil Aggregates by Nuclear Methods

Designation: FM 1-T310

This standard supersedes former FM 1-T238.

1. SCOPE

1.1 This method covers procedures for a rapid, nondestructive measurement of the in-place density of soil and soil-aggregates using Direct Transmission by means of a Nuclear Density Gauge, NDG (Method A) and Direct Transmission by means of a Low-Activity Nuclear Density Gauge, L-NDG (Method B).

1.2 The test method is used for quality control and acceptance testing of compacted soil and rock for construction and research and development with allowance for repetitive measurements at a single location and statistical analysis due to the non-destructive nature of the test.

1.3 *Density* – For Direct Transmission, the total or wet density of in-place soil and soil-aggregate material is determined by the attenuation of gamma radiation from the source or detector placed at a known depth, up to 12 inches, while the detector(s) or source remain on the surface of the material.

1.4 *Moisture* – For gauge models containing a neutron source and authorized by the Florida Department of Transportation, hereon after referred to as Department, for use in moisture determination, moisture content is measured by thermalization or slowing of the neutrons where the neutron source and detector remain on the surface.

2. REFERENCES

AASHTO T 310 - In-Place Density and Moisture Content of Soil and Soil-Aggregate by Nuclear Methods (Shallow Depth) and all documents referenced within.

ASTM D6938 - Standard Test Methods for In-Place Density and Water Content of Soil and Soil-Aggregate by Nuclear Methods (Shallow Depth) and all documents referenced within.

ASTM D8167 - Standard Test Method for In-Place Bulk Density of Soil and Soil- Aggregate by a Low-Activity Nuclear Method (Shallow Depth) and all documents referenced within.

3. ASSUMPTIONS AND BIAS

3.1 Fundamental assumptions inherent to the method of measuring density and moisture (for gauges with a neutron source) are:

3.1.1 Material tested is assumed to be homogenous.

3.1.2 *Density* – The dominant interaction between the radioactive sources and the material is Compton scattering.

3.1.3 *Moisture* – The hydrogen present is in the form of water.

3.2 Test results may be affected by chemical composition, sample heterogeneity, material density, and the surface texture of the material being tested.

3.3 The test method exhibits spatial bias for moisture measurements in that the gauge is more sensitive to the water content of the material close to the surface than at deeper levels.

4. INTERFERENCES

4.1 Oversize rock or large voids may cause inaccurate density measurements.

4.2 Other radioactive and neutron sources must not be within thirty (30) feet of the gauge in operation.

5. APPARATUS

5.1 Nuclear Gauge (with lock) – Any gauge listed in Table 1 containing a sealed source of gamma radiation and gamma detector with the ability to test up to a depth of 12 inches in one-inch increments. In addition, NDG's contain a sealed neutron source and neutron detector unlike L-NDG's.

Table 1 – Department Authorized Nuclear Gauges for Determination of In-Place Density

Manufacturer	Authorized Models
Troxler	3411B, all 3430 models, all 3440 models, 3450 Plus, 4590, and 4540
CPN	All MC-1, MC-3, and MC-4 models
Humboldt	HS-5001SD, HS-5001EZ, and HS-5001EZ-2
InstroTek	3500

Nuclear gauges are authorized based on meeting Department Specifications and having a proven history of reliable results.

5.2 Reference Standard – Block of material of uniform, unchanging density used to establish conditions for a reproducible reference count rate and account for source decay. For L-NDGs, a reference standard is not required.

5.3 Scraper Plate (with drill rod guide) – A rectangular-shaped, straight edge metal plate with a drill rod guide used to prepare the test site for direct transmission measurements.

5.4 Drill Rod – Metal rod used to prepare the hole for direct transmission measurements.

5.5 Drill Rod Extraction Tool – metal tool used to aid in the extraction of the drill rod from the test hole.

5.6 Hammer – For driving the drill rod.

5.7 Eye Protection/Shield (Recommended) – Goggles, glasses, or other types of eye protection designed to reduce the risk of injury from chipping of material when hammering against metal or stone.

6. HAZARDS

6.1 The gauge utilizes radioactive materials that may be hazardous to the health of the users unless proper precautions are taken. Any person operating equipment containing radioactive materials (nuclear gauges) should be experienced with the materials with which they are working. All NDG operators are required to undergo radiation safety training meeting the requirements of **49 CFR Part 172, Subpart H**.

6.2 Persons operating equipment containing radioactive materials (nuclear gauges) shall be familiar with and comply with the requirements set out in the Operator Manual for the piece of equipment being utilized. The manual for the gauge being utilized shall be placed in the gauge's transport container and be readily available.

6.3 Routine safety procedures recommended by the gauge manufacturer and regulatory agency are required such as source leak tests, inventory, recording and evaluation of dosimetry badge data (if applicable), etc.

7. CALIBRATION

7.1 Calibration of nuclear gauges by qualified personnel is required annually and any time the operator determines there is a need for recalibration and/or repair.

7.2 If a nuclear gauge does not meet the comparison requirement as per subsection **120-10.1.1** of the Department's Standard Specifications for Road and Bridge Construction, the nuclear gauge must be recalibrated.

7.3 Nuclear gauges out of calibration are not to be used on any Department construction project.

8. STANDARDIZATION

8.1 Radioactive sources, detectors, and electronic systems in nuclear gauges are subject to long-term aging which may change the relationship between count rates and the density and water content of the material. To offset this aging, gauges are calibrated as a ratio of the test count rate to a reference count rate.

8.2 Standardization of the gauge at the start of each day's use and recording of this data is required. A log or diary is to be utilized to calculate the day-to-day shift in the standard counts.

8.3 Perform the standardization with the gauge at least thirty (30) feet away from other nuclear gauges, any sources of radiation, large masses of water, or anything that may affect the count rates (see **Note 1**)

Note 1 – The serial number on both the reference block and the NDG shall match. L-NDG's do not use a reference block.

8.4 Standard counts are to be taken in the same environment as the density measurements.

8.5 Standard Count Limits

8.5.1 NDGs – Day-to-day shift in the density standard counts and moisture standard count shall not be greater than one (1) percent and two (2) percent, respectively, when compared to the average of the previous four sets of counts (see **Note 2**).

8.5.2 L-NDGs – Day-to-day shift in the density standard counts (DS) shall not be greater than one (1) percent when compared to the average of the previous four sets of counts (see **Note 2**).

Note 2 – During the first four days of receiving a new gauge or a recalibrated gauge, compare the daily standard count to the factory-calibrated values. The factory standard count values from the most recent calibration report should be used as a reference if the daily standard counts are ever in question.

8.6 Check that the standard counts are within the range of the expected standard count provided with the calibration paperwork. If not, have the gauge inspected and repaired, if necessary.

8.7 If the day-to-day shift is greater than the allowable limits, additional attempts to obtain a usable standard count are recommended. If routine failure occurs, repair and recalibrate the gauge.

9. GENERAL PROCEDURE FOR DAILY STANDARD COUNTS

9.1 Turn the gauge on and allow for stabilization as per the manufacturer's recommendations. If the gauge is to be used consistently or intermittently throughout the day, it is recommended to leave the gauge on to prevent having to repeat the stabilization procedure.

9.2 For NDGs

9.2.1 Place the standard reference on a flat level surface of compacted soil with a unit weight of at least 100 pounds per cubic feet (pcf), asphalt, or concrete. Ensure the gauge is a minimum of ten (10) feet away from any large objects and thirty (30) feet from another nuclear gauge and other radioactive sources.

9.2.2 Follow the manufacturer's instruction and obtain the *standard density count* and *standard moisture count* and record these values in the gauge's diary.

9.3 For L-NDGs

9.3.1 Place the gauge directly on soil with a wet unit weight of at least 100 pcf, asphalt, or concrete. Ensure the gauge is a minimum of ten (10) feet away from any large objects and thirty (30) feet from another nuclear gauge and other radioactive sources.

9.3.2 Follow the manufacturer's instruction and obtain the standard density count (DS) and background standard count (BGD or DSB) and record these values in the gauge's diary.

10. SITE PREPARATION

10.1 Select a smooth test site free of surface irregularities where the gauge in test position will be at least (6) six inches away from any vertical projections.

10.2 Remove all loose and disturbed material, as necessary, to expose the top of the material to be tested.

10.3 Prepare a horizontal area sufficient in size to accommodate the gauge by flattening the surface to a smooth condition to obtain maximum contact between the gauge and the material being tested.

10.4 The maximum void beneath the gauge shall not exceed $^1/_8$-inch. Use native fines or fine sand to fill the voids and smooth the surface using the scraper plate or other suitable tool. Do not exceed approximately $^1/_8$-inch of filler.

10.5 Place the scraper plate with the drill rod guide and drill rod extraction tool (optional) on the test site.

10.6 Place the drill rod into the drill rod guide and drive a hole at least two (2) inches deeper than the desired test depth ensuring the hole is perpendicular to the prepared surface of the test site.

10.7 Remove the drill rod by rotating and pulling straight up. The drill rod extraction tool may be used to facilitate this procedure. Do not loosen the drill rod by tapping with a hammer.

METHOD A – DETERMINATION OF IN-PLACE DENSITY OF SOIL AND SOIL AGGREGATES USING DIRECT TRANSMISSION BY MEANS OF A NUCLEAR DENSITY GAUGE

11. PROCEDURE

11.1 Remove the scraper plate and place the gauge on the prepared surface making sure maximum surface contact is achieved. Align the gauge to allow placing the rod directly into the test hole from the shielded position.

11.2 Lower the source rod into the hole to the desired test depth. Pull gently on the gauge in the direction that will bring the side of the source rod in intimate contact with the side of the hole.

11.3 Follow the manufacturer's instructions to obtain a density reading for a minimum duration of one (1) minute (see **Note 3**).

Note 3 – Time settings on the nuclear gauge must be set to a minimum of 1 minute or "Normal" (applicable for some models).

11.4 Record the standard density count, standard moisture count, wet density, material density count, and material moisture count in the Earthwork Record System section of the Department's database.

11.5 Moisture Content Determination:

11.5.1 In-place moisture content of the material shall be determined in accordance with **FM 5-507** (Determination of Moisture Content by Means of a Calcium Carbide Gas Pressure Moisture Tester), or **ASTM D-4643** (Laboratory Determination of Moisture Content of Granular Soils by use of a Microwave Oven) (see **Note 4**).

Note 4 – Sample for moisture determination shall be obtained from within the area underneath the gauge.

11.5.2 In-place moisture content of the material may be determined using the nuclear gauge's moisture reading provided the following criteria are met:

a. Material tested is limerock, cemented coquina, shell-rock, shell base, Graded Aggregate Base (GAB), or Recycled Concrete Aggregate (RCA).

b. The nuclear gauge being utilized is listed in Table 2.

Table 2 – Department Authorized Nuclear Gauges for Determination of In-Place Moisture

Manufacturer	**Authorized Models**
Troxler	3411B, all 3430 models, all 3440 models, 3450 Plus
CPN	All MC-1, MC-3, and MC-4 models.
Humboldt	HS-5001SD, HS-5001EZ, and HS-5001EZ-2
InstroTek	3500

11.5.3 Follow the manufacturer's instructions to obtain the percent moisture when using the nuclear density gauge.

11.5.4 Record the moisture content in the Earthwork Record System section of the Department's database.

METHOD B – DETERMINATION OF IN-PLACE DENSITY OF SOIL AND SOIL AGGREGATES USING DIRECT TRANSMISSION BY MEANS OF A LOW-ACTIVITY NUCLEAR DENSITY GAUGE

12. PROCEDURE

12.1 Meet the requirements of **11.1** and **11.2**.

12.2 Follow the manufacturer's instructions to obtain a density reading for a minimum duration of two (2) minutes (see **Note 5 and Note 6**).

Note 5 – Measure mode for gauge must be set to SOIL.

Note 6 – Time settings on the nuclear gauge must be set to a minimum count of two (2) minutes for the density measurement.

12.3 After the density measurement is complete, follow the manufacturer's instructions to complete a background count. A new background count is required for *all* tests depths (see **Note 7).**

Note 7 – Time settings on the nuclear gauge must be set to a minimum count of one (1) minute for the background measurement.

12.4 Moisture Content Determination*:*

12.4.1 In-place moisture content for *all* materials tested using L-NDGs, regardless of material type, shall be determined in accordance with **FM 5-507** (Determination of Moisture Content by Means of a Calcium Carbide Gas Pressure Moisture Tester), or **ASTM D-4643** (Laboratory Determination of Moisture Content of Granular Soils by use of a Microwave Oven). No other means of moisture determination are permissible (see **Note 8**).

Note 8 – Sample for moisture determination shall be obtained from within the area underneath the gauge.

12.4.2 Once the moisture content has been determined, manually input the value in the gauge following the manufacturer's instructions (see **Note 9**).

Note 9 – Measurement order setting shall be set to "Gauge First" and moisture input method shall be set to "Manual Input".

12.5 Record the *standard density count, standard background count, wet density, material density count (DC), background count (BC), and moisture content* in the Earthwork Record System section of the Department's database.

13. CALCULATION OF RESULTS

13.1 Determine the dry density of the material as follows:

$$\gamma_d = \frac{\gamma_w}{\omega + 100} \times 100$$

where:

γ_d = dry density in pounds per cubic feet (pcf)

γ_w = wet density in pounds per cubic feet (pcf)

ω = water content as a percent (%) of dry mass

13.2 Percent Maximum Density – Determine the percent compaction by dividing the in-place dry density by the laboratory dry density (Proctor value) and multiplying by 100.

13. REPORT

14.1 Test date

14.2 Technician Identification Number (TIN)

14.3 Location of test (Station/Length, Elevation, Offset, Reference Line)

14.4 Serial number of the nuclear density gauge

14.5 Standard counts for the date of test

14.6 Test depth in inches

14.7 Soil counts (density count, moisture count/background count)

14.8 Maximum dry density (Proctor value) in pcf

14.9 Wet density in pcf rounded to the nearest tenth

14.10 Moisture content in percent (%) rounded to the nearest tenth

14.11 Dry density in pcf rounded to the nearest tenth

14.12 Percent maximum density (%) rounded to the nearest whole number.