Method of Test
FIELD MOISTURE- DENSITY RELATIONSHIPS
DOTD Designation: TR 415

DETERMINATION BY FIELD CURVE

I. Scope

A. This test procedure is designed to determine the optimum moisture and maximum dry density of material based on a curve developed from field- condition material. The procedure is applicable to all soils and soil aggregates with or without cement or lime additive, including recycled in- place material. This method is to be used as permitted by DOTD TR 418 or the specifications.

Note 1: *If the moisture contents are properly adjusted during the test to provide a minimum of one point on the wet side and two points on the dry side, maximum density and optimum moisture can be determined with three points by using the Zero Air Voids Line to establish the wet leg of the curve. Additional points will be necessary if the first three moisture contents do not result in two points on the dry side and one point on the wet.*

B. Reference Documents
1. TR 418 - Moisture-Density Relationships
2. TR 403 - Determination of Moisture Content
3. AASHTO M 92 - Wire Cloth Sieves for Testing Purposes
4. DOTD S 401 -Sampling Soils
5. DOTD TR 108 - Splitting and Quartering Samples

II. Apparatus

A. Mold
1. A cylindrical metal mold having a capacity of 1/30 ft^3 manufactured with an internal diameter of 4.000 ± 0.016 in. and a height of 4.584 ± 0.005 in. and with a detachable collar approximately 2.5 in. in height, which can be fastened firmly to a base plate.
2. Molds are to be replaced when any diameter is more than 4.024 in. or the height is less than 4.550 in. at any point.
3. A cylindrical metal mold, having a capacity of 1/10 ft^3 manufactured with an internal diameter of 6.000 ± 0.026 in. and a height of 6.100 ± 0.016 in., and with a detachable collar approximately 3.5 in. in height, which can be fastened firmly to a base plate.
4. Molds shall be replaced if any diameter is more than 6.039 in. or the height is less than 6.000 in. at any point.
5. A cylindrical metal mold, having a capacity of 0.075 (1/13.33) ft^3, manufactured with an internal diameter of 6.000 ± 0.0026 in. and a height of 4.584 ± 0.0005 in., and with a detachable collar approximately 2.5 in. in height, which can be fastened firmly to a base plate.
6. Molds shall be replaced if any diameter is more than 6.039 in. or the height is less than 4.550 in. at any point.

Note 2: *Different makes of compactive devices may use mold base plates of different designs. The mold base plate must be compatible with the make of the compactive device used.*

B. Compactive device
   1. A metal 5.50 ±0.05 lb. rammer with a circular striking face with a diameter of 2.00 ±0.01 in. and arranged to control the height of drop to 12.00 ±0.06 in..
   2. A metal 10.0 ±0.1 lb. rammer, with a circular striking face with a diameter of 2.00±0.01 in. and arranged to control the height of drop to 18.00±0.06 in. (for use with 1/10 ft^3 mold only).

C. Compaction block - A uniform rigid foundation such as a stable block or pedestal composed of portland cement concrete with a smooth, level surface on the top and bottom, with both surfaces parallel, weighing a minimum of 200 lbs. The compaction block may be obtained from the district laboratory.

D. Straightedge - steel straightedge, approximately 12 in. long.

E. Balance or scale- a balance having a capacity of 30 lb. or more and sensitive to 0.01 lb.

F. Sieve - a No. 4 sieve conforming to AASHTO Designation M 92

G. Tools
   1. Mixing pans - with appropriate covers
   2. Shovel
   3. Spoons
   4. Pointed trowel
   5. Spatula - or large suitable mechanical device for thoroughly mixing the soil with water
   6. Large screwdriver- to remove material from mold
   7. Graduated cylinder (optional)
   8. Scalping screen - 1 in. brass sieve or box screen

H. Water

I. Sealable Containers - capable of holding required quantity of material (e.g., gallon cans with friction top lids)

J. Laboratory Curve

K. Density and Moisture Content Worksheet - Form No. 03-22-0750 (Figure 1)

L. Field Compaction Curve - Form No. 03-22- 4193 (Figure 2)

M. Engineer's Curve- Alvin 1010-21 or equivalent.

III. Sample: Processed material in field condition.

A. When the aggregate retained on the No. 4 sieve is 5% or greater, obtain a representative sample of 75 lb. of material in accordance with S-401. Obtain the sample from the roadway after blending of soil and additive (if applicable) prior to compaction.

B. When the aggregate retained on the No. 4 sieve is less than 5%, obtain a representative sample of 30 lb. of material in accordance with S-401. Obtain the sample from the roadway after blending of soil and additive (if applicable) prior to compaction.

C. Thoroughly mix the material.

D. In accordance with TR 108, split the mixed sample into five reasonably equal sized representative portions. Seal the representative portions in separate containers that will prevent moisture loss.

IV. Procedure

A. Select one of the representative portions. Squeeze a handful of material in the palm of your hand and analyze the moisture content in terms of the following.
   1. Material forms a cake which will bear very careful handling without breaking- material is at least 3 - 5% below optimum moisture.
   2. Material just dampens the hand when squeezed - material is near or at optimum moisture.
   3. Material leaves visible moisture on the hand when squeezed - material is above optimum moisture. For the purpose of this test, the material should be approximately 2 - 3% above optimum.

B. Adjust the moisture content of the representative portions until three portions meet each of the moisture conditions shown in Steps A. 1 - 3, using the following methods. Reseal each portion in its container. Set the remaining portions aside.
   1. Air - drying - Spread the representative portion into a pan and stir it as often as possible during the drying period.

   Note 3: *Under some weather conditions (e.g., low temperature, high humidity), it may be necessary to use the procedure for drying material in TR 403 to dry the material to a suitable moisture content. If this method is used, take care not to dry the material beyond the point needed to perform this test. Do not dry to constant weight.*

   2. Increase moisture content - Place a representative portion into another pan. Determine the weight of the representative portion. In accordance with Step V. A., calculate the amount of water required to increase the moisture content of the material approximately 2 - 3%. Add sufficient water to increase the moisture content of the material in increments of approximately 2 - 3%.

   Note 4: *The actual quantity of water needed will depend on the gradation and initial moisture content of the representative portion.*

C. Select the correct size mold.
   1. If the percent retained on No. 4 sieve is less than 5, select the 1/30 ft^3 mold.
   2. If the percent retained on the No. 4 sieve is 5 or greater, select the 1/10 ft^3 or the 0.075 ft^3 mold.

D. Mold the representative portions.
   1. Attach base plate to mold. Weigh mold and base plate to the nearest 0.01lb. and record as **e** on the worksheet.
   2. Attach the collar to the mold to complete the mold assembly and place the mold on the compaction block.
   3. Open the container of one representative portion and thoroughly mix the material.
   4. Place a quantity of the material in the mold in an even layer that will yield slightly more than 1/3 the volume of the mold after compaction. Remove and discard any material larger than one in. in diameter (e.g., aggregate, RAP, clumps of previously stabilized materials), and any trash (e.g., bottle caps, pavement markers, pieces of

concrete, steel, etc.). Reseal the container.

5. Use a pointed trowel to rearrange particles, filling voids in the loose material without compacting the material, to a uniform lift thickness.
6. Rest the rammer on top of the layer to be compacted. Compact the layer.
   a. When using the 1/30 ft^3 mold, use 25 blows per layer with the 5.50 lb. rammer from a 12 in. drop.
   b. When using the 1/10 ft^3 mold, use 75 blows per layer with the 5.50 lb. rammer from a 12 in. drop or 28 blows per layer with the 10.0 lb. rammer from an 18 in. drop.
   c. When using the 0.075 ft^3 mold, use 56 blows per layer with the 5.50 lb. rammer from a 12 in. drop or 20 blows per layer with the 10.0 lb. rammer from an 18 in. drop.
7. Note the height of the compacted material. If the compacted layer is not 1/3 the height of the mold, correct for any deviation by adjusting the quantity of material used for the subsequent layer.
8. Repeat Steps IV. D. 1 - 7 for two more layers.
9. After the third layer has been compacted, place the mold assembly and compacted specimen in a pan.
10. Tap the collar with the straightedge to loosen material bond. Remove the collar from the mold, without twisting or causing shear stress to the molded specimen.
11. Note the height of the compacted material.
   a. If the compacted material is greater than 0.25 in. above the top of the mold (for the 1/30 ft^3 mold) or 0.5 in. (for the 1/10 or 0.075 ft^3 mold), remix it with the original material and repeat the test.
   b. If the compacted material is below the rim of the mold, remove all the material from the mold, remix it with the original material and repeat the test.
12. Keeping the mold, base plate, and specimen in the pan, trim the specimen even with the top of the mold, using the straightedge. Fill any depressions formed during trimming with the trimmed material. After the depressions are filled, smooth the top of the cylinder with the straightedge even with the top of the mold.
13. Determine the weight of the mold, base plate, and specimen and record as d on the worksheet.
14. Determine the wet density of the specimen in accordance with Step V.B. Record as g on the worksheet.
15. Detach the base plate from the mold.
    Remove the specimen from the mold.
16. Take a moisture sample from the center of the compacted specimen. Determine the wet weight, dry weight, weight of water, and moisture content of the test specimen in accordance with DOTD TR 403. Record on the worksheet as i, j, and k (respectively).
17. Determine the dry density of each specimen in accordance with Step V.C.
18. Plot the point on the Field Compaction Curve, representing the intersection of a horizontal line projected from the dry densities and a vertical line projected from the moisture contents.
19. Open the container for the second representative portion and thoroughly mix the material.
20. Mold this material in accordance with Steps D.1 - 18.

21. Thoroughly mix the third representative portion. Mold this material in accordance with Steps D. 1 - 16.

E. Develop a moisture-density curve.
   1. Draw a line parallel to the Zero Air Voids Line through the point with the highest moisture content.
   2. Draw a line through the other two points, intersecting the line drawn in Step 1.
   3. Evaluate the two lines in terms of the following:
      a. Ensure that a minimum of three points meet the conditions in Step IV. A.
      b. No point falls to the right of the Zero Air Voids Line. Any point that falls to the right of the Zero Air Voids Line is not valid and must be rerun.
   4. If the above conditions are met, round the peak of the curve, as closely as possible to the intersection, to form a smooth continuous line.
   5. If all above conditions are not met, run additional representative portions in accordance with Steps IV.D.1 -18 until these conditions are met.
   6. Determine the Optimum Moisture Content, %. The Optimum Moisture Content is the moisture content corresponding to the peak of the Dry Weight Density Curve.
   7. Determine the Maximum Dry Density. The Maximum Dry Density is the dry density of the soil at the optimum moisture content.

V. Calculations

A. Use the following formula to calculate the quantity of water needed to increase the moisture content of the representative portion by approximately 2- 3%, as needed.

$$C = A \times B$$

Where:

C= approximate quantity of water to be added, lb.
A = wet wt of representative portion, lb.
B = water to be added, decimal

Example:

A= 5lb.
B= 0.02

$$C = 5 \times 0.02$$
$$C = 0.1 lb.$$

Note 5: *If the technician prefers to measure water, instead of weighing it, to convert from weight to volume in mL, multiply water weight by the constant 454 (the number of grams in a pound) [1 g = 1 mL].*

Example: $0.1\ lb \times 454 = 45.4\ ml$

B. Calculate the wet density of each test specimen
   1. Calculate the wet weight of compacted soil to the nearest 0.01 lb. using the fallowing formula:

$$f = d - e$$

Where:
d = 13.51 lb.
e = 9.32 lb.

$$f = 13.51 - 9.32$$
$$f = 4.19\ lb$$

2. Calculate the wet density of each specimen to the nearest 0.1 ft^3 using the following formulas:
   a. For the 1/30 ft^3 mold: g = f × 30
   b. For the 1/10 ft^3 mold: g = f × 10
   c. For the 0.075 ft^3 mold: g = f ÷ 0.075

   Where
   g = wet density of the specimen
   f = wet wt. of compacted soil
   30 and 10 = constants, representing the reciprocal of the volumes of the molds, ft^3

   Example:
   f = 4.19

$$g = 4.19 \times 30$$
$$g = 125.7 lb/ft^3$$

C. Calculate the dry density to the nearest 0.1 lb/ft^3 using the following formula:

$$l = \frac{100 \times g}{100 + k}$$

Where:
l = dry density, lb/ft^3
g = wet density of specimen, lb/ft^3
k = moisture content, %
100 = constant, converts to decimal

Example:
g = 125.7
k = 15.2

$$l = \frac{100 \times 125.7}{100 + 15.2}$$

$$l = \frac{12{,}570}{115.2}$$

$$l = 109.114 = 109.1$$

VI. Report

Report optimum moisture (OM) and maximum dry density (PR).

VII. Normal Test Reporting Time

Normal testing and reporting time is two hours.

Louisiana Department of Transportation and Development
DENSITY & MOISTURE CONTENT WORK SHEET

DOTD 03-22-0750
Metric / English
Rev. 12/98

Metric / English E (M or E) **SMM ID#** ______

Project No. ______ **Date Tested** ______ **Matl Cd** ______

Submitted By ______ **Purpose code** ______ **Item No.** ______

Test Method ___ N = Nuclear S = Sand Cone **Spec** ______

Station Tested ______ Section & Test No. ______

Location: ______ Lift No: ______ Depth of Test: ______

OM:	Optimum % Moisture Content of Total Material (TR 415 or 418)	OM	
%FM:	Field % Moisture Content at Compaction (TR 403) (see back for calculations)	%FM	
P_1:	% Pulverization 19mm (3/4" SIEVE) (TR 431) (see back for calculations)	P_1	
P_2:	% Pulverization 4.75mm (NO.4 SIEVE) (TR 431) (see back for calculations)	P_2	

(TR 415) Cross Reference Test No.	Max. Dry Density Method (TR 415)		
a: Total Wet Mass (Wt.) of Sample			
b: Mass (Wt.) of +4.75 (+4) Material			
c: % By Mass (Wt.) of 4.75 (+4) Retained (100 b/a)			
d: Mass (Wt.) of Mold & Soil	13.51	13.34	13.51
e: Mass (Wt.) of Mold	9.32	9.33	9.32
f: Mass (Wt.) of Compacted Soil (d - e)	4.19	4.01	4.19
g: Wet Density (f x 30)	125.7	120.3	125.7
h: Mass (Wt.) of Wet Soil	1.44	1.39	1.40
i: Mass (Wt.) of Dry Soil	1.25	1.23	1.18
j: Mass (Wt.) of Water (h - i)	0.19	0.16	0.22
k: % Moisture Content (100 j / i) (TR 403)	15.2	13.0	18.6
l: Dry Density 100g / (100 + k)	109.1	106.5	106.0

SAND METHOD (TR 401)	
SA: Mass (Wt.) of Sand in Mold	
SB: Vol. of Mold	
SC: Unit Mass (Wt.) of Sand (SA / SB)	
SD: Orig. Mass (Wt.) of Sand	
SE: Final Mass (Wt.) of Sand	
SF: Mass (Wt.) of Sand in Cone (SD - SE)	
SG: Orig. Mass (Wt.) of Sand	
SH: Final Mass (Wt.) of Sand	
SI: Mass (Wt.) of Sand in Cone & Hole (SG - SH)	
SJ: Mass (Wt.) of Sand in Hole (SI - SF)	
SV: Vol. of Hole (SJ / SC)	
SW: Dry Mass (Wt.) of Material	
SSD: Dry Density (SW / SV)	
PR: Maximum Dry Dens. (TR 415 / TR 418)	
%PR: % Density (Sand) (SSD / PR) x 100	

NUCLEAR METHOD (TR 401) Nuclear Device Number Insp. (Nuclear Badge No.)	Test 1	Test 2	Test 3
DS: Density Standard Count			
DC: Density Test Count			
DR: Density Count Ratio (DC / DS)			
WD: Wet Density			
MS: Moisture Standard Count			
MC: Moisture Test Count			
MR: Moisture Count Ratio (MC / MS)			
M: Moisture by Mass (Wt.)			
MP: Moisture by Percent - TR 401 / TR 403			
NDD: Dry Density (WD - M) or (100WD)/(100+MP)			
%NPR % Density (NDD / PR) x 100			
ADD: Average Dry Density (NDD) or (NDD/3)			
PR: Maximum Dry Density (TR 415 / TR 418)	109.8		
%PR: % Dens. (Nuclear) (% NPR) or (% NPR/3)			

Remarks ______

______ (Signature)

Figure 1
Density and Moisture Content Worksheet (03-22-0750)

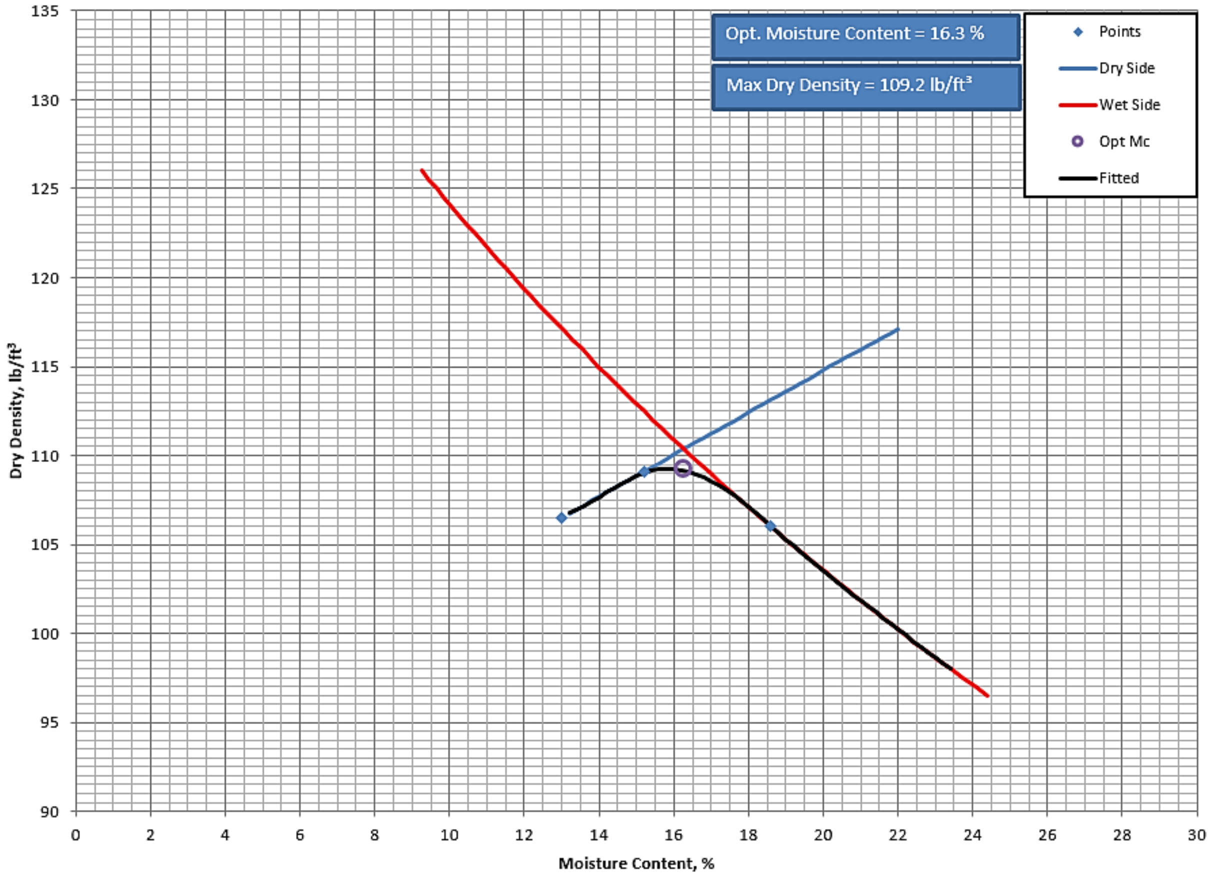

Figure 2
Field Compaction Curve