State of Nevada
Department of Transportation
Materials Division

METHOD OF TEST FOR DENSITY AND MOISTURE CONTENT OF SOILS AND AGGREGATES BY THE USE OF NUCLEAR DENSITY GAUGES

SCOPE

This test method is used to determine in-place density and moisture content of soils and aggregates by the use of nuclear equipment. The wet density in kg/m^3 (lb/ft^3) is determined using the "Direct Transmission Mode". The rod containing the Cesium-137 (Cs-137) source is lowered to the desired depth, resulting in Gamma radiation emission. It is a rapid, non-destructive technique, designed for control and acceptance testing of compaction of soils and aggregates for highway construction.

This method described for density is suitable to a test depth from 50 to 200 mm (2 to 8 in.). The moisture test is generally suitable to a depth of up to 175 mm (7 in.). However, it is heavily dependent on the moisture content, with very high moisture contents reducing the effective depth to about 100 mm (4 in.). Test results may be affected by the chemical composition, sample heterogeneity and surface texture of the material.

Nuclear density gauges utilize radioactive materials, which, that even though present in small quantities, must be handled with care to avoid health hazards to the operator and other individuals surrounding the moisture-density gauge.

APPARATUS

1. Moisture-Density Gauge, Troxler Model 3440 or 3450, consisting of the following major components:

    a. Gamma Source, housed in the probe, shall be an encapsulated and sealed radio isotopic source such as Cesium-137 (Cs-137).

    b. Probe, containing the gamma source, designed for inserting into a preformed hole in the soil. It shall be marked in increments to indicate the depth it is to be placed in the soil. It shall be constructed so that when moved to a desired depth, it will be held securely in position at that depth and have an automatic depth indicator with a back up manual depth indicator.

    c. Gamma Detector, such as a Geiger-Mueller tube or tubes.

    d. Fast Neutron Source, a sealed isotope material such as Americium 241:Beryllium (AM 241:Be). It shall be contained in a separate sealed capsule.

e. Slow neutron detector, such as helium three tubes (He-3 tubes).

f. Readout Device, any suitable type which usually includes a high and low voltage power supply necessary to operate the detectors, readout, and accessory devices. Commonly referred to as the scaler.

g. Housing, shall be moisture and dust proof and of rugged construction to protect the sources, detectors, readout device and power supplies which are contained therein.

h. Offsets, capable of performing density, moisture and trench adjustments through offset functions.

2. Drill Rod, a steel pin having a nominal diameter slightly greater than the probe, but not to exceed the diameter of the probe by more than 3 mm (1/8 in.). Used to form a hole in the soil to be tested.

3. Guide and Site Preparation Device, one piece of equipment, a steel or aluminum plate leveling tool used to plane the test site to the required smoothness and for aligning the hole perpendicular to the prepared surface for the probe.

4. Reference Standard Block, provided with each moisture-density gauge for checking equipment operation and to provide a stable condition for a reproducible count rate.

STANDARDIZATION

1. Warm up period: Turn the moisture-density gauge on and warm up for ten minutes. This allows the regulators and deflectors to stabilize.

2. At the start of each shift, standardize the moisture-density gauge to check equipment operation. This procedure can also be used as an operational check whenever test measurements are suspect or when poor correlation is encountered during the correlation check.

3. The site chosen for standardization should remain the same throughout the contract. Outline the standard block with keil (lumber crayon) to ensure the same location is used.

4. Place the standard block on a solid surface having a density of 1600 kg/m^3 (100 lb/ft^3) or greater, preferably a plantmix or concrete surface. Ensure that the standard block is level and does not rock back and forth. This location should be at least 3 m (10 ft) from any large object such as a vehicle, field lab, wall, or any water source and at least 9 m (30 ft) from another nuclear gauge.

5. Place the moisture-density gauge on the standard block and properly seat within the recessed area of the standard block. Place the scaler end against the metal plate on the standard block and check to make sure the moisture-density gauge does not rock on the standard block.

6. With the lock attached and the handle in the "safe" position, press the "STANDARD" key on the keypad. The screen will show "Standard Count DS=XXX MS=XXX Take a new count"? Press the "YES" key. The screen will then show "Is gauge on standard block and source rod in safe position"? Check to make sure, then press the "YES" key. The moisture-density gauge will begin taking a four-minute standard count.

7. When counting stops, at the end of the four minutes, screen will say "MS = XXX XX.XX % P, DS = XXX XX.XX % P, Do you want to use new standards"? If it shows a PASS/PASS, record the density standard count (DS) and moisture standard count (MS) in the gauge log book and on the appropriate form, then press the "YES" key. If you receive a PASS/PASS to the right of the percentages, it indicates that the standard counts are within the 1% density tolerance and 2% moisture tolerance.

8. If the density standard (DS) or moisture standard (MS) count fails, the screen will show "Do you want to use the new STD"? Press the "YES" key. Check the moisture-density gauge seating and positioning, is the standard block on a flat and recommended surface? If yes, then take another standard count.

9. It may take up to five standard counts before obtaining a PASS/PASS result. In the event that a PASS/PASS result is not obtainable, contact the Independent Assurance Lab for further assistance.

DENSITY CORRELATION (3440 or 3450 SERIES GAUGES)

1. During correlation, the offsets must be <u>off</u>.

2. Perform correlation tests at three locations. Correlation tests may be performed on the jobsite or an informational pad using approved representative material that will be incorporated into the project. Take the moisture-density gauge tests first. Refer to Figure 1 for correct positioning of the moisture-density gauge during correlation testing. For the correlation procedure, be sure to perform all of the nuclear density tests and the sand cone tests at the same depth to allow all tests to be compared as a group. Once correlated, the moisture-density gauge may be used at any rod depth.

3. After the three correlation holes are completed in accordance with Test Method Nev. T102 and this test method, <u>average</u> the three sand cone wet densities and <u>average</u> the three moisture-density gauge wet densities. Subtract the moisture-density gauge wet density average from the sand cone wet density average, this equals the moisture-density gauge offset for the wet density. See Table 1 for an example.

4. Enter the density offset, calculated above in kg/m^3 (lb/ft^3) with the proper sign (±) into the moisture-density gauge. Follow the flow chart in the moisture-density gauge manual under wet density offsets.

5. Check the density offset every shift and every time a different material is used to ensure that the number entered into the moisture-density gauge is still the correct value for the material being tested. If the moisture-density gauge turns off, all offsets may default to the off position.

MOISTURE CORRELATION (3440 or 3450 SERIES GAUGES)

1. During correlation, the offsets must be off.

2. Perform correlation tests at three locations. Correlation tests may be performed on the jobsite or an informational pad using approved representative material that will be incorporated into the project. Take moisture-density gauge tests first. Refer to Figure 1 for correct positioning of the moisture-density gauge during correlation testing. For the correlation procedure, be sure to perform all of the moisture-density gauge tests and the sand cone tests at the same depth to allow all tests to be compared as a group. Once correlated, the moisture-density gauge may be used at any rod depth.

3. After the three correlation holes have been completed in accordance with Test Method Nev. T102 and this test method, average the three sand cone moistures and average the three moisture-density gauge moistures. See Table 1 for an example.

4. Determine the moisture content of the samples obtained from the moisture-density gauge/sand cone correlation tests per Test Method Nev. T112. Record these results on the appropriate form. See Table 1 for an example.

5. Use the formula in Table 1 to calculate the moisture correction factor.

6. Follow the flow chart in the moisture-density gauge manual under "Moisture Offsets". Select "Gauge Derived" for source of offset. The moisture-density gauge will derive the moisture offset.

7. Once derived, follow the flow chart in the moisture-density gauge manual under "Moisture Offset - Gauge Derived".

8. Check the moisture offsets every shift and every time a different material is used to ensure that the number entered in the gauge is still the correct value for the material being tested. If the moisture-density gauge turns off, all offsets may default to the off position.

Table 1
In-Place Wet Density Correlation
With Offsets Disabled

Test No.	Sand Cone Wet Density	Nuclear Gauge Wet Density	
1-1B-95	2.239 (139.7)	2.228 (139.0)	
2-1B-95	2.210 (137.9)	2.189 (136.6)	
3-1B-95	2.212 (138.0)	2.228 (139.0)	
			Difference (±)
Average	2.220 (138.5)	2.215 (138.2)	+ 0.005 (+ 0.3)

Avg. Sand Cone - Avg. Nuclear Gauge = Nuclear Gauge Offset (carry to .001 (0.1))

Test No.	% Moisture Oven Dry	% Moisture Gauge
1-1B-95	4.8	5.0
2-1B-95	5.4	6.9
3-1B-95	4.9	6.3
Average	5.0	6.1

Calculate the moisture correction factor using the average % moisture oven dry and average % moisture gauge as follows:

$$\text{Moisture Correction Factor} = \left(\frac{\text{avg. \% moisture oven dry - avg. \% moisture gauge}}{100 + \text{avg. \% moisture gauge}} \right) \times 1000$$

Example**:**

Round to the nearest 0.01

$$\text{Moisture Correction Factor (M.C.F.)} = \left(\frac{5.0 - 6.1}{100 + 6.1} \right) \times 1000 = -10.37$$

Enter the moisture correction factor value into the moisture-density gauge as per the manufacturer's instruction manual. Pay close attention to the algebraic sign.

Once the density and moisture offsets have been entered into the moisture-density gauge, perform two "check tests" at two random locations with the offsets "enabled". Check tests may be performed on the jobsite or an informational pad using representative material to ensure the results are within the maximum deviation tolerance as shown in Table 2.

Table 2
Tolerances for Two Check Tests
With Offsets Enabled

Maximum deviation is defined as the largest difference between any single moisture-density gauge test and sand cone test (at the same site) obtained during the check tests.

Maximum Deviation for Wet Density:
± .032 Mg/m^3 (± 2.0 lb/ft^3)

Check Tests
(Gauge Correlation Check)

Test No.	Sand Cone Wet Density	Nuclear Gauge Wet Density	Difference (±)
4-1B-95	2.271 (141.7)	2.255 (140.7)	+ 0.016 (+ 1.0)
5-1B-95	2.256 (140.8)	2.239 (139.7)	+ 0.017 (+ 1.1)

Maximum Deviation for Wet Density: + 0.017 (+ 1.1)
(± 0.032 Mg/m^3 or ± 2.0 lb/ft^3 Allowable)

Check Test
(Every 25 Compaction Test)

Test No.	Sand Cone Wet Density	Nuclear Gauge Wet Density	Difference (±)
10-1B-95	2.271 (141.7)	2.255 (140.7)	+ 0.016 (+ 1.0)

Maximum Deviation for Wet Density: + 0.016 (+ 1.0)
(± 0.032 Mg/m^3 or ± 2.0 lb/ft^3 Allowable)

NOTES PERTAINING TO MOISTURE-DENSITY GAUGE CORRELATION PROCEDURE

1. When performing the correlation tests, special attention should be given to ensure the sand cone tests and oven-dry moisture tests are completed carefully and accurately. If the soil is found to be non-uniform during the excavation of the sand cone test, or if the first two moisture-density gauge tests do not check within the 6% tolerance described in the PROCEDURE section, the test site should be abandoned and another site chosen for correlation test purposes.

2. Each correlation will consist of three moisture-density gauge tests and three sand cone tests.

3. Perform all three moisture-density gauge tests and sand cone tests (correlation tests), at the same time to avoid a deviation in the material. Once the density and moisture offsets have been determined and entered into the gauge, perform the moisture-density gauge tests and sand cone tests (check tests), to ensure the offsets were entered correctly, and that the correlation meets the maximum deviation specification for wet density (Table 2).

4. The two check tests for gauge correlation only need to be completed through the field density dry in accordance with Test Method Nev. T102 and this test method.

5. Once the moisture-density gauge is correlated, that moisture-density gauge correlation will be used until any of the conditions listed under RECORRELATION REQUIRED occur.

6. Correlation is gauge specific and will not be used for other gauges.

7. If the moisture-density gauge fails to meet the correlation tolerances, try to re-correlate the moisture-density gauge. If the moisture-density gauge re-correlation is still outside of the correlation tolerances, then sand cone Test Method Nev. T102 shall be performed on that material. There are no exceptions to the correlation procedure. Partial correlations will not be accepted.

PROCEDURE (3440 or 3450 SERIES GAUGES)

1. Use the moisture-density gauge for acceptance testing when a passing moisture-density gauge correlation has been accepted per the correlation tolerances.

2. Prior to performing the moisture-density gauge test, use the "Guide and Site Preparation Device" to clear away all loose surface material to obtain a smooth surface large enough to seat the moisture-density gauge. After the completion of compaction, where sheepsfoot and similar type compaction rollers have been used, remove the loose surface material to a depth of not less than 50 mm (2 in.) below the deepest disturbance by the rollers. If voids are present, fill them in using the material to be tested. Avoid building a pad, by using the 4.75 mm (No. 4) sieve to obtain the - 4.75 mm (- No. 4) material to smooth minor depressions or protrusions to a smoothness within ± 3 mm (± 1/8 in.).

3. Set the count time to one minute by pressing the "TIME" key. The screen will show "TIME: XX min 1 - 15 sec, 2 - 1 min, 3 - 4 min", press the "2" key to select one minute tests. The screen will then go back to the normal display.

4. Check the density and moisture offsets to make sure the proper correlation values are in the gauge for the material being tested. Press the "OFFSET" key and check.

5. Use the guide and drill rod to perforate a hole in the soil that is perpendicular to the surface. The hole shall be 50 mm (2 in.) deeper than the desired test depth. When using the guide and drill rod provided with the moisture-density gauge, the drill rod accounts for the extra 50 mm (2 in.). Place the drill rod through the extraction tool and insert into the scraper plate guide. Remove the drill rod by rotating and pulling up horizontally. Do not loosen the drill rod by tapping from side to side with a hammer. Care should be taken to avoid penetrating the lift below the material being tested.

6. Place source rod in the hole to the desired test depth. Ensure that the bottom of the moisture-density gauge is firmly seated and is in contact with the soil without rocking or tilting. Pull the moisture-density gauge backwards so the source rod is in firm contact with the side of the hole toward the scaler end of the moisture-density gauge.

7. Press the "START/ENTER" key. The screen will show "DEPTH: XX PR: XXXX, TIME: XX sec." After one minute, the counting will stop. The screen will show "%PR= XXX%, DD= XXX WD=XXX M=XX, %M=XX %VOIDS= XXXX". Record the wet density (WD), moisture (M), dry density (DD), and percent moisture (%M) on the appropriate form. Press the "SHIFT" key, then press the "COUNTS" key, and record the density counts and moisture counts. Rotate the moisture-density gauge 10 to 20 degrees and repeat this step. If the difference between the two density counts or the two moisture counts is less than or equal to 6% of the average of the two counts, then the average of these two tests constitutes one in-place test. The 6% rule is used to determine if the material under the moisture-density gauge is uniform.

   Example**:**

   Density Counts = 1486 and 1512

   1512 - 1486 = 26 (difference)

   $\frac{1486 + 1512}{2} = 1499$

   1499 x .06 = 90 (maximum allowable)

   * $26 \leq 90$

   Moisture Counts = 69 and 64

   69 - 64 = 5 (difference)

   $\frac{69 + 64}{2} = 67$

   67 x .06 = 4 (maximum allowable)

   ** $5 > 4$

   * Density counts are within the 6% rule.

   ** Moisture counts are not within the 6% rule.

   If either set of counts are not within this tolerance, obtain two additional one minute tests by rotating the moisture-density gauge each time to a new position. Rotate the moisture-density gauge 10 to 20 degrees to the left and right of the first two tested positions. In this case, the average of all four readings constitutes one in-place test and the 6% rule does not apply to the four sets of density counts and moisture counts.

RECORRELATION REQUIRED

The moisture-density gauge shall be re-correlated if any of the following occur:

a. Change in project.
b. Visual change in material or fails with the same compactive effort and moisture.
c. Change in source of material.
d. Check tests not within tolerances.
e. Change in the moisture-density gauge.
f. Moisture-density gauge is calibrated by Manufacturer or CRSO.
g. Compaction readings are over 102 percent.
h. At the discretion of the Engineer.
i. If, at any time, a single check test is out of the ± 0.032 Mg/m^3 (± 2.0 lb/ft^3) maximum deviation per Table 2, a new moisture-density gauge correlation is required.

TEST MAXIMUM DENSITY AND PERCENT RELATIVE COMPACTION

1. Obtain a representative sample of soil from the moisture-density gauge test site.

2. Determine the maximum dry density of the soil sample in accordance with Test Methods Nev. T104 and T108.

3. When the "SHIFT" and "% PR" buttons are pressed at the same time, the moisture-density gauge calculates the % relative compaction of the soil using the following formula:

$$\% \text{ Relative Compaction} = \left(\frac{\text{in-place dry density}}{\text{maximum dry density}} \right) \times 100$$

Note 2: Since there will always be at least two and sometimes four tests at each test site, % relative compaction will have to be calculated using the average of the dry densities from the site, divided by the maximum dry density of the particular material.

Note 3: In-place dry density is obtained by averaging the two or four in-place dry densities. Maximum dry density is obtained from Test Methods Nev. T104 and T108.

CHECK TEST

1. Every twenty five acceptance test performed with the moisture-density gauge will require a check of the moisture-density gauge correlation.

2. Run a single moisture-density gauge test and a sand cone test (refer to Figure 1 for correct positioning of the moisture-density gauge and sand cone test). It will also be required that a new calculated maximum dry density be determined. These tests shall be completed in accordance with Test Methods Nev. T102, T104, T108 and this test method.

3. During the check test, the gauge offsets must be enabled.

4. If the single correlation test between the moisture-density gauge and the sand cone test (wet densities) is not within the tolerance ± 0.032 Mg/m^3 (± 2.0 lb/ft^3) listed in Table 2, a new correlation will be required.

NOTES

1. Under no circumstance is the moisture-density gauge (Troxler Model 3440) to be used for testing the compaction of concrete or plantmix bituminous surface. Excessive temperatures may cause serious damage to the gauge affecting its longevity and operating performance.

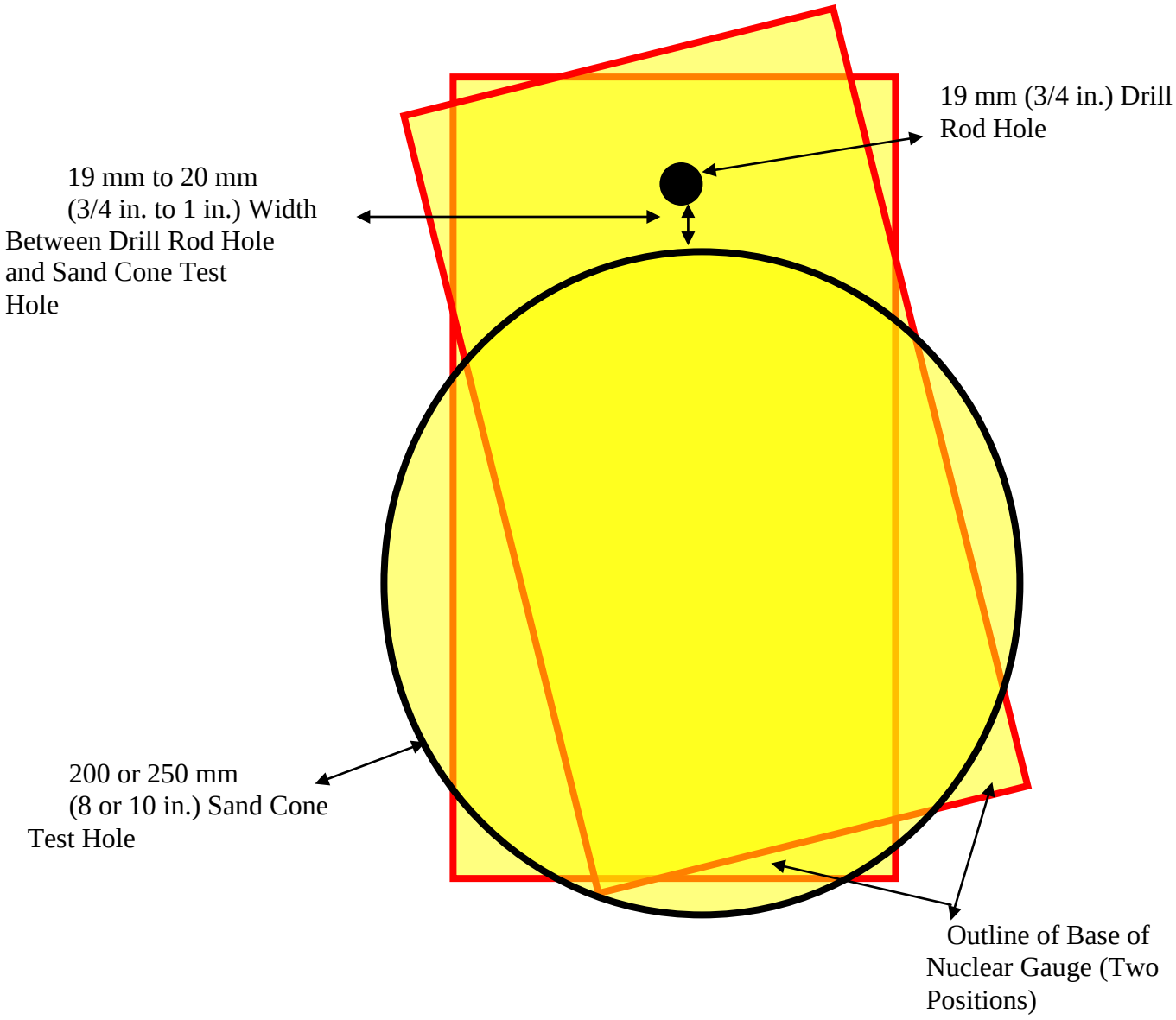
2. When the moisture-density gauge is within .6 m (2 ft) of any vertical object, a trench correction must be used for the moisture tests. Procedures for this setting are outlined in each individual gauge manual.

3. A total of 5 in-place densities (sand cones) are required to be performed for a valid Moisture/Density gauge correlation. A single maximum dry density determination as obtained per Test Method Nev. T108 may be utilized for all five locations.

4. Test Methods Nev. T104 and T108 must be performed whenever a second re-test is required.

REPORT

Report percent compaction to the nearest whole percent.



Correlation Test Site Location
Showing Relative Positions of the Moisture-Density Gauge and the Sand Cone Test

FIGURE 1