

2026 Edition



SOIL DENSITY



**Intentionally Left Blank-
Notes if Needed**

Soil Density Technician

Updates

- **2026 Updates:**
 - No Method updates
 - Make sure to use whole numbers when running the corrected Dry density & Moisture
- **2025 Updates:**
 - No Method updates
- **2024 Updates:**
 - No Method updates.
- **2023 Updates:**
- **AASHTO T99:**
 - **T99 Drying Oven:** The thermometer for measuring the oven temperature shall meet the requirements of M339M/M339 with a range of at least 0 to 130°C (32 to 266°F) and an accuracy of $\pm 1.25^{\circ}\text{C}$ ($\pm 2.25^{\circ}\text{F}$) (see note 1),
 - NOTE 1: Thermometer types to use include:
 - ASTM E1 Mercury Thermometer
 - ASTM 2877 digital metal stem thermometer
 - ASTM E230/E230M thermocouple thermometer, Type J or K, Special Class, Type T any Class
 - IEC 60584 thermocouple thermometer, Type J or K, Class 1, Type T any Class
 - Dial gauge metal stem (bi-metal) thermometer
- **AASHTO T265:**
 - **T265 Drying Oven:** The thermometer for measuring the oven temperature shall meet the requirements of M339M/M339 with a range of at least 0 to 130°C (32 to 266°F) and an accuracy of $\pm 1.25^{\circ}\text{C}$ ($\pm 2.25^{\circ}\text{F}$) (see note 1),
 - NOTE 1: Thermometer types to use include:
 - ASTM E1 Mercury Thermometer
 - ASTM 2877 digital metal stem thermometer
 - ASTM E230/E230M thermocouple thermometer, Type J or K, Special Class, Type T any Class
 - IEC 60584 thermocouple thermometer, Type J or K, Class 1, Type T any Class
 - Dial gauge metal stem (bi-metal) thermometer

- **AASHTO T310:**

- **T310 Drying Oven:** The thermometer for measuring the oven temperature shall meet the requirements of M339M/M339 with a range of at least 0 to 130°C (32 to 266°F) and an accuracy of $\pm 1.25^{\circ}\text{C}$ ($\pm 2.25^{\circ}\text{F}$) (see note 1),
 - NOTE 1: Thermometer types to use include:
 - ASTM E1 Mercury Thermometer
 - ASTM 2877 digital metal stem thermometer
 - ASTM E230/E230M thermocouple thermometer, Type J or K, Special Class, Type T any Class
 - IEC 60584 thermocouple thermometer, Type J or K, Class 1, Type T any Class
 - Dial gauge metal stem (bi-metal) thermometer

2021-22 – NO Updates

Intentionally Left Blank- Notes if Needed

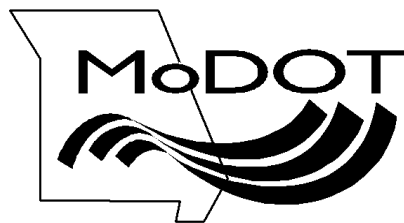
COURSE CONTENT

SOIL DENSITY

AASHTO T 265	Laboratory Determination of Moisture Content of Soils
AASHTO T 99	Moisture-Density Relations of Soils
MoDOT TM 40 (AASHTO T 272)	A One-Point Method for Determining Maximum Dry Density & Optimum Moisture
AASHTO T 310	In-Place Density and Moisture Content of Soil and Soil-Aggregate by Nuclear Methods (Shallow Depth)
MoDOT TM 35	Moisture Offset Factor for a Nuclear Gauge

Appendix

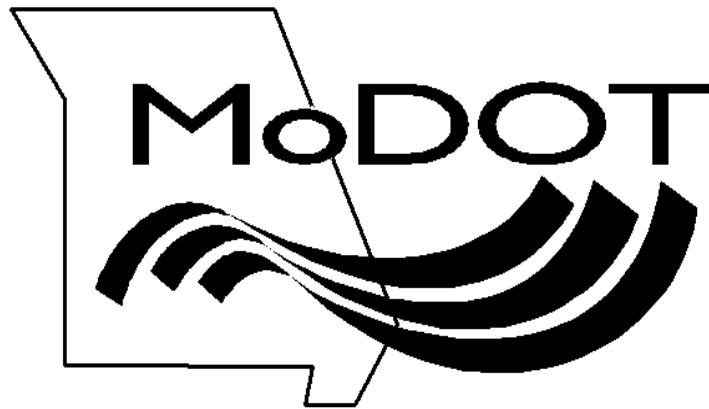
Glossary



Intentionally Left Blank- Notes if Needed

AASHTO T 265

Laboratory Determination Of Moisture Content of Soils



**Intentionally Left Blank-
Notes if Needed**

Required Audits

All testers on Federal-Aid Projects (MoDOT or Off-System) are required by the FHWA to be audited at least once per year.

Reasons:

- To ensure proper test procedures are being utilized.
- To ensure testing equipment is calibrated and operating properly.
- **Types of Audits;** procedure or comparison.
- **Be Proactive;** schedule your audit as early as possible with MoDOT Materials in district offices, do NOT wait until the end of the year.
- **Provide Proof;** when audited, present a MoDOT Certification Card, or a MoDOT Letter.

1

AASHTO T 265

LABORATORY DETERMINATION OF MOISTURE CONTENT OF SOILS



10/22/2019

2

SCOPE

- This method covers the laboratory determination of the moisture content of soils.

(3)

3

INFORMATIONAL

Moisture Content:

- Soil that is not completely dry contains moisture.
- Everything that identifies soil properties for the construction process revolves around moisture content.
- It is important to know the percentage of moisture in the soil in order to perform the tests that identify a soil's engineering properties.

[4]

4

- Moisture content is a factor in determining Atterberg Limits.
- The correct moisture content is needed to achieve maximum compaction and to allow stabilizing or modifying chemicals to work.
- Adequate compaction can only be achieved if a soil is very close to its optimum moisture content.

Informational

[5]

5

- Moisture content of a soil also influences the processes used to excavate it, consolidate it, aerate it, and determine its gradation.
- The moisture content of a soil refers to the quantity of water it contains.
- In soil mechanics, soil moisture content is always expressed as a percent by dry mass.

Informational

[6]

6

• **There are four types of soil moisture:**

1. Gravitational: water that is free to move under the influence of gravity.
2. Capillary: water held by capillary action in the soil pores.
3. Hygroscopic: water that forms a film around the individual soil particles.
4. Interstitial: loosely bonded water contained within the internal structure of soil particles.

Informational

[7]

7

TERMINOLOGY

- Moisture or Water Content of a Soil – The ratio, expressed as a percentage, of the mass of water in a given mass of soil, to the mass of the solid particles.
- Practical application is to determine the mass of water removed by drying the moist soil to a constant mass in a drying oven controlled at $230 \pm 9^{\circ}\text{F}$ ($110 \pm 5^{\circ}\text{C}$) and to use this value as the mass of water in the given soil mass. The mass remaining after oven-drying is used as the mass of the solid particles.

Informational

[8]

8

EQUIPMENT

- **Scale** – readable to 0.1% of the sample mass or better.
- **Oven** – $230 \pm 9^{\circ}\text{F}$ ($110 \pm 5^{\circ}\text{C}$).
- **Drying containers** – Made of material resistant to corrosion and not subject to change in mass or disintegration on repeated heating and cooling, equipped with close fitting lids to prevent moisture loss before initial weighing and moisture absorption following drying, before final weighing.

Informational

[9]

9

TEST SAMPLE

Maximum Particle Sieve Size*:in.(mm)	Minimum Mass of Test Sample, grams
#40 (0.425)	10
#4 (4.75)	100
½" (12.5)	300
1" (25.0)	500
2" (50.0)	1000

* Sieve size which 100% of material passes.

10

10

PROCEDURE

1. Preheat oven and allow the temperature to stabilize to $230 \pm 9^\circ\text{F}$ ($110 \pm 5^\circ\text{C}$).
2. Weigh a clean, dry, sample container and lid and record the weight to the nearest 0.1g.
3. Place the moist sample in the container, cover immediately, weigh and record the weight to the nearest 0.1 g.
(Wet Weight)



11

11

4. Remove the lid and place the container with the moist sample and lid in the drying oven at $230 \pm 9^\circ\text{F}$ ($110 \pm 5^\circ\text{C}$).

Samples from AASHTO T 99



5. Dry overnight (15 hours minimum) or dry until the mass loss of the sample after 1 hour of additional drying is less than 0.1% (Constant Mass).

Field Samples MoDOT TM 35



12

12

6. Upon removal from the oven, immediately replace the lid, and allow the sample to cool to room temperature.

7. Weigh the container including the lid and the dried sample and record the weight.
(Dry Weight)

8. Calculate percent moisture to the nearest **0.1%**

Procedure

13

13

NOTES:

- NOTE 1:
 - Since dry soil may absorb moisture from wet samples, dried samples should be removed before placing wet samples in the oven.
- NOTE 2:
 - Soil containing gypsum or other minerals having loosely bound water from hydration or for soil containing significant amounts of organic material, may be dried in an oven at approximately 140°F (60°C), or by vacuum desiccation at a pressure of approximately 10 mmHg and at a temperature not lower than 70°F (23°C).

Notes

14

14

- NOTE 3:
 - A container without a lid may be used provided the moist sample is weighed immediately after being taken, and provided the dried sample is weighed immediately after being removed from the oven or after cooling in a desiccator.
- NOTE 4:
 - Moisture content samples should be discarded and should not be used in any other tests.

Notes

15

15

CALCULATIONS

- The calculations are represented by the following equation:

$$w = \left[\frac{(W_1 - W_2)}{(W_2 - W_c)} \right] \times 100$$

- w = Moisture content, %
- W_1 = Mass of container (with lid) and moist soil, g
- W_2 = Mass of container (with lid) and oven dried soil, g
- W_c = Mass of container (with lid), g
- Report Percent Moisture to the nearest 0.1%**

16

16

- Another way to understand the equation:

$$\% \text{ Moisture Content} = \left[\frac{\text{mass of moisture}}{\text{mass of oven dry soil}} \right] \times 100$$

Calculations

17

17

EXERCISE #1:

Wet Sample $W_1 = 329.6$ grams

Dry Sample $W_2 = 276.2$ grams

Container & cover $W_c = 15.2$ grams

Report to the nearest **0.1%**

$$w = \left[\frac{(W_1 - W_2)}{(W_2 - W_c)} \right] \times 100$$

18

18

EXERCISE #1:

$$w = \left[\frac{(329.6 - 276.2)}{(276.2 - 15.2)} \right] \times 100$$

$$w = 20.459 = \mathbf{20.5\%}$$

ANSWER

19

19

EXERCISE #2:

Wet Sample = 325.2 grams

Dry Sample = 299.3 grams

Container & cover = 14.9 grams

Report to the nearest 0.1%

20

20

TESTING ERRORS:

- Failure to protect sample from exposure to air.
- Overheating the test specimen.
- Losing material when a forced air oven is used.
- Failure to dry to a constant mass.
- Weighing inaccuracy caused by placing a too hot container on scale.
- Placing a wet sample in an oven with an almost dry sample.

21

21

ORGANIC SOILS:

- Care must be used to obtain accurate moisture content of soils containing organic material.
- Air dry or dry at 140°F (60°C).
 - Note: Not much of a problem in Missouri.

22

Answer to exercise #2 = 9.1% Moisture

22

AASHTO T 265: Laboratory Determination of Moisture Content of Soils PROFICIENCY CHECKLIST

Applicant: _____

Employer: _____

	Trial #	1	2
Procedure			
1. Preheat oven to 230 ± 9°F (110 ± 5°C)			
2. Mass of clean, dry container plus lid determined			
3. Sample placed in container, lid immediately placed, and weighed. (Wet Weight)			
Note: Soils containing organic material can be air dried or oven-dried at approximately 140°F (60°C).			
4. Lid removed and placed container with the moist sample and lid in the drying oven at 230 ± 9°F (110 ± 5°C).			
5. Dried overnight (15 hours minimum) or until the mass loss of the sample after 1 hour of additional drying is less than 0.1% (Constant Mass).			
6. Lid replaced immediately, and sample cooled to room temperature.			
7. Container, including lid and dried sample, weighed. (Dry Weight)			
8. Percent moisture calculated to the nearest 0.1% by:			
$w = \left[\frac{(W_1 - W_2)}{(W_2 - W_c)} \right] \times 100$			

PASS PASS

FAIL FAIL

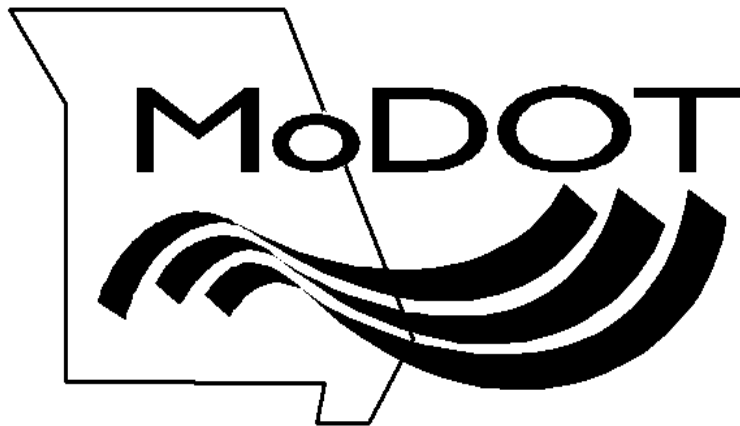
Examiner: _____ Date: _____

Intentionally Left Blank- Notes if Needed

AASHTO T 99

Moisture-Density Relations of Soils

(Standard 4 – Point Proctor Test)



**Intentionally Left Blank-
Notes if Needed**

AASHTO T 99

Moisture - Density Relations of Soils (Standard 4-Point Proctor Test)

1

Rev 08/22/2024

1

SCOPE

- It is important to know the percentage of moisture in the soil to perform several tests that identify a soil's engineering properties.
- The following methods of testing are intended for determining the relations between the moisture content and the density of soils compacted in a mold of a given size with a 5.5 lb. rammer dropped from a height of 12 inches.

2

2

Scope

- Four alternate methods are provided; Methods A, B, C and D.
- **This review will focus on Method A and Method C; both use a 4" mold.**

3

3

Proctor Compaction Curve

Scope

- This method creates a Proctor Compaction Curve using the data from each sample compacted.
- The data is then used to create a graph with a curve going through the Proctor points to determine **Optimum Moisture** and **Maximum Dry Density**.

7

7

Example of a Proctor Compaction Curve.

Scope

Plot Proctor Points

- X – axis: % Moisture (MC)
- Y – axis: Dry Density (DD)

Draw Proctor Curve

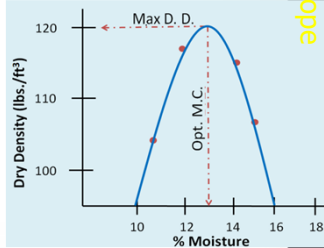
- Decide \approx peak location
- Draw smooth parabola

Record Peak Values

- Maximum Dry Density (Max DD)
- Optimum Moisture Content (Opt. MC)

Report Density (DD) & Moisture Content (MC)

- Max DD: Nearest 0.1 lb./ft³
- Optimum MC: Nearest 0.1%



8

8

TERMINOLOGY

Terminology

- **Maximum Dry Density:** Proctor value entered Nuclear Gauge for future compaction testing out in the field to determine the % compaction of the soil.
- **Optimum Moisture:** Used in the field as a target to help achieve the desired degree of compaction and prevent instability of the soil structure.

9

9

- **Percent Compaction:** Comparison between the compaction achieved in the field (in-place density) and the maximum compaction possible for that soil when compacted under a set of controlled conditions as they exist in the laboratory.
- **Proctor:** Principles of compaction were developed by R.R. Proctor in the 1930's. Some may refer to this method as a "Proctor Compaction Test" or a "Proctor Test".

Terminology

10

10

- **Plasticity Index:** Range of moisture in which a soil remains in a plastic state while passing from a semisolid state to a liquid state.
- The liquid state is called the Liquid Limit (**LL**) and the semisolid state is called the Plastic Limit (**PL**).
- The **PL** may be used to determine the starting point of adding a moisture to a proctor sample.

Terminology

11

11

EQUIPMENT

Diagram of Equipment

The diagram illustrates the equipment used for soil compaction. On the left, a 'Manual Sleeve Rammer' is shown with a '12" Drop' and a '2" diameter'. Below it, a '5.5 lb. Rammer' is shown with a '4" diameter'. On the right, a soil sample is shown in three layers (Layer 1, Layer 2, Layer 3) with a 'Total of 5" In depth'. An 'Extension Collar' is also indicated on the left side of the diagram.

Equipment

12

12

Adding Moisture

- Prepare the sample(s) by mixing with water to produce the desired moisture content.
- Thoroughly mix the selected representative sample with sufficient water to dampen it to approximately 4% to 8% points below optimum moisture content.

Sample Preparation

16

16

- For the first point, the soil should barely form a cast after moisture has been added.



First Point Moisture

17

17

Degradable Soils:

- Add water to increase the moisture content of the soil from 1 to 2% (2.5% max) percentage points.
- When the series indicate a decrease or no change in wet unit mass, W_1 lb. per ft³ of the compacted soil, perform one more determination for a **minimum of two** determinations pass optimum moisture.

Sample Preparation

18

18

• **Heavy Clay Soils or Organic Soils:**

- To handle **Clayey** or **Organic** fragile type soils that may be difficult to incorporate water into, perform the following:
 - Mix a separate sample for each compaction test.
 - Each test will increase in **2% - 4%** max moisture increments from the previous one to the next.
 - Place each sample in an airtight container for at least **12 hours** prior to testing.

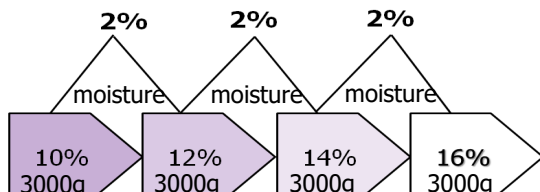
Note: Clayey Soil will have \approx LL greater than 50

Sample Preparation
19

19

Moisture Increment : Is a consistent change in moisture content between points.

- Usually **1 – 2%** Max is **2.5%**
- Heavy clays and organic soils are allowed up to **4%** increments.



Sample Preparation
20

20

• The following examples show how to calculate the amount of water to be added:

To convert desired moisture percentage to a decimal value for calculation, divide by 100.
 Example: For 14% Moisture
 $14/100 = 0.14$

Sample Preparation
21

21

• **Method A** - 3000g (7 lb.) of material.

Target desired = 14% moisture

Multiply 3,000 g x 0.14 = 420 g or ml of water to be added for the initial point.

Each subsequent **2%** increase would be calculated as follows:

Multiply 3,000 g x 0.02 = 60 g or 60 ml of additional water to be added to the 2nd, 3rd and 4th proctor point. (480 ml, 540 ml, 600 ml)

Note: 1 g of water equals 1 ml of water.

Sample Preparation

22

22

• **Method C** – 5,000 g (11 lb.) of material

Target desired = 14% moisture

Multiply 5,000 g x 0.14 = 700 g or ml of water to be added for initial point.

Each subsequent **2%** increase would be calculated as follows:

Multiply 5,000 g x 0.02 = 100 g or 100 ml of additional water to be added to the 2nd, 3rd, and 4th proctor point. (800 ml, 900 ml, 1000 ml)

Sample Preparation

23

23

Practice Calculation (4-point proctor):

- Using **Method C**, 5,000g of material,
- First target desired = 15% moisture
- Calculate the initial amount of water added.
- Then using a **2.5%** increment, calculate the amount of water to be added to the 2nd, 3rd, and 4th proctor point.

Practice Calculation

24

24

ANSWER

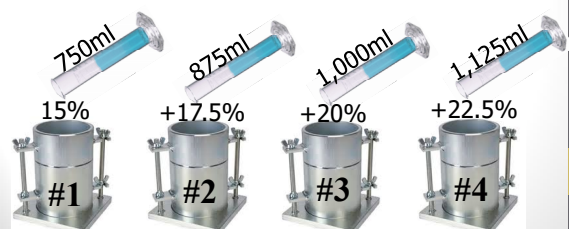
$$5,000 \times 0.15 = 750 \text{ ml}$$

$$2.5/100 = 0.025$$

$$5,000 \times 0.025 = 125 \text{ ml increments of water}$$

ml = milliliters

Using **2.5%** increments



25

25

PROCEDURE

Standard Proctor Test



Method A

4-inch Mold
25 blows
12-inch drop
3 Layers

26

26

- After sample preparation, compact three approximately equal layers for a total compacted **depth of 5 inches:**

- Record mass of the mold and base plate (without the collar) to the nearest 0.005 lb. (1 g).



27

27

2. Attach the collar to the mold and place the mold on a stable foundation that will remain stationary during compaction.

Stable Foundation or base:

Lab = A 200lb. Concrete block supported by a solid foundation (concrete floor).

Field = Concrete box culverts, bridges, and pavements.

Procedure

28

28

3. Place loose soil into the mold, evenly distribute to yield approximately 1/3 full after compaction (2/3 or 3/3 full).

4. Lightly tamp the soil with a 2" face tamper until it is not in a fluffy or loose state.

Note: The 12" drop is from the bottom side of the rammer face to the surface of the soil and shall uniformly distribute the blows over the entire surface area of the sample in the mold assembly.

Procedure

29

29

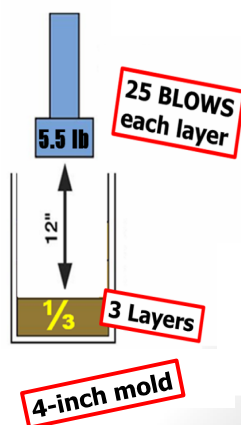
5. Apply 25 blows with the 5.5 lb. rammer with a 12 in. drop.

Move the rammer blows around the surface for even compaction.

6. After compaction, use a knife or suitable tool to trim the soil from the sides of mold and evenly distribute it on top of the layer.

Procedure

30



30

7. Repeat steps 3 through 6 for the two remaining lifts.

NOTE: The 3rd lift should be slightly above the top of the mold.



Procedure

31

31

After compacting the final layer,

8. Remove the extension collar and trim the sample even with the top edge of the mold using the straight edge.

- Remove any particles lodged between the mold and base plate.
- If there are voids, from coarse aggregate fill with excess soil.



Procedure

32

32

9. Clean off the mold base before weighing.



Clean the mold off before weighing

10. Weigh mold and base with sample.

- For **lb./ft³**, record to the nearest **0.005 lb.**
- For **kg/m³**, record to the nearest 1 gram.

Procedure

33

33

11. Extract the compacted sample.

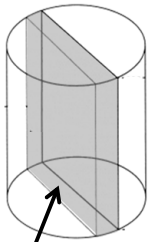


Procedure

34

34

12. Slice vertically through the center for a representative moisture content sample.

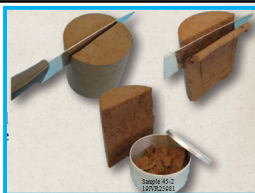


Procedure

35

Shaded area illustrates a representative moisture content sample.

35



Procedure

36

13. Remove a moisture sample from the slice and place it in pre-weighed can and weigh immediately.

Method A: Need approx. 100 g

Method C: Need approx. 500 g

Record Wet Weights to **0.1 g**

Write on the can: weight of can, sample ID, & No in sequence of moisture %

36

14. Sample dried and % moisture determined according to AASHTO T 265, Report moisture (w) to 0.1%.



37

37

15. If the remaining sample is to be reused, break up the remainder of the sample from the mold until it is judged by eye to pass the following:

- For Method A : **#4** (4.75 mm) sieve.
- For Method C : **3/4"** (19 mm) sieve with 90% of the fines in the sample passing a #4 (4.75 mm) sieve.

Add the broken-up sample to the remainder of the sample being used for the test.

38

38

16. Add an increment of water to increase the moisture content of the soil.

Select an increment;
usually 1 – 2%
Maximum of 2.5%

Mix thoroughly.

39

39

- Repeat the compaction process (Steps 2 through 15) for each increment of water added, until wet density either decreases or stabilizes
- Perform one more determination such that there is a minimum of two determinations over optimum moisture.

NOTE: Skip this step if samples were separate density points prepared prior to testing (i.e., clayey soils).

NOTE: If the soil sample is a non-cohesive drainable soil, one additional determination over optimum moisture is sufficient.

Procedure

40

40

CALCULATIONS

- Calculate the **wet density** of the material for Method A or C as follows:

$$W_1 = (M_{ms} - M_m) \times \text{Constant}$$

W₁ = Wet Density in lbs./ft³ (g/m³)

M_{ms}= Mass of mold, base, and sample in lbs. (g)

M_m = Mass of the mold and base in lbs. (g)

Report to the nearest 0.1 lbs./ft³

Calculations

41

41

English Constant

Constant = 30 = (per ft³.) based on English mold sizes. Same as dividing by 0.033333 ft³. which is the mold volume.

Metric Constant

Constant = 1060 = (per m³.) based on metric mold sizes. Same as dividing by 0.000943 m³. which is the mold volume.

Calculations

[42]

42

• Example

What is the **Wet Density** given:

Mass of mold, base, and wet sample: 8.925 lbs.

Mass of the mold and base: 5.325 lbs.

$$W_1 = (M_{ms} - M_m) \times \text{Constant}$$

$$W_1 = (8.925 - 5.325) \times 30$$

$$= 3.600 \times 30$$

$$= 108.0 \text{ lbs./ft}^3$$

Calculations

43

43

Determine Moisture Content

(AASHTO T 265)

Use material from the slice collected from the proctor; 100 g or 500 g.

$$w = \left[\frac{(W_1 - W_2)}{(W_2 - W_c)} \right] \times 100$$

w = Moisture content, %

W_1 = Mass of container (with lid) and moist soil, g

W_2 = Mass of container (with lid) and oven dried soil, g

W_c = Mass of container (with lid), g

Calculations

44

Report Percent Moisture to the nearest 0.1%

44

- Calculate the **Dry Density** for each compacted sample based on the corresponding moisture sample.

$$W = \frac{W_1}{w + 100} \times 100$$

W = Dry density in lbs./ft³

w = Moisture content of sample in %

W_1 = Wet Density in lbs./ft³

Report to the nearest 0.1 lbs./ft³

Calculations

45

45

• **Example**

• Calculate the **Dry Density** when Moisture Content (w), is 18.5%, and Wet Density (W_1) is 108.0 lbs/ft³?

$$W = \frac{W_1}{w + 100} \times 100$$

$W = \frac{108.0}{18.5 + 100} \times 100$ Dry Density

$W = \frac{108.0}{118.5} \times 100$ $W = 91.1 \text{ lb./ft}^3$

Calculations
46

46

Density-Moisture Content Graph

- Plot each compaction point for the dry density on graph paper with dry density on the (y-axis) and moisture content on the (x-axis). Draw a curve connecting the points.
- This can be done using a computer with a special program for Proctor Curves, or manually with graph paper and an Engineering Curve.
- If doing this manually, form a smooth line using the engineering curve by connecting the plotted points to form two curves as close as possible to the intersection, round the peak to form a smooth, continuous line.

Calculations-graph
47

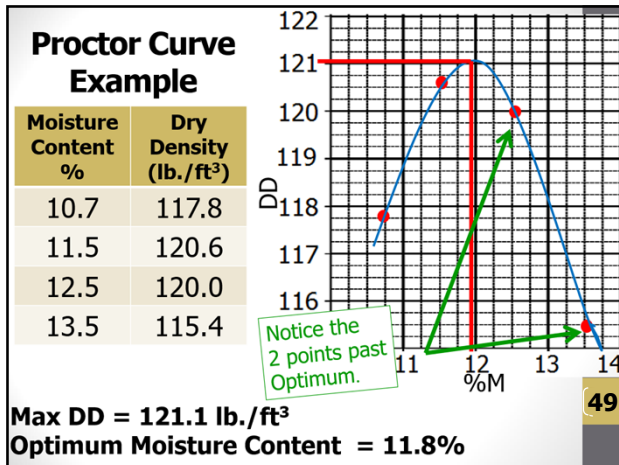
47

- The moisture content at the peak is the "Optimum Moisture Content".
- The Dry Density corresponding to the peak is the "Maximum Dry Density".

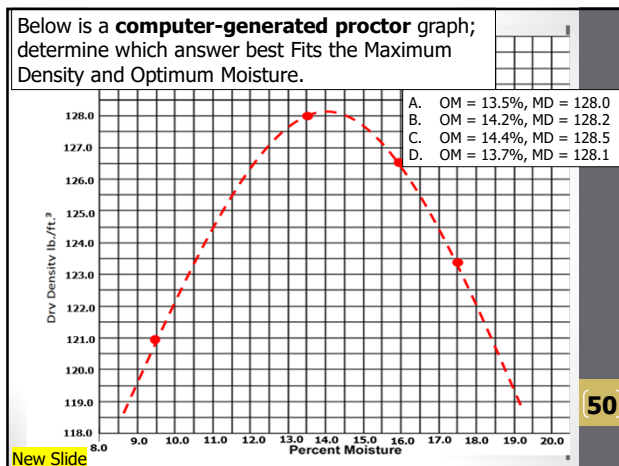
Maximum Dry Density is a proctor value entered into the nuclear gage.

Calculations-graph
48

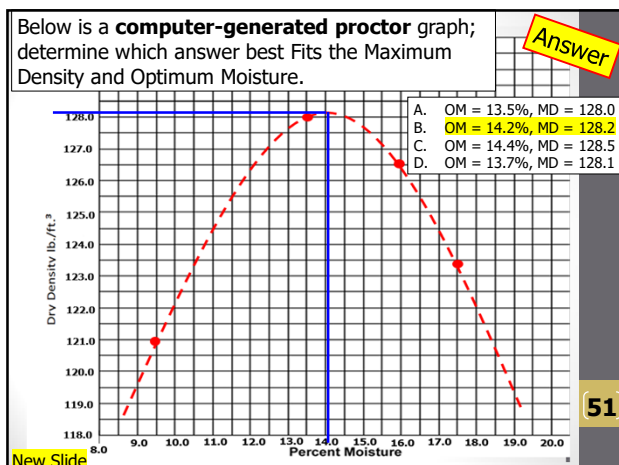
48



49



50



51

- Many Proctor Curves are generated by computers, however for today we will be generating curves manually, using graph paper and an Engineering Curve.

Calculations-graph

52

52

Classroom Exercise

- On the form provided draw a proctor curve manually using an Engineering Curve.
- Calculate the % Moisture for each point.
- Calculate the Dry Density for each point.
- Use calculated values to plot each point on the graph.
- Draw the parabolic curve
- Determine Maximum Dry Density and Optimum Moisture.

Calculations-graph

53

53

Practice Calculation

A.	Mold & Wet Soil, in lbs.	8.910	9.050	9.240	9.170
B.	Wt. of Mold, in lbs.	5.220	5.220	5.220	5.220
C.	Wt. of wet Soil in mold = A-B				
Moisture Determination					
D.	Wet Wt., in g	584.9	619.8	631.5	620.9
E.	Dry Wt., in g	486.6	509.7	506.0	488.9
F.	Wt. of Water = D-E				
G.	% Moisture = (F ÷ E) x 100				
H.	Dry Wt./Cu. Ft. = [(C x 30) / (100 + G)] x 100				
% Optimum Moisture =		0.1			
lbs./ft ³ Maximum Density =		0.1			

Enlarged

Calculations-graph

54

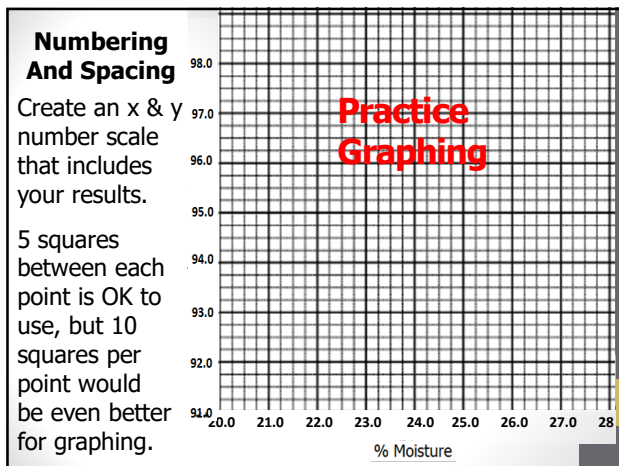
54

Practice Calculation					
A.	Mold & Wet Soil, in lbs.	8.910	9.050	9.240	9.170
B.	Wt. of Mold, in lbs.	5.220	5.220	5.220	5.220
C.	Wt. of wet Soil in mold = A-B	3.690	3.830	4.020	3.950
Moisture Determination					
D.	Wet Wt., in g	584.9	619.8	631.5	620.9
E.	Dry Wt., in g	486.6	509.7	506.0	488.9
F.	Wt. of Water = D-E	98.3	110.1	125.5	132.0
G.	% Moisture = (F ÷ E) x 100	20.2	21.6	24.8	27.0
H.	Dry Wt./Cu. Ft. = [(C x 30) / (100 + G)] x 100	92.1	94.5	96.6	93.3
% Optimum Moisture =		24.2	%	0.1	
lbs./ft. ³ Maximum Density =		96.8	lbs./ft. ³	0.1	

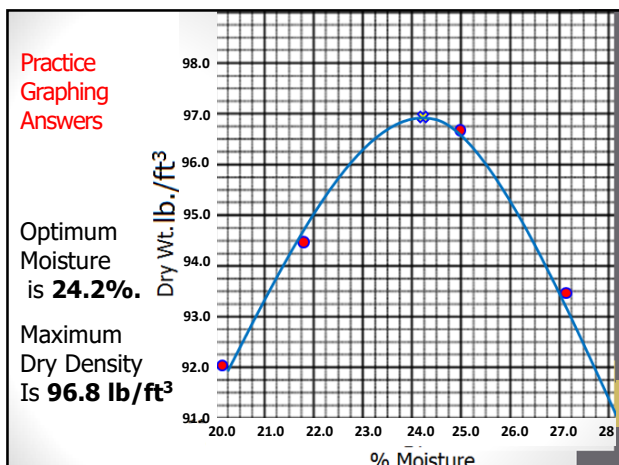
Answer

55

55



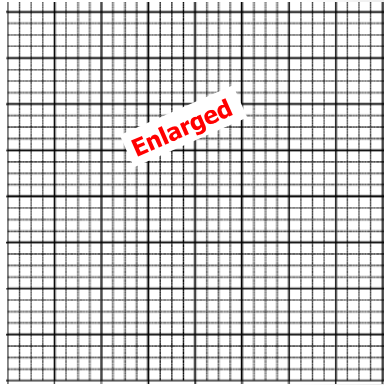
56



57

Graphing – On Your Own

Hand in your work to the instructor for approval.



Calculations-graph

58

58

REPORTING

- Report **Percent Moisture** at the peak of the curve taken as Optimum Moisture to the nearest **0.1%** and
- Report **Dry Density** mass at Optimum percent Moisture as Maximum Dry Density, to nearest **0.1 lb./ft³**.
- Report type of face if tamper was different than 2" circular.
- Report method used: **A, B, C, or D**

Reporting

59

59

Reporting for Oversized Particles

- Oversized particle correction
- Adjusted maximum dry density to the nearest **0.1lb/ft³**
- Corrected optimum moisture content to the nearest **0.1%**
- Oversized particles to the nearest **0.1%** of the original dry mass of the sample
- G_{sb} of oversized particles to the nearest **0.001**

Reporting

60

60

ANNEX 1

(Mandatory Information)

Correction for Densities With Oversized Particles

To adjust densities of soil or soil aggregate for with 5.1 - 30% retained on the $\frac{3}{4}$ " sieve, use AASHTO T 99 **Annex A1** calculations.

Annex-Correction for Densities

61

61

CALCULATIONS FOR DENSITY ADJUSTMENT

- **Method C**, when required, perform the following calculations to adjust from "compacted laboratory dry density *corrected*", to "field dry density".
- Material retained on the $\frac{3}{4}$ " sieve is between 5.1% and maximum allowed, 30% or as specified: **20% for MODOT**.
- When material retained on the $\frac{3}{4}$ " sieve exceeds specified maximum, material is deemed "Too Rocky to Test".

Annex-Correction for Densities

62

62

MoDOT Spec. 203.5.5

Oversized Particles - Too Rocky to Test:

For Method C, MoDOT uses specification 203.5.5: When a sample has **20% retained on a $\frac{3}{4}$ -inch sieve, it will generally be considered too rocky for satisfactory density testing.**

- See MoDOT specification for compactive effort requirements.
- This information differs from what is in AASHTO T99.

Scope

63

Updated slide

63

Annex-Moisture Correction

64

Annex-Density Correction

65

- ## Annex Corrections

66

Example Calculation

$$MC_T = \frac{(MC_F \times P_f) + (MC_C \times P_c)}{100} \quad D_d = \frac{(100 \times D_f \times k)}{(D_f \times P_c) + (k \times P_f)}$$

Enlarged

Given:

- $P_f = 93\%$
- $P_c = 7\%$
- $MC_C = 2.0\%$
- $G_{sb} = 2.600$
- $MC_F = 11.0\%$
- $D_f = 108.0$
- Calculate k

From gradation or as determined (use as whole #)

Assumed per test method or as determined.

Determined for each point from test.

67

67

- Calculations are performed for each differing moisture content of fine particles ($\frac{3}{4}$ " minus).

- The percentage of coarse particles ($\frac{3}{4}$ " plus) by weight and moisture content of the coarse particles along with the bulk specific gravity are kept constant throughout the different trials.

68

68

Common Testing Errors

- Wrong number of blows.
- Lifts vary in thickness.
- Soil not thoroughly mixed.
- Sample not dried properly, or moisture content improperly taken.
- Manual rammer not held vertically.
- The drop of rammer is incorrect.
- Manual rammer not lifted to the full stroke.
- Compaction block is unstable.
- Compaction block not heavy enough.
- Points are not plotted correctly on graph.

69

69

* Use graph paper to draw a curve and determine Optimum Moisture and Maximum Density.

* Show your work to the Instructor for approval.

Practice Calculation

Enlarged

A.	Mold & Wet Soil, in lbs.	8.910	9.050	9.240	9.170
B.	Wt. of Mold, in lbs.	5.220	5.220	5.220	5.220
C.	Wt. of wet Soil in mold = A-B				

Nearest
0.005

Moisture Determination

D.	Wet Wt., in g	584.9	619.8	631.5	620.9
E.	Dry Wt., in g	486.6	509.7	506.0	488.9
F.	Wt. of Water = D-E				
G.	% Moisture = $(F \div E) \times 100$				
H.	Dry Wt./Cu. Ft. $= [(C \times 30) / (100 + G)] \times 100$				

0.1

0.1

0.1

% Optimum Moisture = 0.1

lbs./ft³ Maximum Density = 0.1

T99 Correction of Maximum Density & Optimum Moisture for Oversized Particles **Example Calculation**

Given:

$$P_f = 93 \%$$

$$MC_F = 11 \%$$

$$P_c = 7 \%$$

$$MC_c = 2 \%$$

$$D_f = 108.0 \text{ pcf}$$

$$G_{sb} = 2.600$$

$$G_{sb} = 2.600$$

$$k = 62.4 \times G_{sb}$$

Corrected Moisture Content of Total Sample:

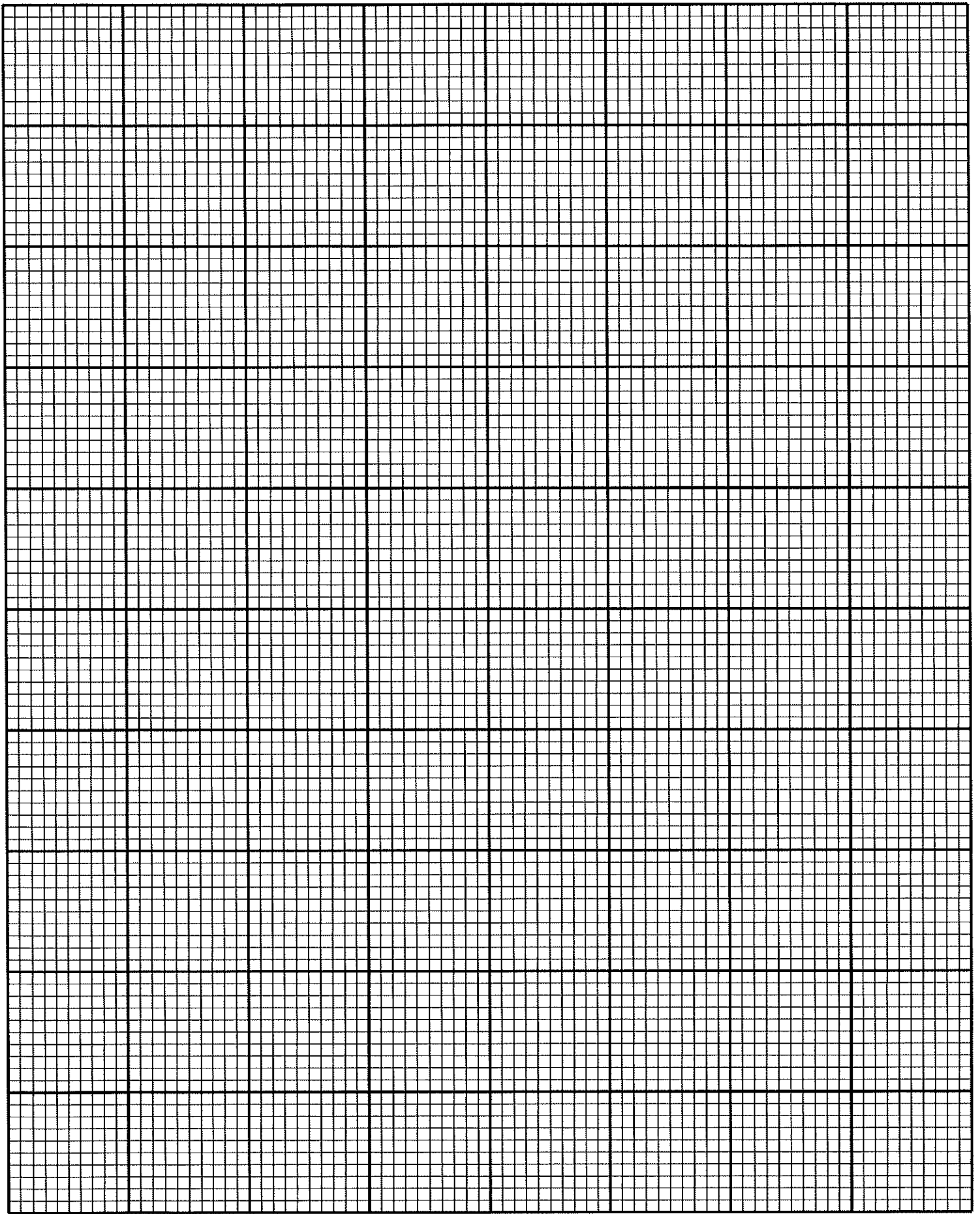
$$MC_T = \frac{(MC_F \times P_f) + (MC_c \times P_c)}{100}$$

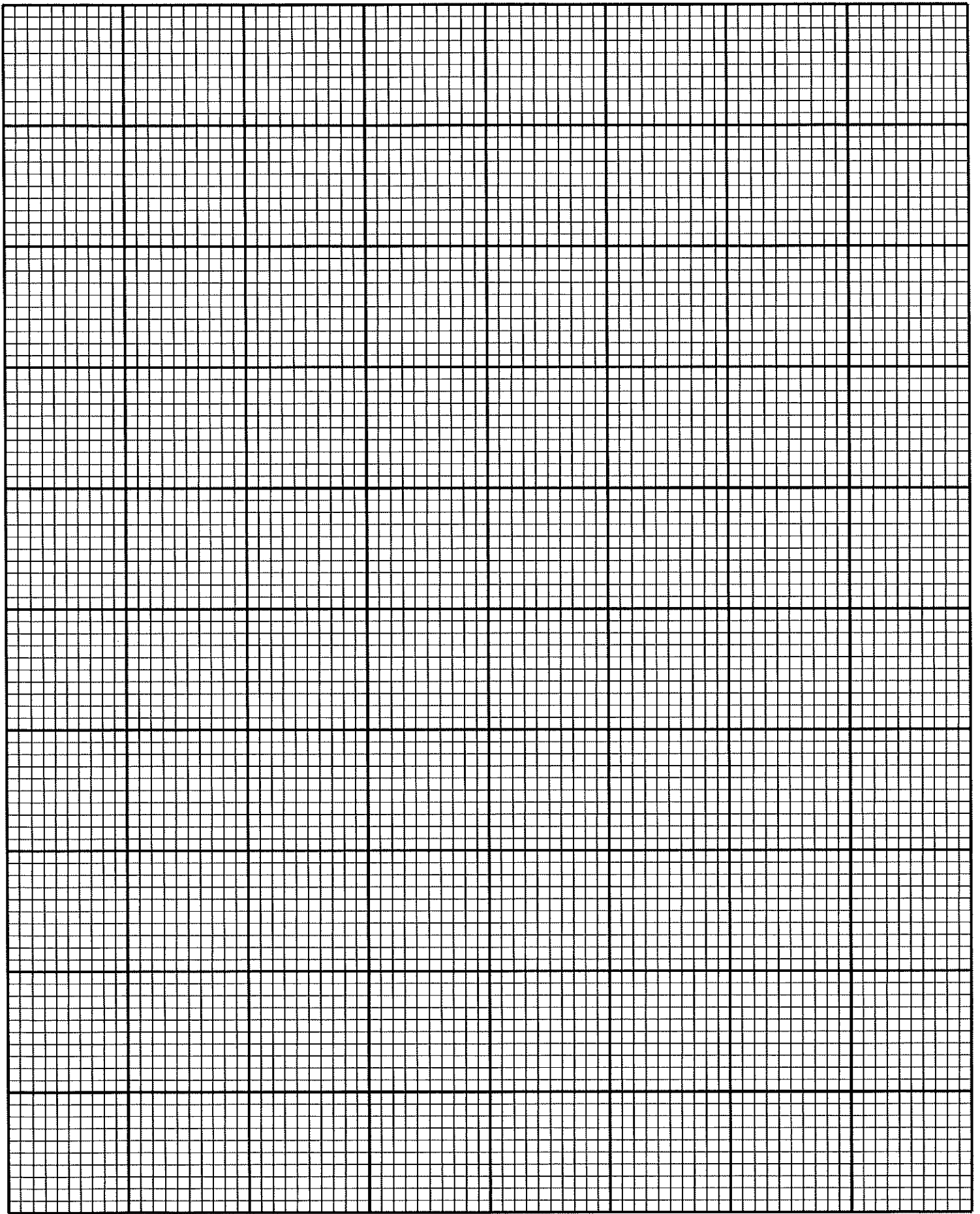
Corrected Dry Density of Total Sample:

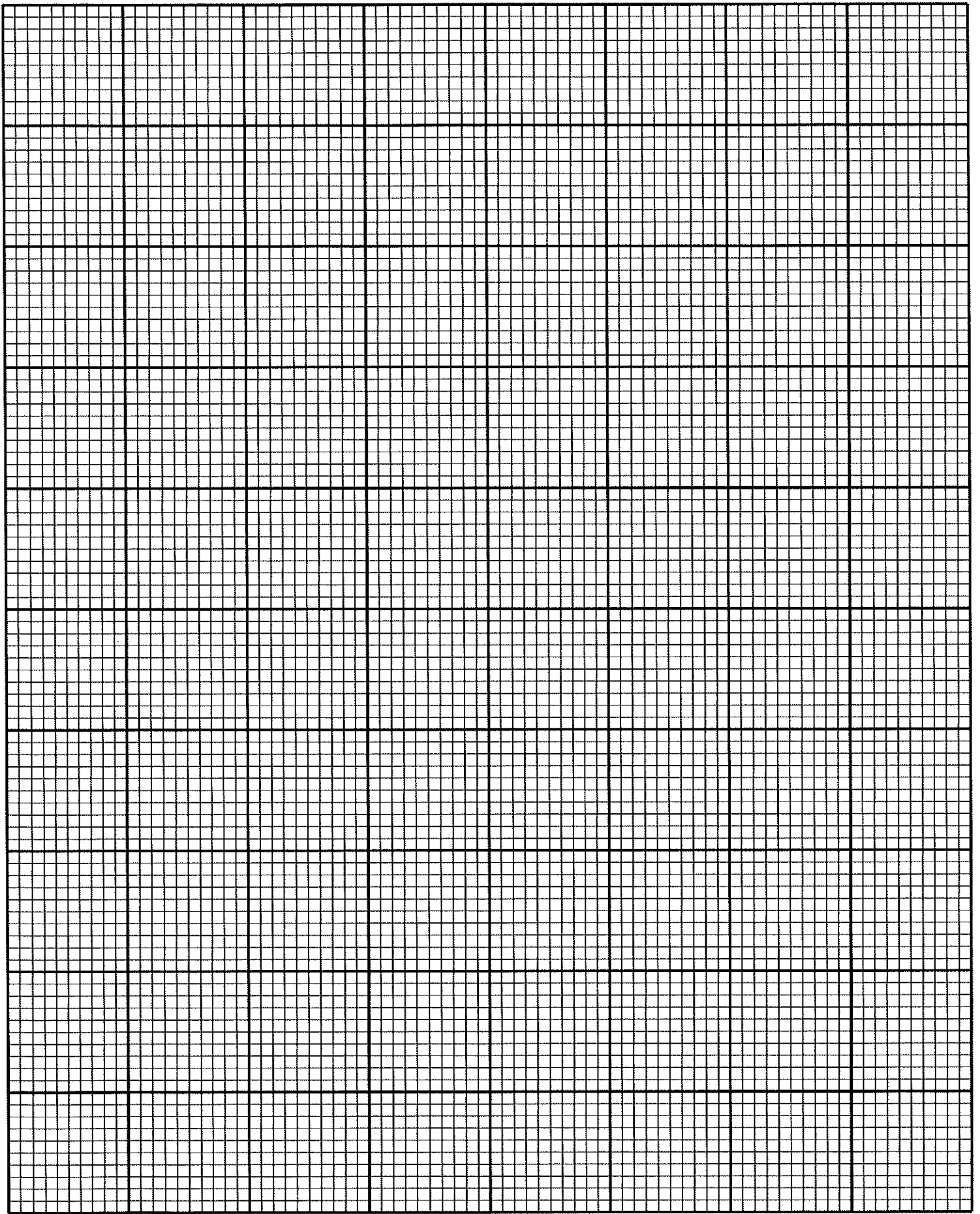
$$D_d = \frac{(100 \times D_f \times k)}{(D_f \times P_c) + (k \times P_f)}$$

Ans : 10.4

Ans : 110.8

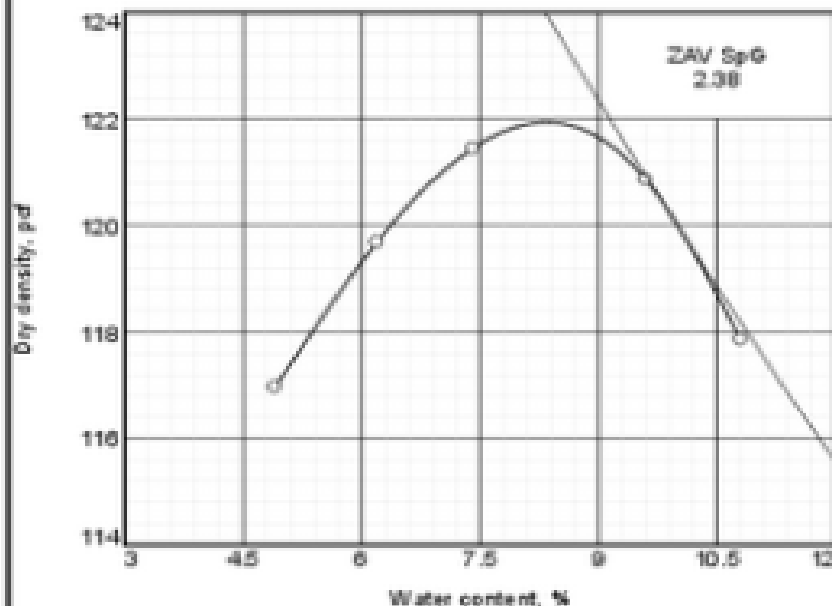






COMPACTION TEST REPORT

Curve No. C-281



Preparation Method	
Reamer: 5.5 in.	Drop: 12 in.
Type	
Layer: No. 1	Blows per
Mold Size	0.075 cu. ft.
Soil Performed on Material	
Permeability	3.4 in.
Soils	
No. of tests	12.4
No. of tests	4.9
AASHTO (D-1557) LL	52
PI	32
USCS (D-2487)	CL
AASHTO (M-191)	A-7-6(31)
Date: Sampled	4 June 2003
Received	
Tested	5 June 2003
Tested By	ALV

COMPACTION TESTING DATA AASHTO T 99-01 Method B Standard AASHTO T 228-01 Overline Correction Applied to Final Results

	1	2	3	4	5	6
WM + WS	9242.4	7275.9	6248.4	6189.5	6123.2	
WM	7247.4	5247.4	4247.4	4247.4	4247.4	
WW + T M1	738.9	723.9	687.2	751.0	727.3	
WD + T M1	684.9	660.1	639.8	737.2	693.3	
TARE M1	0.0	0.0	0.0	0.0	0.0	
WW + T M2						
WD + T M2						
TARE M2						
MOIST.	10.0	9.4	7.4	6.2	4.9	
DRYDENS.	117.9	120.9	122.3	119.7	117.0	

SIEVE TEST RESULTS

Opening Size	% Passing	Specs.

ROCK CORRECTED TEST RESULTS

Maximum dry density = 126.3 pcf

Optimum moisture = 8.3 %

Project No. 991003-34 Client: County of Berthoud
Project: Berthoud County Landfill Expansion

Source: Boring B-2 Depth: 0-2' Sample No.: S-1

ALV ENGINEERS

Material Description

Dark Brown Sandy Lean Clay w/ Organics & Rubble

Remarks:

T-112=0.0% SE-6P Sandness=3.2%

Checked by: ERIC

Title:

Figure F-22

**Intentionally Left Blank-
Notes if Needed**

AASHTO T 99: Moisture-Density Relations of Soils PROFICIENCY CHECKLIST

Applicant: _____

Employer: _____

Updated for 2025

Method A	Trial #	1	2
SAMPLE PREPARATION			
1. Sample air dried or dried in oven not exceeding 140°F (60°C).			
2. Sample broken up and an adequate amount sieved over the #4 sieve			
3. Material retained on No. 4 sieve, <ul style="list-style-type: none"> • Less than 5.0% - discard • Over 5.0% - see Annex A1 for over size particles 			
4. Material passing No. 4 sieve, reduced to 7lb. (3,000g) for testing. (Method A)			
5. If soil is degradable: <ul style="list-style-type: none"> • Multiple samples mixed with water varying moisture content by 1 to 2 %, bracketing the optimum moisture content. If soil is clayey – or – organic soil: <ul style="list-style-type: none"> • Multiple samples mixed with water varying moisture content by 2 to 4%, bracketing the optimum moisture content. • Samples placed in airtight containers for at least 12 hrs. 			
6. Sample mixed with water to approximately 4 to 8% below optimum moisture.			
PROCEDURE – Method A			
1. Determine mass of clean, dry 4" mold and base plate (without collar) to nearest 0.005 lb. (1g).			
2. Attached collar to the mold and placed on a stable foundation.			
3. Place loose soil in mold distributed evenly to yield approximately 1/3 full (then 2/3, then 3/3 full)			
4. Lightly tamp the surface with a 2-inch face tamper			
5. Applied 25 blows with a 5.5 lb. rammer, 12 inch drop (move the blows across the surface)			
6. Trim excess soil from mold walls, distribute on top surface			
7. Repeat steps 3 – 6, for 3 equal layers, last lift is slightly above the top of the mold.			
8. Remove the collar and trim soil to top of mold with straightedge, fill holes as needed			
9. Remove all soil from exterior surface of mold and base plate.			
10. Weigh the mold, base, and contents, and record to nearest 0.005 lb. (1g).			
11. Extract the sample from the mold.			
12. Slice vertically through the center to collect a 100g moisture content sample.			
13. Place the 100g in a pre-weighed sample container for moisture testing, weigh & record to 0.1g			
14. Sample dried and % moisture determined according to AASHTO T 265, reported <i>w</i> to 0.1%.			
15. Material left over, broken up, pass #4 size sieve and add to the remainder of original sample.			
16. Samples mixed with water varying by 1-2% (2.5% max) increments of moisture and mix well. <ul style="list-style-type: none"> - Repeat steps 2 – 15 for each increment of water added. - Minimum of 2 determinations pass optimum density. 			

AASHTO T 99: Moisture-Density Relations of Soils PROFICIENCY CHECKLIST (cont.)

Trial #		1	2
CALCULATIONS AND REPORTING			
CALCULATE: Wet Density, Dry density and Percent Moisture calculated for each sample.			
<div style="display: flex; justify-content: space-around; align-items: flex-end;"> <div style="border: 1px solid black; padding: 5px; text-align: center;"> $W_1 = (M_{ms} - M_m) \times \text{Constant}$ <p>Wet Density</p> </div> <div style="border: 1px solid black; padding: 5px; text-align: center;"> $W = \frac{W_1}{w + 100} \times 100$ <p>Dry Density</p> </div> <div style="border: 1px solid black; padding: 5px; text-align: center;"> $w = \left[\frac{(W_1 - W_2)}{(W_2 - W_c)} \right] \times 100$ <p>Moisture Content</p> </div> </div>			
- Dry density plotted on vertical axis.			
- Percent moisture content plotted on horizontal axis			
- Points connected with a smooth curve			
REPORT: *Percent Moisture At peak of curve taken as Optimum Moisture reported to nearest 0.1%. *Dry Density Mass at Optimum percent moisture reported as maximum dry density to the nearest 0.1 lb./ft ³ . *Method Used A, B, C, D. *Information on oversized particles and adjusted Max DD, Corrected Optimum MC and Gsb to 0.001.			

PASS PASS

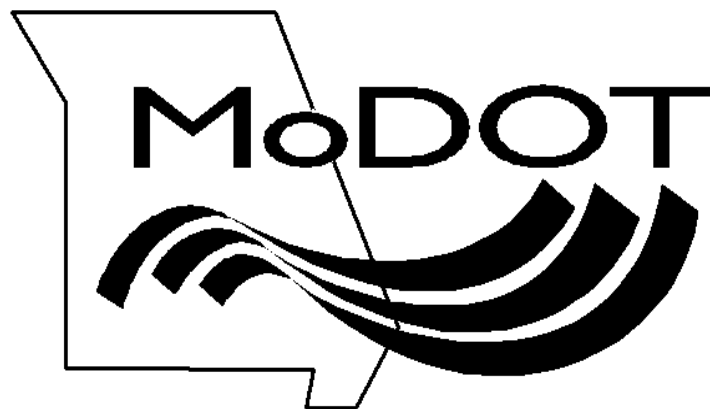
FAIL FAIL

Examiner: _____ Date: _____

MoDOT TM 40

AASHTO T 272

A One-Point Method for
Determining Maximum Dry
Density and Optimum
Moisture
(1-Point Proctor)



**Intentionally Left Blank-
Notes if Needed**

MoDOT TM 40

(AASHTO T 272)

A One-Point Method for Determining
Maximum Dry Density and Optimum
Moisture
(1-Point Proctor)

Rev 09/21/2023

1

SUMMARY

- MoDOT TM 40 is identical to AASHTO T 272, except that the family of curves is provided by MoDOT.

2

2

SIGNIFICANCE AND USE

- This method corresponds to the methods in either AASHTO T 99 or AASHTO T 180 and must be chosen accordingly; for example, when moisture-density relationships as determined by Method C of AASHTO T 99 are used to form the family of curves, then Method C described in AASHTO T 99 must be used for the one-point determination.

3

3

- A family of curves is a group of typical soil moisture-density relationships determined using AASHTO T 99 or AASHTO T 180, which reveal certain similarities and trends characteristic of the soil type and source.
- Soils sampled from one source will have many different moisture-density curves, but if a group of these curves are plotted together, certain relationships usually become apparent.

Significance and Use

4

4

BACKGROUND

- The Family of Curves is a conversion tool developed to provide maximum dry density and optimum moisture for soils commonly used in highway construction.
- The Family of Curves provide a method to estimate the maximum dry density and optimum moisture content from a single moisture-density point.

Background

5

5

- Soils are composed of various combinations of sand, silt and clay.
- Where a material fits on the Family of Curves depends on its composition.

Background

6

6

- Sandy or silty soils fit on the curves with higher maximum densities, while clay soils fit those curves with lower densities.
- Since sands do not hold water, the optimum moisture for sand will be much lower than for a soil that contains more fines.


Background

7

7

EQUIPMENT

Same as AASHTO T99



Equipment

8

8

- **Sieves**
 - #4 or 3/4"
- **Scales**
 - Readable to 1g
 - Readable to 0.1g (MC)
- **Oven**
 - 230 ± 9°F (110 ± 5°C)
 - 140°F (60°C)
- **Mold Assembly**
 - 4" or 6"
- **Sample Extruder**
- **Mixing Tools**
- **Straight Edge**
 - 10" steel with beveled edge
- **Moisture Tins**
- **Rammer**
 - (Mechanical or Manual)
 - 5.5 lb. – 12" drop
- **Small Tamper**
 - 2" diameter
- **Compaction Base**
 - 200 lbs.

*More equipment information can be found in the appendix

Equipment

9

9

PROCEDURE



Procedure

10

10

- The representative sample needs to be between 80 to 100 percent of the optimum moisture or (4% below Optimum Moisture).
- Adjust the moisture content, if necessary.
- The maximum density determination will be more accurate the closer the moisture content is to the optimum moisture content.
- Compact the prepared soil using the selected procedural method.

Today we are using [Method A](#) of AASHTO T 99.

Method A Procedure

11

11

Method "A" PROCEDURE

SAMPLE PREPARATION:

- After performing the in-place density-moisture test with the nuclear gauge, remove a 7 lb. (3 kg) sample of representative soil from the test site.
- Remove oversize material from the sample using a No.4 (4.75 mm) sieve.

Method "A" Procedure

12

12

- Test the material which passed the sieve and discard what was retained.
- Refer to AASHTO T 99 instructions for preparation procedures.
- Record on the test data sheet "Test Method performed on material passing No.4 (4.75 mm) sieve".
 - Method A, Method B, Method C, Method D

Method A Procedure

13

13

- Thoroughly mix the sample with sufficient water to dampen to a moisture content that is between the assumed optimum moisture content and **4%** below.
- Generally a good starting point is **4%** below the Plastic Limit, if available.

Method A Procedure

14

14

- Greater accuracy in the determination of the maximum density will result as the moisture content used approaches optimum moisture content.
- Do not allow the moisture content to exceed the optimum.

Method A Procedure

15

15

After the sample has been prepared, testing should progress as follows:

1. Record the mass of the mold and base plate (without collar) to the nearest 0.005 lb. (1 g).
2. Place a representative portion of the sample into the mold, to yield approximately 1/3 full after compaction.
3. Lightly tamp soil prior to compaction until it is not in a loose or fluffy state.
 - Use a 2 inch face.

Method A Procedure

16

16

4. Apply 25 blows with the 5.5 lb. rammer with a 12 inch drop.
 - When compacting with a manual rammer, uniformly distribute the blows over the entire surface area of the sample.
 - During compaction, the mold should rest on a rigid and stable foundation or base.
5. Clean soil from side of mold.
 - Repeat steps 2-5 for the two remaining layers.

Method A Procedure

17

17

6. After compacting the final layer, remove the extension collar and trim the sample even with the top edge of the mold using the straight edge.
7. Remove any particles lodged between the mold and base plate.
8. If there are voids, fill with excess soil.
9. Weigh mold with sample and record to the nearest 0.005 lb. (1 g).

Method A Procedure

18

18

10. Multiply the wet mass times a constant to obtain the wet density of the soil in lb./ft³ (kg/m³).

- For 4" molds, the constant is 30.
- For 100 mm molds, the constant is 1,060.

11. Remove the material from the mold and slice vertically through the center.

12. Take a representative sample from one of the cut faces.

- Sample should be at least 100 grams.

13. Determine moisture content of sample by AASHTO T 265.

Method A Procedure

19

19

CALCULATIONS

Calculating Wet Density

$$W_1 = (M_{ms} - M_m) \times \text{Constant}$$

W_1 = Wet Density in lb./ft³ (kg/m³).

M_{ms} = Mass of mold, base, and sample in lb. (g)

M_m = Mass of mold and base in lb. (g)

Constant = 30 = Based on size of English units

Constant = 1060 = based on size of Metric units

Report to the nearest **0.1 lb./ft³**

Calculations

20

20

Calculate the Dry Density

$$W = \frac{W_1}{w + 100} \times 100$$

W = Dry density in lb./ft³

w = Percent moisture content of sample

W_1 = Wet density in lb./ft³

Report to **0.1 lbs./ft³**

Calculations

21

21

Method "C" PROCEDURE

• Method C is the same as Method A, with the following exceptions:

- Sample size is 11 lb. (5 kg)
- Material must pass the $\frac{3}{4}$ " (19.0 mm) sieve

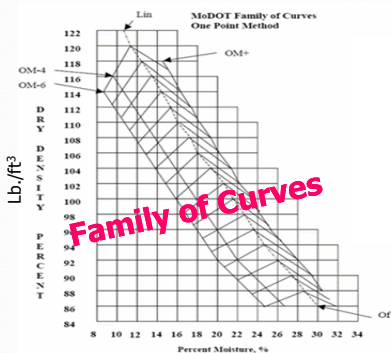
Note: This method is not applicable to free draining granular materials.

Method C Procedure

22

22

ONE-POINT MOISTURE-DENSITY



One Point Moisture-Density

23

23

• After completion of one of the methods, you will have calculated:

- Dry Density
- Moisture Content

• These are applicable for this soil at this particular moisture content.

One Point Moisture-Density

24

24

Maximum Density and Optimum Moisture

To use this procedure, the user must have a Family of Curves produced in accordance with the Appendix procedure outlined in AASHTO T 272 relevant to the soils anticipated to be encountered in the geographical area.

**This is provided in MoDOT
EPG106.3.2.40**

25

25

- Plot the values of dry density and moisture content calculated previously on the Family of Curves.

- If the point falls on one of the curves and within the allowable range, (**Optimum to 4% below Optimum**), the maximum density and optimum moisture for that curve shall be used.

One Point Moisture-Density

26

26

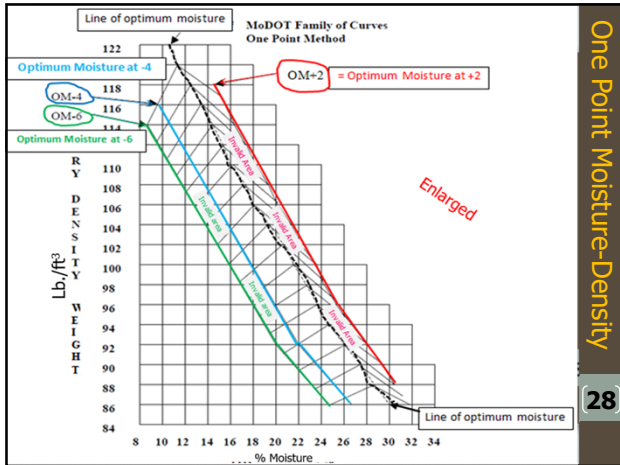
- If the one-point falls within the family, but not on the curve, a new curve shall be drawn through the plotted point, parallel to and in the same general shape as the nearest curve in the Family of Curves.

- If the one-point falls within or on the Family of Curves but does not fall within the allowable moisture range (Optimum to 4% below Optimum), the test is considered **invalid**, compact another sample at an adjusted moisture content.

One Point Moisture-Density

27

27



28

Classroom Exercise

MoDOT TM 40

Use Family of Curves to determine the Maximum Dry Density and Optimum Moisture using the data below. State whether test is valid.

Test	W ₁ (Wet Density)	w (% Moisture)	Dry Density	Valid (Y/N)	Optimum Moisture	Maximum Dry Density
Report to	0.1	0.1	0.1	Y/N	1	0.1
1	123.5	13.9				

NOTE: If the point lands in the OM-6 area just put an X for optimum Moisture and Max Dry Density and N for not Valid.

29

29

REPORT

- Method used (A or C).
- The optimum moisture content as a whole (1) percentage.
- The maximum dry density (mass) to the nearest 0.1 lb./ft³ (0.5 kg/m³).

30

30

TYPICAL TEST RESULTS

- MoDOT TM 40 will give the same range of results as AASHTO T 99, moisture-density relations of soil using a 5.5 lb. (2.5 kg) rammer and 12" (305 mm) drop.
- This method can be used for any soil that develops a classic parabolic "Proctor" curve.
- This method is not applicable to free *draining granular materials*.

31

31

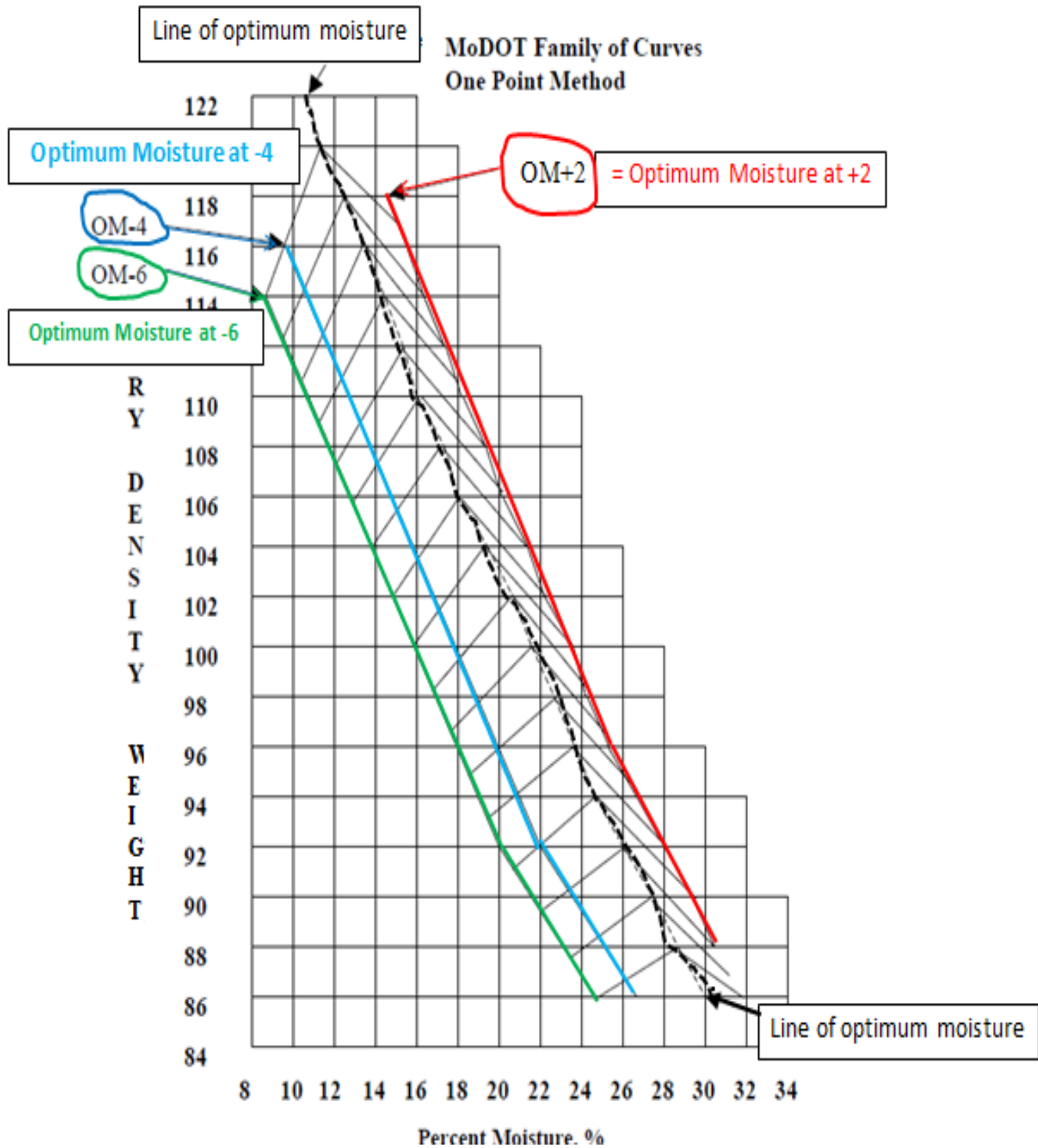
COMMON TESTING ERRORS:

- Failure to protect samples from changes in moisture content.
- Not using a substantial base, 200 lb. (90 kg) or larger, while compacting.
- Not taking care to level scales and protect them from breezes.
- Not using care in reading the graphs. It is very easy to misinterpret the data. You should read, record, read again and check.

32

32

**Intentionally Left Blank-
Notes if Needed**



**Intentionally Left Blank-
Notes if Needed**

Family of Curves Exercise

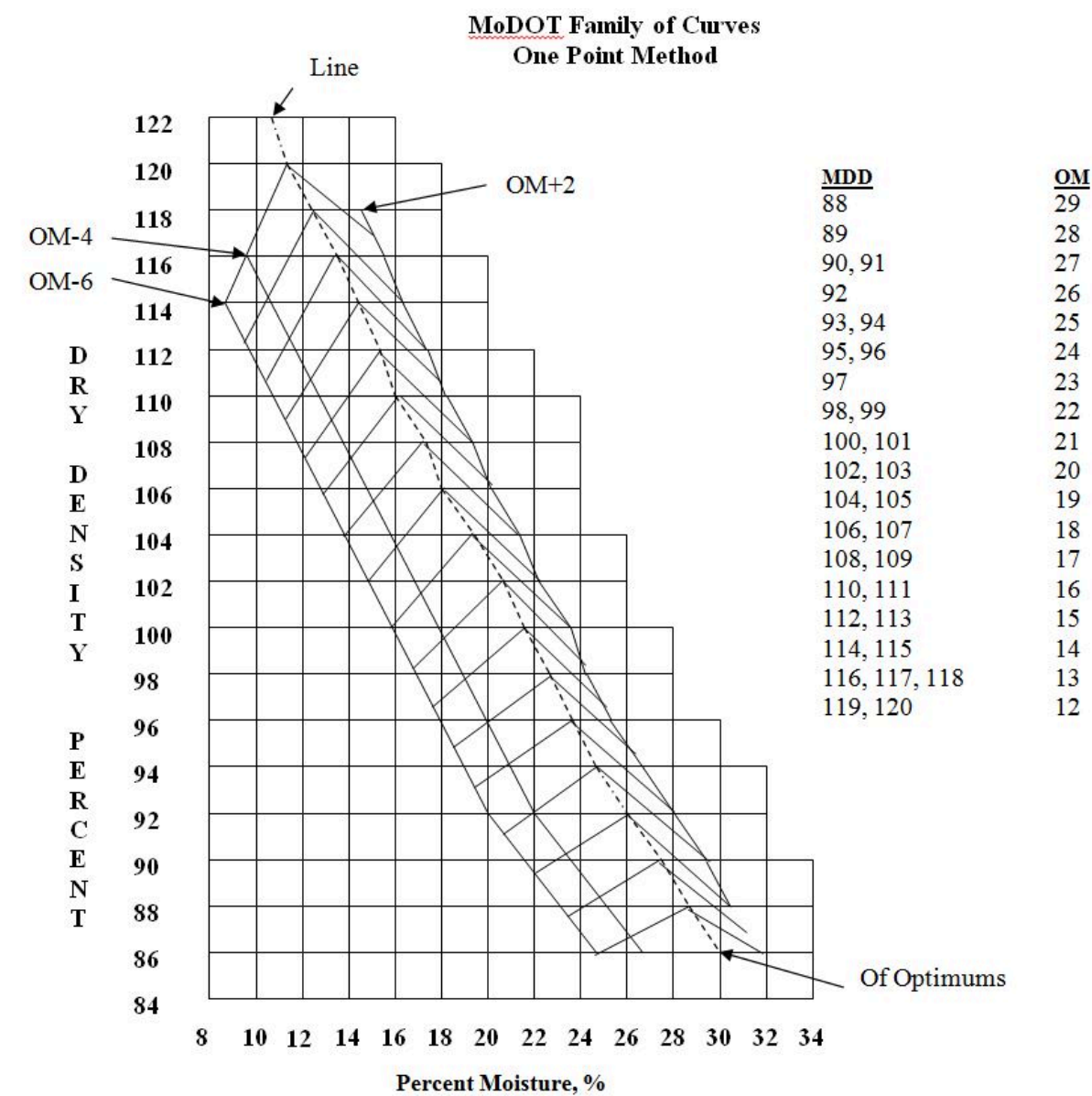
MoDOT TM40

Use the Family of Curves to determine the Maximum Dry Density and Optimum Moisture using the data below. State whether the test is valid or not valid.

Test #	W_1 (Wet density)	w (%Moisture)	Dry Density	Valid (Y/N)	Optimum Moisture	Maximum Dry Density
Report to:	0.1	0.1	0.1		1	0.1
1	123.5	13.9				

**Intentionally Left Blank-
Notes if Needed**

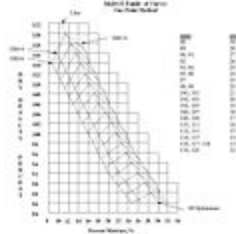
File:106.3.2.40.jpg



Size of this preview: 610 × 599 pixels.
Original file (845 × 830 pixels, file size: 107 KB, MIME type: image/jpeg)

File history

Click on a date/time to view the file as it appeared at that time.

	Date/Time	Thumbnail	Dimensions	User	Comment
current	<u>10:46, 25 January 2018</u>		845 × 830 (107 KB)	EPGsysop (talk contribs)	

You cannot overwrite this file.

File usage

The following page uses this file:

- [106.3.2.40 TM-40, A One-Point Moisture-Density Relations Test for Soils](#)

Metadata

This file contains additional information, probably added from the digital camera or scanner used to create or digitize it.

If the file has been modified from its original state, some details may not fully reflect the modified file.

Author	Keith Smith
Date and time of data generation	10:38, 25 January 2018

Retrieved from "<https://epg.modot.org/index.php?title=File:106.3.2.40.jpg&oldid=40280>"

This page was last edited on 25 January 2018, at 10:46.

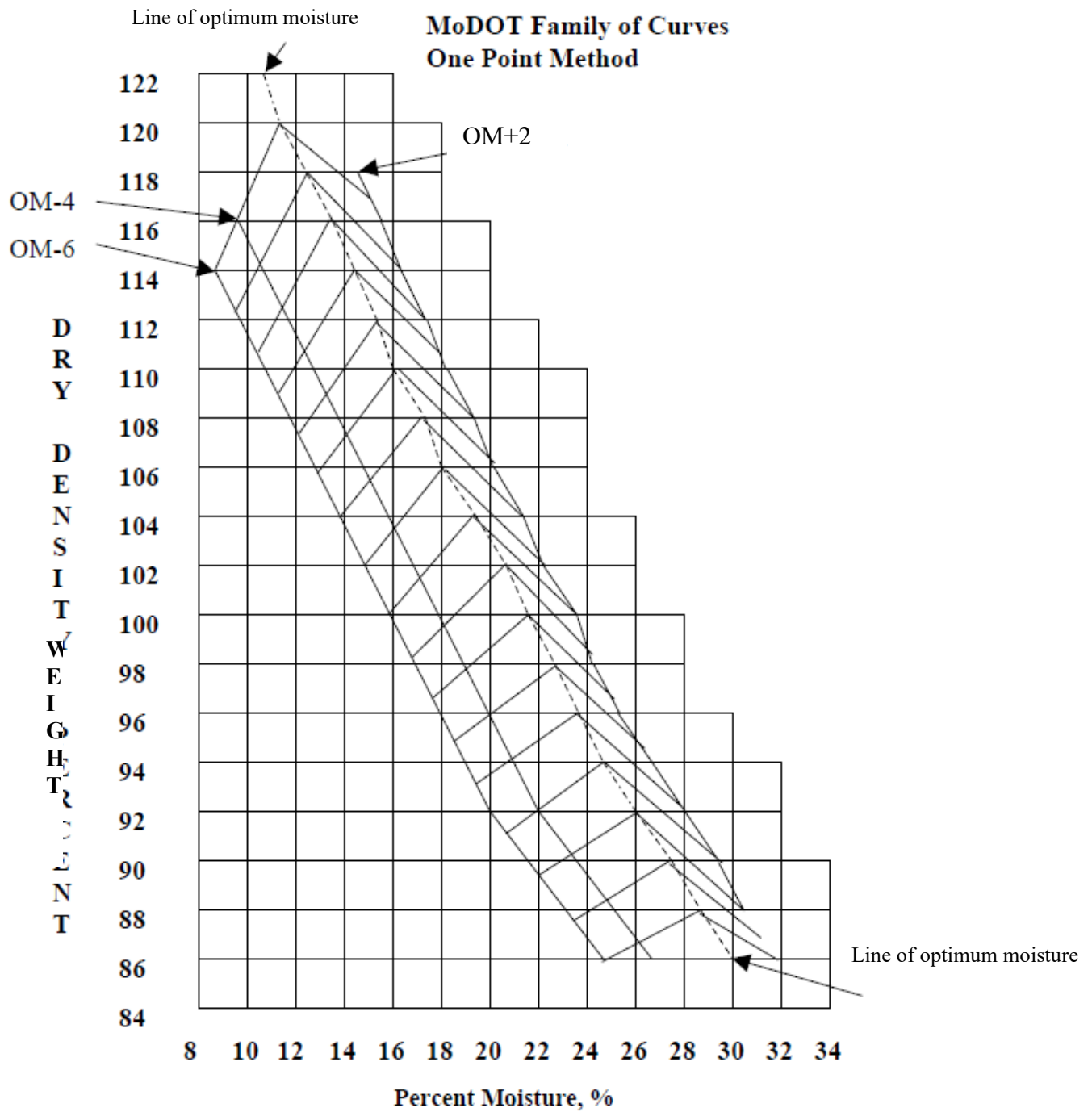


Figure 1

**Intentionally Left Blank-
Notes if Needed**

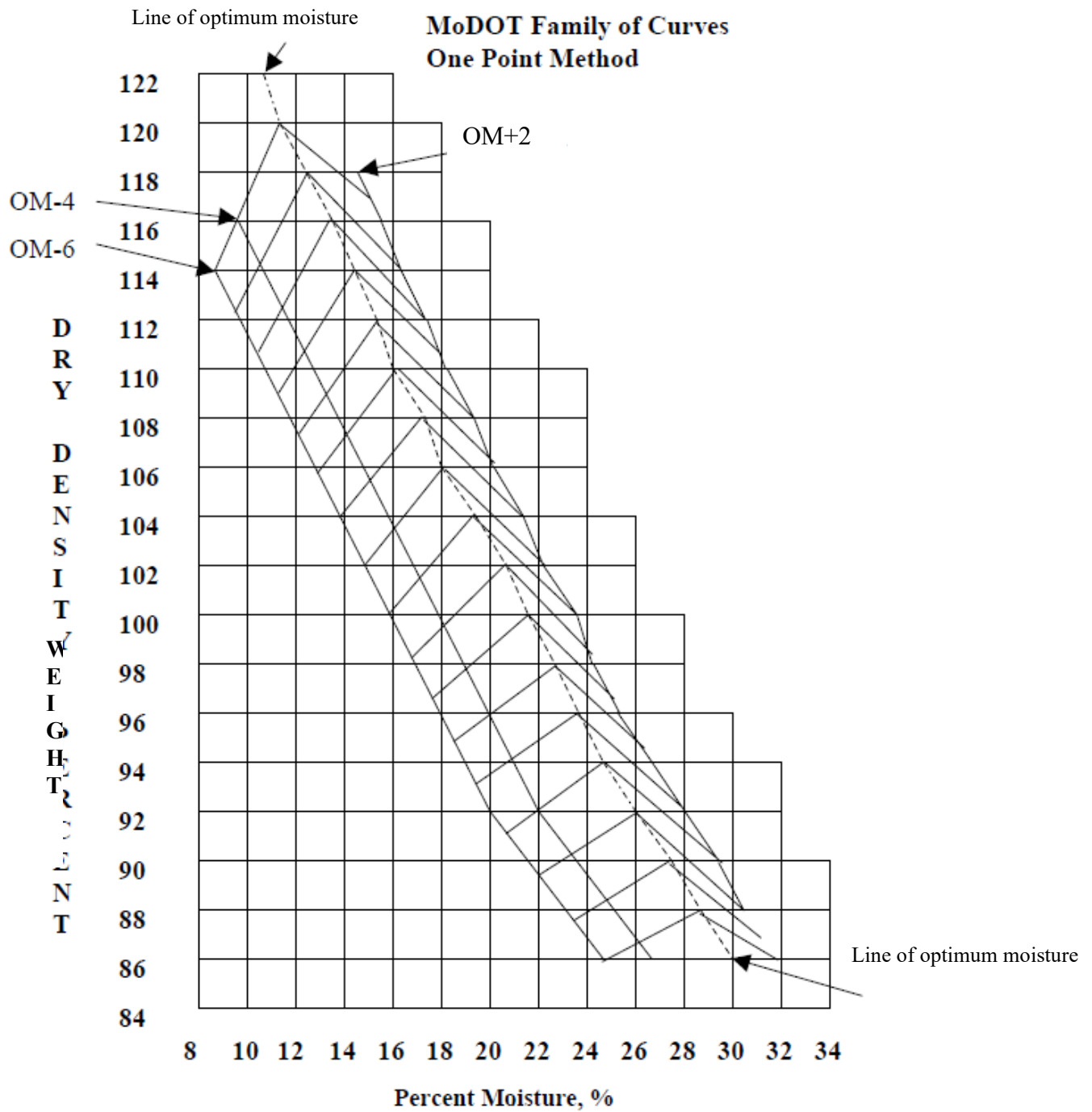


Figure 1

**Intentionally Left Blank-
Notes if Needed**

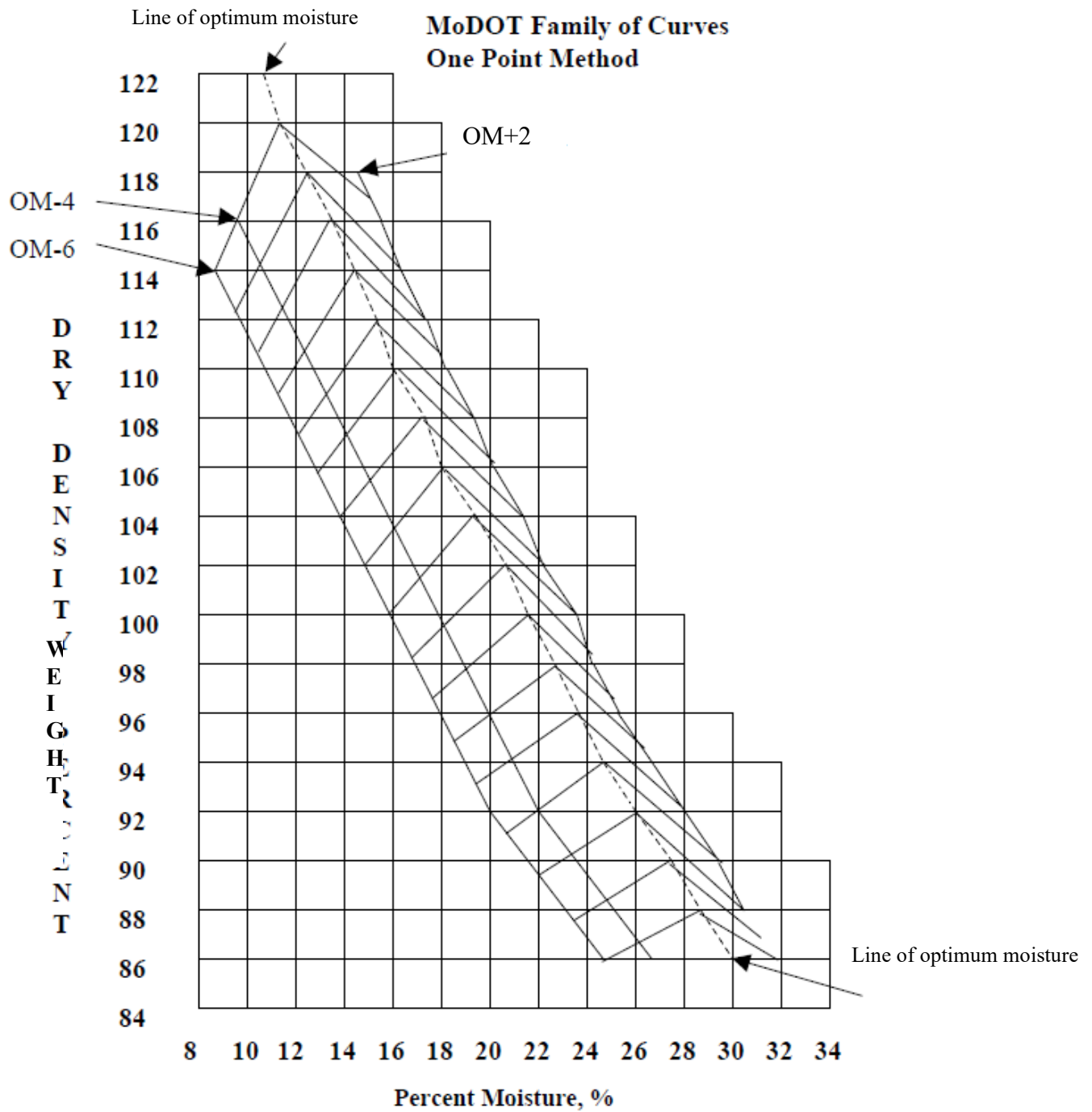


Figure 1

**Intentionally Left Blank-
Notes if Needed**

MoDOT TM 40: A One-Point Method for Determining Maximum Dry Density and Optimum Moisture

PROFICIENCY CHECKLIST

Applicant: _____

Employer: _____

Trial #	1	2
1. One-point determination of dry density and corresponding moisture content made in accordance with AASHTO T 99 or AASHTO T 180, and moisture content determined in accordance with AASHTO T 265.		
2. Optimum Moisture and Maximum Dry Density calculated for the one-point.		
3. A Current MoDOT Family of Curves for specific sample on hand.		
4. Used the correct Method A, B, C, or D as described on the Current MoDOT Family of Curves.		
5. A One-Point plotted on the family of curves, was in the OM-4 area of the MoDOT graph, counted as VALID and Maximum Dry Density and Optimum Moisture Content determined.		
6. OR A One-Point plotted on the family of curves, was not in the OM-4 area of the MoDOT graph, was counted as NOT VALID, made another one-point determined with adjusted water content and plotted for a valid test.		
7. Report Method used, optimum moisture content as a percentage to the nearest whole number, maximum density to the nearest 0.1 lb./ft ³ (1 kg/m ³).		

PASS PASS

FAIL FAIL

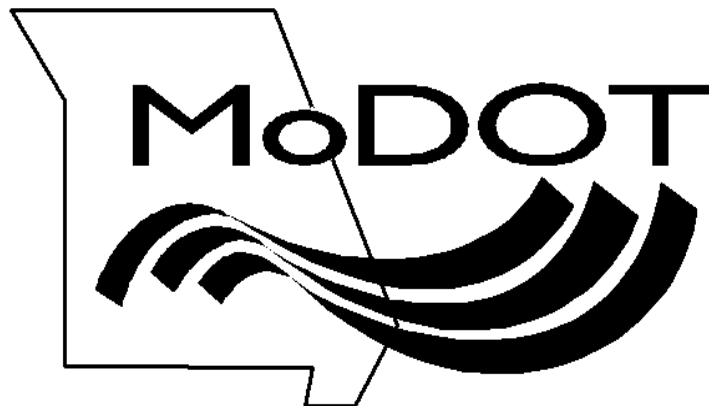
Examiner: _____ Date: _____

**Intentionally Left Blank-
Notes if Needed**

AASHTO T 310

In-Place Density and Moisture Content of Soils and Soil-Aggregate by Nuclear Methods

(Shallow Depth)



**Intentionally Left Blank-
Notes if Needed**

AASHTO T 310

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

1

Rev 09/20/23

1

SCOPE

- Specifications require that the field earthwork be compacted to a target density (% compaction), related to the maximum density (Proctor).
- A nuclear density gauge is one device that is used to determine if the earthwork has met this requirement.
- Density readings for depths between 2" (50 mm) and 12" (300 mm) can be found.

2

2

- This test method describes the procedure for determining the in-place density and moisture of soil and soil aggregate by use of a nuclear gauge.
- The density of the material may be determined by either:
 1. Direct Transmission – used for agg. base
 2. Backscatter - used for asphalt mat
 3. Backscatter/Air-Gap Ratio Method - Not covered in this certification.

Scope

3

3

- The moisture of the material is determined only from measurements taken at the surface of the soil (i.e., backscatter).
- **Density** – The total of 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 12 inches 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).

Scope

4

4

DIRECT TRANSMISSION MODE	BACKSCATTER MODE
<p>Direct Transmission Measures the density of the material between the source and the surface.</p>	<p>Backscatter Measures the density of the material close to the surface (80% in top 2").</p>

Scope

5

5

- **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.
- 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.

Scope

6

6

SIGNIFICANCE

- 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.
- The test method is used for quality control and acceptance testing of compacted soil and rock for construction and for research and development.

7

7

- Density- Assumptions in the methods are that Compton scattering is the dominant interaction and that the material under test is homogeneous.
- Moisture – Assumptions in the method are that the hydrogen present is in the form of water as defined by AASHTO T265 and that the material under test is homogeneous.

Significance

8

8

- 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.

Significance

9

9

INTERFERENCES

- In-Place Density Interferences
 - The chemical composition of the sample may affect the measurement, and adjustments may be necessary.
 - The gauge is more sensitive to the density of the material in-close proximity to the surface in the Backscatter Method.

10

10

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

11

11

Interferences

- In-Place Moisture Content Interferences:
 - Chemicals in the soil such as boron, chlorine, and minute quantities of cadmium, will cause measurements lower than the true value.
 - Other neutron (radioactive) sources should be **30 ft.** away from the gauge in operation.

12

12

Interferences

SAFETY

DO NOT USE GAUGE UNLESS PROPERLY TRAINED!!

- Anyone who operates a nuclear gauge is required to successfully complete a nuclear safety training class.

13

13

Radiation poisoning is very serious.

Always practice the “**ALARA**” principles to minimize exposure.

(**As Low As Reasonably Achievable**)

Four important facts to remember:

1. Time
2. Distance
3. Shielding
4. 2 Barriers

14

14

Safety

EQUIPMENT



15

15

- Nuclear gauge
- Plastic reference standard
- Site preparation device – shovel, dozer, etc.
- Drill rod
- Dry, fine sand for filling voids
- Operators instruction manual
- Small sledge hammer
- Extraction tool
- Scraper plate (template)

Equipment

16

16

Equipment

17

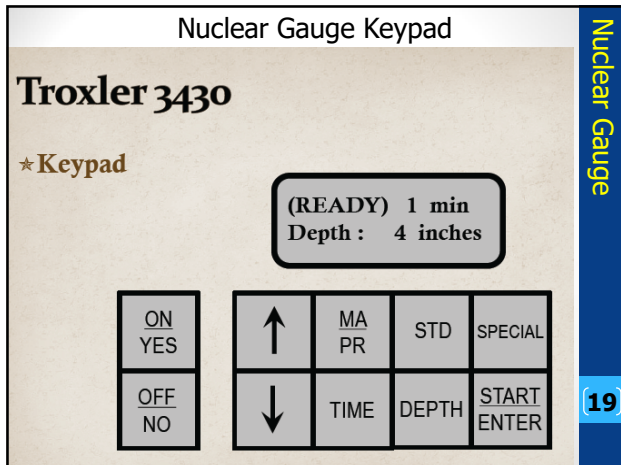
17

Nuclear Gauge Diagram

Nuclear Gauge

18

18



19



20

Nuclear Gauge - Description

- A sealed source of high-energy gamma radiation, such as cesium or radium.
- **Fast Neutron Source** - A sealed mixture of a radioactive material, such as americium, radium, or californium 252, and a target material such as beryllium.
- **Gamma Detector** – Any type such as Geiger-Mueller tube(s).
- **Slow Neutron Detector** – Such as boron trifluoride or helium-3 proportional counter.

21

21

How it Works

- The gauge uses radiation, a gamma source and a gamma detector, to obtain several readings to determine wet density.
- To determine the dry density of a soil in place, it is also necessary to determine the moisture content.
- The nuclear gauge uses a second source, emitting fast neutrons, and a thermal neutron detector, which determines the intensity of slow or moderated neutrons to determine the moisture content.

Nuclear Gauge-How it Works

22

22

- Moisture is determined by the relationship of nuclear count-to-mass of water per unit volume of soil.
- These readings are then used to calculate the in-place or dry density for soils and soil-aggregate mixtures.

Nuclear Gauge-How it Works

23

23

CALIBRATION

- AASHTO T 310 requires that the gauge read within $\pm 1 \text{ lb./ft}^3$ on a standard block(s) of material(s) with established density and moisture content.
- Calibration on the gauge is performed by the manufacturer.
- Gauges will be calibrated once a year or when a gauge is not working correctly and/or giving irregular readings.

24

24

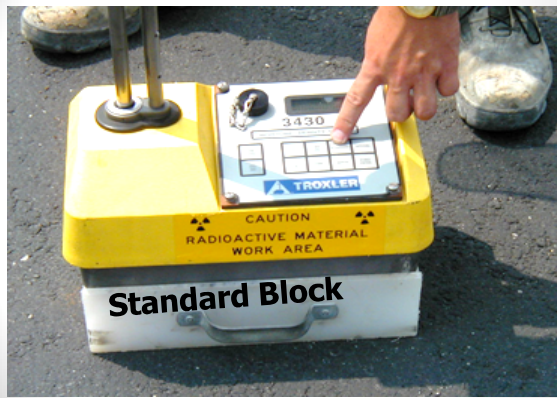
STANDARDIZATION

- Standardization must be performed daily or whenever gauge readings are suspect.
 - Place the standard block on a dry, flat surface in the same environment as the actual measurement counts.
 - **10'** (3 meters) from any large vertical surface (i.e. concrete block wall).
 - At least **30 feet** (10 meters) from any other radioactive source.
 - "Sound" surface, in the same environment as the actual measurement counts.
- For Troxler 3430, "Sound" defined as $\geq 100 \text{ lb/ft}^3$.

25

25

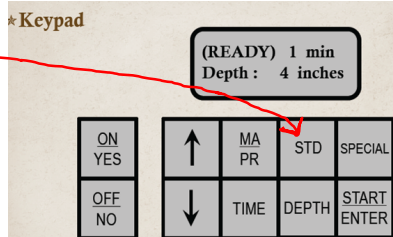
Standard Count



26

26

- Take **4 one-minute** repetitive readings.
- On Troxler 3430's, Press the **STD** button for a standard count, the gauge *automatically* takes 4 one-minute readings.



27

27

Nuclear Gauge-Standardization

- Daily standard count must be within the following range from the average of the last 4 standard counts:

$$N_s = N_o \pm 1.96\sqrt{(N_o/F)}$$

N_s = value of current standardization count
 N_o = average of the past four values of N_s taken prior to usage
 F = factory pre-scale factor, provided with the gauge (16 for a Troxler standard count)

28

28

Nuclear Gauge-Standardization

Standard Count Example

Class Room Exercise

Data from Field Book	Density Count	Moisture Count
4 previous -	2758	667
3 previous -	2766	670
2 previous -	2748	668
1 previous -	2755	665
Average	2757	668

Today's Readings: Density= 2759 Moisture= 665

Q. Are today's readings in the range of previous readings recorded in the Field Book?

29

29

Nuclear Gauge-Standardization

Standard Count - Density

Classroom Exercise

N_o = **2757** for Density
 N_s for Density is calculated as:
 Calculate today's range (N_s)

$$N_s = 2757 \pm 1.96\sqrt{(2757/16)}$$

Note: 16 is typical for a Troxler gauge

30

30

Standard Count – Moisture Classroom Exercise

$N_o = 668$ for Moisture

N_s for Moisture is calculated as:

Calculate today's range (N_s):

$$N_s = 668 \pm 1.96\sqrt{(668/16)}$$

Note: 16 is typical for a Troxler gauge.

Nuclear Gauge Standardization

31

31

- $N_s = 2757 \pm (1.96 \sqrt{(2757/16)})$

- Step One: $(2757/16) = 172.3$

- Step Two: $\sqrt{172.3} = 13.1$

- Step Three: $1.96 \times 13.1 = 25.7 = 26$

- For Step Three round the answer to a whole number

- Step Four: 2757 ± 26

- $2757 - 26 = 2731$

- $2757 + 26 = 2783$

The Range is 2731 to 2783

Density
Calculation
Steps

Nuclear Gauge Standardization

32

32

Answer

► Density range is: **2731 to 2783**

► Moisture Range is: **655 to 681**

► Today's standard count is:

Density **2759** **this is in range.**

Moisture **665** **this is also in range.**

► If "today's standard count" is outside of the calculated range, run another and recalculate including the previous count. Repeat until the count is within the range.

Note: If after four counts, the gauge does not pass, consult technical support.

Nuclear Gauge Standardization

33

33

OFFSETS

- There are three offsets that are to be considered before testing.
- 1. **Moisture Offset** – When measuring materials containing hydrogen not in the form of water, MoDOT TM 35 is used to set this.
- 2. **Trench Offset** – When performing moisture and density measurements in a trench or near a large object the density or moisture may be effected due to reflecting gamma photons or neutrons. (within 2 ft. of any wall)
- 3. **Density Offset** – A density offset is used when measuring materials outside of the normal calibration parameters and often on asphalt materials with surface voids present.

Gauge Offsets

34

34

Moisture Offset

- The moisture/density gauge measures the moisture content of material by detecting hydrogen present in the measurement area.
- Hydrogen may be present in material that is not in the form of water.
 - The presence of hydrogen in materials such as gypsum, mica, lime, phosphates, fly-ash, etc. may cause high moisture readings.
- A moisture offset is necessary to correct to the actual water content of the material.

Moisture Offset

35

35

- A few materials are considered to be neutron absorbers which may cause the gauge to read a falsely low moisture and may also require a moisture offset.

- Examples of neutron absorbers are boron, salt, iron oxide, lithium, and cadmium.
- When testing aggregate bases or encountering contaminants, correct moisture using (K) offset MoDOT TM 35.

Moisture Offset

36

36

Trench Offset

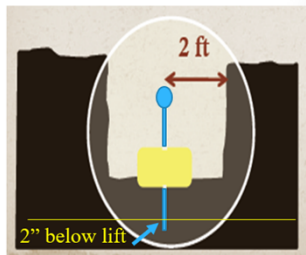
- Normally the gauge only measures the moisture of the material below the gauge because other neutrons are not scattered back to the detectors. In a trench situation, the neutrons traveling above and beside the gauge may read the moisture in the trench walls also.

Trench Offset

37

37

- The trench offset needs to be used if the gauge is within 2 feet (0.6 m) of the trench wall (or vertical structure) on any side of the gauge.
- Refer to the gauge instruction manual for the proper procedure required to complete the Trench Offset Factor.



Trench Offsets

38

38

Density Offset

- The difference between the gauge measured density and the alternative density measurement result (often a core).
- This value is used as the wet density offset in the gauge.

39

39

PROCEDURE



40

40

Density Testing Outline

- Before Testing
- Test Site Location
- Prepare Test Site
- Direct Transmission Procedure
- Backscatter Procedure

41

41

Before Testing:

- Be familiar with the gauge.
- Gauge must be currently calibrated.
 - (Initially and then Annually)
- Gauge papers and radiation training card on hand and ready to travel to the test site.
- Gauge is handled in a safe way for traveling and storing. (Secured and locks are in place).
- Know how to operate gauge, put in lab data, and run all tests.
- Gauge has a good charge and ready to go.
- Standard counts information and log book on hand.
- Check the equipment list to be sure all testing equipment is packed and ready to go.

42

42

TEST SITE PREPERATION

- Choose a test site that represents the test area.
- Avoid localized contaminations such as diesel spills, hydraulic oil, lime etc.
- Select location where the gauge will be 6" (150 mm) away from any vertical projection.
- Look for a level area.
- Area cleared of people and moving vehicles.
- All radioactive sources are at least 30 feet away.

43

43

PREPARE TEST SITE

- Prepare the test site by removing all loose and disturbed material.
- Plane an area to maintain maximum contact between gauge and material being tested.
- Smooth an area to perform the test by use of shovel, dozer, scraper plate, etc.



44

44

- The maximum void beneath the gauge should not be more than $\frac{1}{8}$ " (3 mm).
- Fill voids with sand or native material.
- Filled area shall not be more that **10%** of the surface area beneath the gauge.



45

45

Site Preparation

Direct Transmission PROCEDURE

1. Turn the gauge on to stabilize (warm up).

- Note:** Before testing check gauge parameters
- Depth (lift thickness)
 - Maximum Density (Proctor)
 - Off Sets
 - Daily Standardization was Performed

Operate the gauge according to manufacturers directions.

46

46

2. Drilling the hole.

- Place the scraper plate on prepared site.
- Attach extraction tool and insert drill rod.
- Step firmly on the plate and hammer the drill rod perpendicular to the surface.



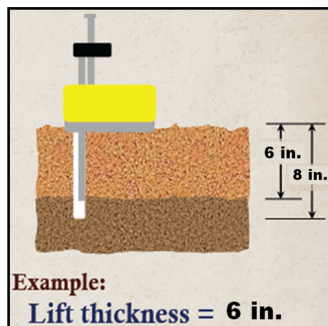
Direct Transmission Procedure

47

47

- Drive the gauge rod **2"** deeper than the lift to be tested.
- Example: 8" deep for a 6" compacted lift.

**Lift depth and
Probe depth
are always
the same.**



Direct Transmission Procedure


48

48


★ **Hole Drilling**

- ✓ Remove drill rod with an upward, twisting motion

✓ Mark plate footprint and hole location



✓ Remove tools from area
• ≈ 3 ft away




Direct Transmission Procedure

49

49

Simply etch around the base of the scraper plate before picking it up.



Direct Transmission Procedure

50

50

3. Remove all equipment from the test area except the gauge.
4. Place the gauge in the marked area, ensuring maximum surface contact.
5. Lower source rod into the hole to the same depth of the lift being tested.

Direct Transmission Procedure

51

51

6. Snug the gauge in the direction that will bring the side of the probe in contact with the side of the hole.



Direct Transmission Procedure

52

52

7. Take one or more 1-minute readings to determine:

- % Compaction
- Dry Density
- % Moisture



Direct Transmission Procedure

53

53

- Newer gauges display the maximum dry density (DD) after taking the readings. Record the readings.



Direct Transmission Procedure

54

54

Note: The gauge may be rotated about the axis of the probe to obtain additional readings. Prepare the site in advance to accommodate a larger testing area for this.

55

8. Always return the source rod to the **"SAFE"** position before lifting the gauge from the test site to minimize exposure to the technician.



Sometimes referred to as the "Peeker" method.

56

Backscatter Procedure

- Used when properties of first few inches are concerned (i.e. overlays).
- The more dense the material, the smaller the volume tested.



What's wrong with this setup?

57

Backscatter Procedure Summary

1. Clear the area of people and equipment.
2. Turn the gauge on, allow to warm up.
3. Perform daily standardization.
4. Set the gauge to Backscatter (BS) position.
5. Find a smooth place on the asphalt 30 feet away from other radioactive sources.
6. Prepare the site.
7. Seat Gauge firmly on prepared test site.
8. Take one or more 1-minute readings to determine the wet density.
9. In-place wet density determined and recorded by the gauge.

58

58

CALCULATIONS

★ Direct Measurements

- ✓ Wet Density
- ✓ Moisture Content



★ Calculated Values

- ✓ Dry Density

$$d = \frac{100}{100 + w} \times (m)$$

- ✓ % Compaction

$$\% PR = \frac{\text{Gauge } DD}{\text{Proctor } DD} \times 100\%$$

59

59

- If dry density is required, the in-place water content may be determined by using the nuclear methods described herein, gravimetric samples and laboratory determination, or other approved instrumentation.
- If the water content is determined by nuclear methods, use the gauge readings directly, or subtract the lb./ft³ (kg/m³) of moisture from the lb./ft³ (kg/m³) of wet density, and obtain dry density in lb./ft³ (kg/m³).

Calculation of Results

60

60

Calculation of Results

- If the water content is determined by other methods, and is in the form of percent, proceed as follows:

$$d = \frac{100}{100 + w} \times (m)$$

d =	Dry density in lb./ft³ (kg/m³)
m =	Wet density in lb./ft³ (kg/m³)
w =	Water as a percent of dry mass

61

61

Calculation of Results

- Percent Density:**
- It may be desired to express the in-place density as a percentage of some other reference density, for example, the laboratory densities determined in accordance with AASHTO T 99, AASHTO T 180, or MoDOT TM 40 (AASHTO T 272).
- This relation can be determined by dividing the in-place density by the laboratory reference density and multiplying by 100.

$$\% PR = \frac{\text{Gauge } DD}{\text{Proctor } DD} \times 100\%$$

62

62

REPORTING

- Standardization and adjustment data for the date of the tests.
- Make, model, and serial number of the test gauge.
- Name of the operator(s).
- Date of last instrument calibration or calibration verification.
- Test site identification.
- Visual description of material tested.
- Test mode (backscatter or direct transmission).
- Wet and dry densities in (kg/m³) or unit weights in lb./ft³.
- Water content in percent of dry mass or dry unit weight.
- Any adjustments made in the reported values and reasons for the adjustments. (offsets, etc.)

63

63

COMMON TEST ERRORS:

- Soil chemical composition.
- Soil not homogenous.
- Equipment not calibrated properly.
- Surface texture too rough.
- Testing too close to vertical wall.
- People or equipment too close.
- Not correcting for moisture using (K) offset MoDOT TM 35, when necessary.
- Testing areas with the presence of soil contaminants, without correcting moisture using (K) offset MoDOT TM35

64

64

MISSOURI DEPARTMENT OF TRANSPORTATION

NUCLEAR DENSITY-MOISTURE TEST DATA

☐ Soil

☐ Type _____ Base

Contract ID _____
 Job No. _____ Route _____ County _____ Report No. _____

Date							
Station							
Location R/L – CL							
Dist. Below Profile Gr.							
Standard Test No.							
*A – Test Number							
*B – Probe Depth							
*C – Density Standard Count							
*D – Moisture Standard Count							
*E – Moisture Correction							
*F – Dry Density = DD							
*G – Wet Density = WD							
*H – Standard Density							
*I – % Compaction = PR							
*J – Minimum Density Required							
*K – % Moisture							
*L – Optimum Moisture							
% Moisture Specified	Min.						
	Max.						
Retest of	Test No.						
	Date						

Remarks: _____

_____ Inspector

* See page 2 of form for more information on testing procedures.

Distribution: RE File

Nuclear Density (C-709ND).dot

MISSOURI DEPARTMENT OF TRANSPORTATION

DENSITY-MOISTURE TEST DATA NUCLEAR

- | | |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p>A – Consecutive, by material per project</p> <p>B – Reading on display must match probe position</p> <p>C – Read direct from display – Daily Standard</p> <p>D – Read direct from display – Daily Standard</p> <p>E – Record correction for current material
(Reference page 3–4 Troxler Manual)</p> | <p>F – Record from display for current test</p> <p>G – Record from display for current test</p> <p>H – Provided by Materials for current material</p> <p>I – Record from display for current test</p> <p>J – Provided in contract documents or specifications</p> <p>K – Record from display for current test</p> <p>L – Provided form Materials for current material</p> |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|

DAILY CHECK LIST

1. Two different keys are needed
2. Wear badge
3. Make entry in sign out diary
4. Place travel papers on truck dashboard in plain view within driver's reach (transport gauge in locked box only)
5. Warm up machine 10 minutes – Set on plate with probe opposite butt plate
6. Take standard count – record standard counts in diary. Follow instruction manual.
1% Density Deviation, 2% Moisture Deviation
7. Enter proctor value from materials
8. Enter applicable moisture correction – See pages 3-4 in Troxler Manual
9. Sign back in at end of day and clean equipment

TROUBLE SHOOTING

Do not charge batteries until “low battery” appears (2-3 hours remaining)

If the display reads “GM Tube A Error, Service Required”, remove and replace fuse; retry entry.

See 203.5 of the Engineering Policy Guide for information on testing with Nuclear Moisture-Density Gauges.
See <http://scweb4/hq/co/radiation> for routine maintenance issues.

Battery Voltage: 3.6, Normal
3.35-3.4, Battery low but serviceable
3.25-Below, No service

Technical Advice: 573-526-4628

**Intentionally Left Blank-
Notes if Needed**

MISSOURI DEPARTMENT OF TRANSPORTATION

NUCLEAR DENSITY-MOISTURE TEST DATA

☐ Soil

☐ Type _____ Base

Contract ID _____
 Job No. _____ Route _____ County _____ Report No. _____

Date							
Station							
Location R/L – CL							
Dist. Below Profile Gr.							
Standard Test No.							
*A – Test Number							
*B – Probe Depth							
*C – Density Standard Count							
*D – Moisture Standard Count							
*E – Moisture Correction							
*F – Dry Density = DD							
*G – Wet Density = WD							
*H – Standard Density							
*I – % Compaction = PR							
*J – Minimum Density Required							
*K – % Moisture							
*L – Optimum Moisture							
% Moisture Specified	Min.						
	Max.						
Retest of	Test No.						
	Date						

Remarks: _____

_____ Inspector

* See page 2 of form for more information on testing procedures.

Distribution: RE File

Nuclear Density (C-709ND).dot

MISSOURI DEPARTMENT OF TRANSPORTATION

DENSITY-MOISTURE TEST DATA NUCLEAR

- | | |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p>A – Consecutive, by material per project</p> <p>B – Reading on display must match probe position</p> <p>C – Read direct from display – Daily Standard</p> <p>D – Read direct from display – Daily Standard</p> <p>E – Record correction for current material
(Reference page 3–4 Troxler Manual)</p> | <p>F – Record from display for current test</p> <p>G – Record from display for current test</p> <p>H – Provided by Materials for current material</p> <p>I – Record from display for current test</p> <p>J – Provided in contract documents or specifications</p> <p>K – Record from display for current test</p> <p>L – Provided form Materials for current material</p> |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|

DAILY CHECK LIST

1. Two different keys are needed
2. Wear badge
3. Make entry in sign out diary
4. Place travel papers on truck dashboard in plain view within driver's reach (transport gauge in locked box only)
5. Warm up machine 10 minutes – Set on plate with probe opposite butt plate
6. Take standard count – record standard counts in diary. Follow instruction manual.
1% Density Deviation, 2% Moisture Deviation
7. Enter proctor value from materials
8. Enter applicable moisture correction – See pages 3-4 in Troxler Manual
9. Sign back in at end of day and clean equipment

TROUBLE SHOOTING

Do not charge batteries until “low battery” appears (2-3 hours remaining)

If the display reads “GM Tube A Error, Service Required”, remove and replace fuse; retry entry.

See 203.5 of the Engineering Policy Guide for information on testing with Nuclear Moisture-Density Gauges.
See <http://scweb4/hq/co/radiation> for routine maintenance issues.

Battery Voltage: 3.6, Normal
3.35-3.4, Battery low but serviceable
3.25-Below, No service

Technical Advice: 573-526-4628

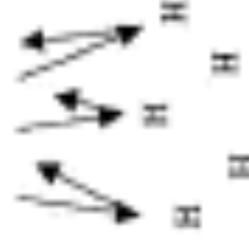
Offsets

- Moisture Offset
 - When measuring materials containing hydrogen not in the form of water or containing neutron absorbers a moisture offset may be necessary.
- Trench Offset
 - When performing moisture and density measurements in a trench or near a large object the density or moisture may be effected due to reflecting gamma photons or neutron.
- Density Offset
 - A density offset is used when measuring materials outside of the normal calibration parameters and often on asphalt materials with surface voids present.

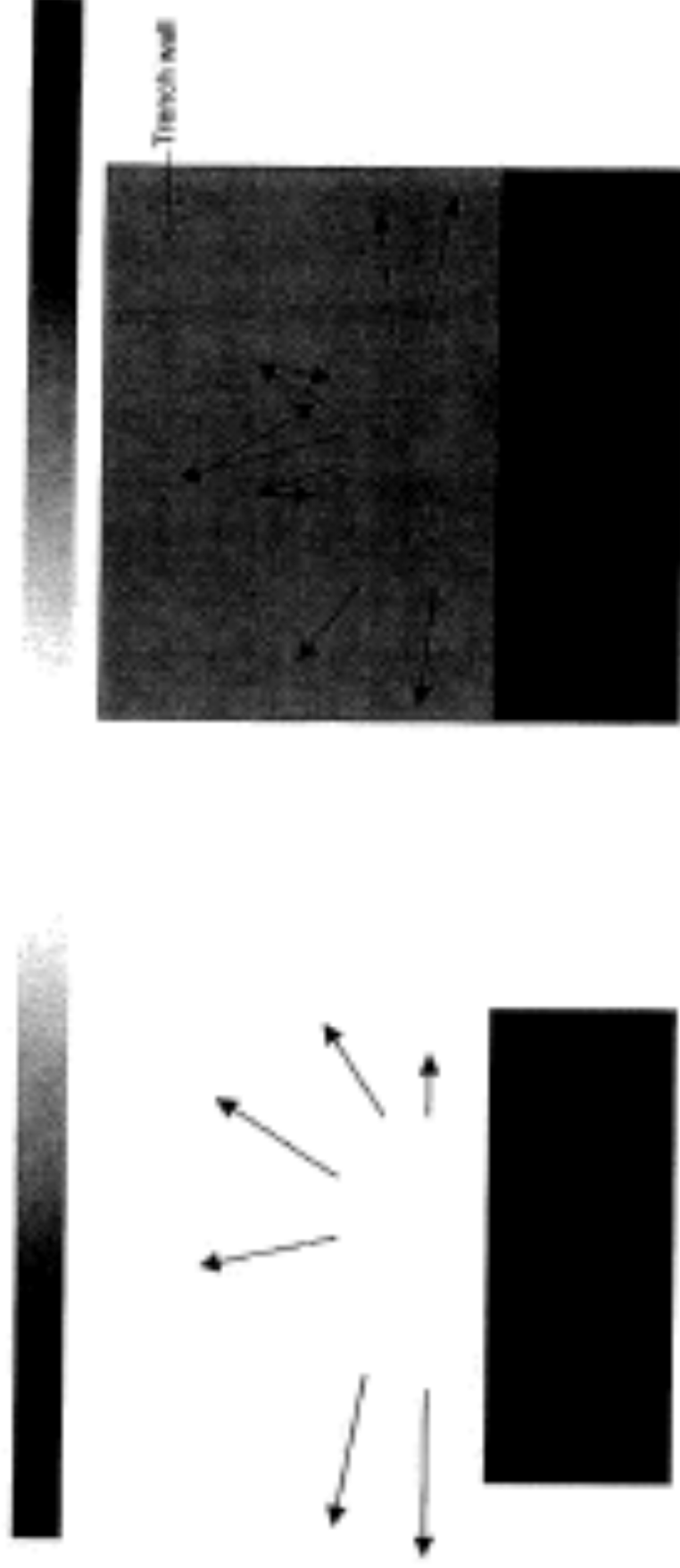
Moisture Offset

- The moisture / density gauges measure the moisture content of the soil material by detecting hydrogen present in the measurement area. Hydrogen may be present in the material that is not in the form of water a moisture offset is necessary to correct to the actual water content of the material. A few materials are considered to be neutron absorbers which may cause the gauge to read a falsely low moisture and may also require a moisture offset.

■ Common materials which contain hydrogen	■ Common neutron absorbers
<ul style="list-style-type: none">• gypsum• lime• mica• organic material (coal, shells, etc.)• fly ash• phosphates	<ul style="list-style-type: none">• cadmium• lithium• boron• salt• iron oxide



Trench Offset



- Normally the gauge only measures the moisture of the material below the gauge because other neutrons are not scattered back to the detectors (Figure I). In a trench situation, the neutrons traveling above and beside the gauge may read the moisture in the trench walls also (Figure II). The trench offset needs to be used if the gauge is within 2 feet (600 mm) of the trench wall (or vertical structure) on any side of the gauge.

Density Offset

- Find the difference between the gauge measured density and the alternative density measurement result (often a core):

	<u>Gauge Measured Dens.</u>	<u>Core dens.</u>	<u>Difference</u>
site A	142.3	143.6	1.3 pcf
site B	143.9	144.9	1.0 pcf
site C	143.4	144.7	1.4 pcf
site D	144.7	145.8	1.1 pcf

Average difference: 1.43 pcf

- This value is used as the wet density offset in the gauge. The Model 3440 will calculate this value for you, please consult your operator's manual.

AASHTO T 310: In-Place Density and Moisture Content of Soil and Soil-Aggregate by Nuclear Methods (Shallow Depth)

PROFICIENCY CHECKLIST

Applicant: _____

Employer: _____

Trial#	1	2
Make sure gauge is calibrated, charged, lab data, or offsets entered if any.		
Standardization		
1. Performed at start of each day's use.		
2. Permanent records of data retained.		
3. Performed with equipment at least 10 m (30 ft.) from other radioactive sources, and clear of large masses of water or other items which may affect reference count.		
4. Using reference standard, at least four repetitive readings taken at normal measurement period, and mean obtained.		
5. Procedure recommended by gauge manufacturer used to determine compliance with gauge calibration curves or – AASHTO Equation 1 used to determine standardization.		
Preparing the test site		
1. All loose, disturbed and additional material removed as necessary to expose top of material to be tested.		
2. Prepared a horizontal area sufficient in size to accommodate the gauge, planed the area smooth with plate or suitable tool to obtain maximum contact between gauge and material tested.		
3. Native fines or fine sand used to fill voids as necessary, for surface area less than 10% beneath the gauge.		
4. The depth of filler does not exceed approximately 1/8" (3 mm).		

AASHTO T 310: Density and Moisture Content of Soils and Soils-Aggregate by Nuclear Methods PROFICIENCY CHECKLIST (CONT.)

	Trial#	1	2
Direct Transmission Procedure			
1. Gauge turned on allowed to warm up.			
2. Drilling the Hole.			
a. Placed scraper plate on prepared test site.			
b. Attached extraction tool and inserted drill rod.			
c. Stepped firmly on center of plate and hammered drill rod perpendicular to the surface 2" deeper than test depth.			
d. Removed drill rod with upward and twisting motion.			
e. After drill rod removed, marked around the scraper plate.			
3. Removed all equipment from the test area except the gauge.			
4. Placed the gauge on marked area, ensuring maximum surface contact.			
5. Source rod lowered into hole to same depth of the lift being tested.			
6. Snugged the probe to contact the soil leaving no gap between the probe and soil.			
7. One or more 1-minute readings secured and % Compaction, Dry Density, % Moisture recorded by the gauge.			
8. Returned source rod to safe position.			
Backscatter Procedure			
1. Cleared the area of people and equipment.			
2. Turned the gauge on, allowed to warm up.			
3. Set the gauge to backscatter mode.			
4. Found a smooth location 30 feet (10 m) from other radioactive sources.			
5. Prepared the site.			
6. Gauge seated firmly on prepared test site.			
7. One or more 1-minute readings.			
8. In-place wet density determined and recorded by the gauge.			

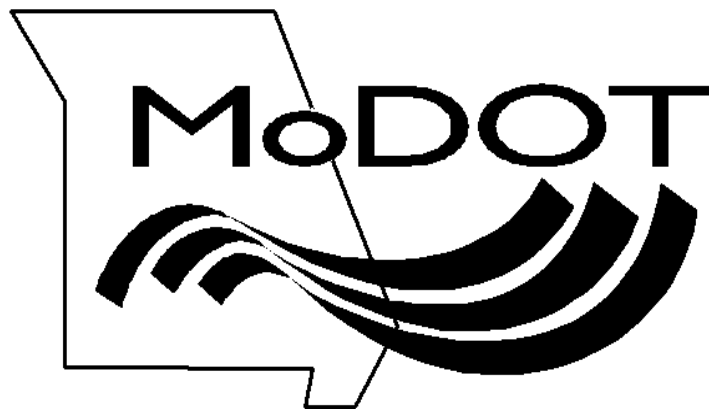
PASS PASS

FAIL FAIL

Examiner: _____ Date: _____

MoDOT TM 35

Moisture Offset Factor for Nuclear Gauge



**Intentionally Left Blank-
Notes if Needed**

MoDOT TM 35

Moisture Offset (K) Factor for a Nuclear Gauge

[1]

Rev 12/28/2018

1

BACKGROUND

- This test method describes the procedure for determining a moisture offset factor to be applied to calibration curve values for moisture content determinations by nuclear gauges in soil, soil-aggregate and crushed stone bases.
- Also Known as the "K" factor.
Do not confuse this with the Proctor Standard.

[2]

2

TERMINOLOGY

- **Heat Dried Moisture** - moisture content test by AASHTO T 265 (%M_{lab})
- **Nuclear Moisture** - uncorrected moisture content by nuclear gauge (%M_{gauge})
- **K** - Moisture Offset factor
- **% Moisture** – corrected moisture reading of soil or aggregate as determined by nuclear gauge.

[3]

3

EQUIPMENT

- Nuclear gauge
- Air tight sample container and other sample collection equipment
- Oven capable of $230 \pm 9^{\circ}\text{F}$ ($110 \pm 5^{\circ}\text{C}$)
- Scale capable of weighing 2 kg
- Other drying equipment - pans, gloves, brushes, etc.

[4]

4

Safety

- Anyone who operates a nuclear gauge is required to successfully complete a nuclear safety training class.
- Always practice the "**ALARA**" principle to minimize exposure.

(**As Low As Reasonably Achievable**)

- Four important facts to remember:

1. Time
2. Distance
3. Shielding
- 4.2 Barriers

Keep the gauge
body between you
and the source rod
to reduce
exposure.

[5]

5

PROCEDURE

1. Using a calibrated gauge select at least 4 testing sites for each soil or aggregate type.
2. Make sure **moisture offset** is **disabled** in the machine.
3. Perform nuclear density tests and percent moisture test for each location.
4. Record percent moisture for each location. This is $\%M_{\text{gauge}}$ for each sample.

[6]

6

5. Obtain field sample from each test site for lab testing. Take sample from material located between source rod and detectors to a depth of 5" but not into underlying layers.
6. Sample weight should weigh 1000 g (2.2 lb.) for sample with particles ¼ inch or less and 1500 g (3.3 lb.) for sample with particles larger than ¼ inch present.
7. Dry the field samples in the lab per AASHTO T 265.
8. Calculate heat dried moisture content, this is the %M_{lab} for each sample. [7]

Procedure

7

CALCULATIONS

- Calculate the average percent nuclear moisture and the average heat-dried moisture from the test sites for each soil/aggregate type.

%M _{gauge}	%M _{lab}
8.5	8.8
8.4	8.6
8.5	8.6
8.3	8.5
Avg. 8.4	Avg. 8.6

[8]

8

- Calculate the moisture offset factor (K) for use in 3430 gauge as follows:

$$K = \frac{(\%M_{lab} - \%M_{gauge})}{(100 + \%M_{gauge})} \times 1000$$

- %M_{lab} = Average heat-dried moisture
- %M_{gauge} = Average % nuclear gauge moisture reading
- (K) can be either positive or negative.
- Report to the nearest tenth (0.1).

Calculations

[9]

9

Classroom Exercise

- Example:

$$K = \frac{(\%M_{lab} - \%M_{gauge})}{(100 + \%M_{gauge})} \times 1000$$

$$\frac{(8.6 - 8.4)}{(100 + 8.4)} \times 1,000$$

$$K = \frac{0.2}{108.4} \times 1,000$$

$$K = 1.8 \text{ positive}$$

- Calculate K Factor to the nearest tenth:

$\%M_{gauge}$	$\%M_{lab}$
8.5	8.8
8.4	8.6
8.5	8.6
8.3	8.5
Avg. 8.4	Avg. 8.6

Calculations

10

10

Classroom Exercise

Calculations

- Proficiency

$$K = \frac{(\%M_{lab} - \%M_{gauge})}{(100 + \%M_{gauge})} \times 1000$$

Enlarged

$K =$

$\%M_{gauge}$	$\%M_{lab}$
15.5	15.8
15.4	15.6
14.9	14.6
15.3	15.5
Avg.	Avg.

Calculations

11

11

Moisture Offset

- Enter the moisture offset (K) into the nuclear gauge per the owner's manual.

Can be ignored if ± 0.5 pcf or less.

- Remember that each nuclear density gauge is unique. The amount of radiation emitted is different, gauge to gauge.
- A (K) factor derived on one gauge cannot be used for another.

Calculations

12

12

REPORTING

- (K) can be either positive or negative.
- Report to the nearest tenth 0.1
- Record moisture offset factor (K) calculations in a bound field book that is stored with the gauge.
- Record in weekly compaction reports.

13

13

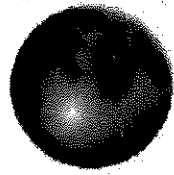
Common Errors

- Not using a calibrated nuclear gauge
- Not using enough testing sites
- Not checking correction factor on each new soil type (ie: rock, sand, clay, silt)
- Not using an airtight sample container to transport sample to lab
- Not drying sample to oven-dry condition
- Mixing soil/aggregate types

14

14

**Intentionally Left Blank-
Notes if Needed**



Calculations

• Proficiency

$$K = \frac{(\%M_{lab} - \%M_{gauge})}{(100 + \%M_{gauge})} \times 1000$$

$\%M_{gauge}$	$\%M_{lab}$
15.5	15.8
15.4	15.6
14.9	14.6
15.3	15.5
Avg.	Avg.

$K =$

(Sec 304.4.1.5) The contractor shall retain the untested portion of the plasticity index, gradation and deleterious sample for the engineer's use.

304.1.4.2 Quality Assurance (Sec 304.4.2)

A vital element in acceptance of aggregate base is the quality assurance. Material properties are to be tested at the frequency stated in Sec 304.4. (http://www.modot.org/business/standards_and_specs/SpecbookEPG.pdf#page=6) Density, gradation, presence of deleterious material and the PI are to be checked and documented by the engineer. Observe the compacting operation to ensure the material forms a firm, stable base. Measure and record the random thickness and template of the finished aggregate base for conformance with specifications, in addition to any inspections performed on items that are not otherwise part of a permanent record.

304.1.5 Method of Measurement (Sec 304.5)

Final measurement of the completed aggregate base course will not be made except for authorized changes during construction, or where appreciable errors are found in the contract quantity. Where required, measurement of aggregate base course, complete in place, will be made to the nearest square yard. Where the aggregate base course extends to the inslope of the shoulder, the pay limit of the aggregate base course will be measured from the mid-point of the sloped portion. The revision or correction will be computed and added to or deducted from the contract quantity.

304.1.6 Basis of Payment (sec 304.6)

The accepted quantities of aggregate base course of the thickness and type specified will be paid for at the contract unit price for each of the pay items included in the contract. When bituminous pavement cold millings or recycled crushed concrete are substituted for aggregate base, payment will be made for the aggregate base quantity provided in the plans, regardless of whether millings, recycled crushed concrete or the aggregate base is used.

304.2 Material Inspection for Sec 304

304.2.1 Scope

This guidance establishes procedures for inspection and acceptance of material used in aggregate base. Aggregate for use in base courses is to be inspected in accordance with Aggregate for Base.

304.2.2 Apparatus

The apparatus and materials required are listed in General Requirements for Material.

304.2.3 Procedure

304.2.3.1 Quality Control/Quality Assurance (QC/QA)

The contractor (QC) shall control operations to ensure the aggregate base, in place, meets the specified requirements for density, thickness, gradation, deleterious and plasticity index. Tests are to be taken at random locations designated by the engineer. The inspector (QA) shall take test, at random locations and at a reduced frequency, to accept the contractor's results.

304.2.3.2 Compaction Standard

Aggregate base course construction, except as noted in the Standard Specifications, requires that a certain density be achieved. In order that this density can be checked in the field, a sample must be submitted to the Laboratory for standard maximum density determination. The contractor is also required to determine the compaction standard. The contractor's compaction standard shall be within 3.0 pounds of the compaction standard determined by the Central Laboratory. When the contractor's compaction standard compares favorably with the engineer's standard, the contractor's standard will be used as the basis of subsequent density tests.

The inspector shall obtain representative samples and submit two full sample bags of material in accordance with the procedures outlined in General Requirements for Material. In addition, the sample record in AASHTOWARE Project (AWP) shall request that a compaction standard test be performed.

304.2.3.3 Random Sampling

The inspector shall generate random numbers for both the inspector's and contractor's sampling, for the testing of each "lot" of material. A "lot" is defined in Sec 304.4.1 (http://www.modot.org/business/standards_and_specs/SpecbookEPG.pdf#page=6). For example, a "lot" for the contractor's determination of gradation and deleterious is defined as 2,000 tons or a days production, whichever is greater.

The inspector shall generate the numbers either using a random number table or with a random number generator on a calculator or computer. Using a random number generator is the preferred method.

The inspector shall generate two (2) random numbers for each lot. One to determine the longitudinal offset and one for the transverse offset. Only one set of random numbers needs to be determined for the Density and Thickness "lot". Determine the density and thickness of the base at the same location.

304.2.3.4 Sampling

Samples for gradation, deleterious and Plasticity Index (PI) shall be taken at the roadway, behind the placing operation, prior to compaction. Care should be taken to not contaminate sample with sub-grade material when extracting a sample from the roadway. The recommended sample size is outlined in General Requirements for Material. The contractor's QC sample shall be large enough so that after removal of the material for the QC tests, all retained material from the QC's final split will be an adequately large amount for comparison testing.

304.2.3.5 Testing

Tests are to be run in accordance with the applicable test methods at the frequency listed in Sec 304.4.1. (http://www.modot.org/business/standards_and_specs/SpecbookEPG.pdf#page=6) Please note that the frequencies listed are minimums. If material is approaching specification limits or if problems are encountered the inspector should increase the testing frequency.

Inspectors shall test one of the contractor's retained QC samples at the following frequencies:

Test	Frequency
Gradation and Deleterious	1 per project with a minimum of 1 per week and at least 1 per 16,000 tons
PI	1 per project with a minimum of 1 per week and at least 1 per 80,000 tons

For determination of thickness a rule with suitable graduations should be used to accurately measure the material to be inspected.

For the determination of density the inspector should use AASHTO T 310, Direct Transmission, for wet density. In order to determine the wet density the inspector must have first submitted a sample for the determination of the Compaction Standard. At the start of the job, a moisture-offset factor shall be determined in accordance with MoDOT Test Method T35.

For retained samples, the contractor's test results and the engineer's test results shall compare within the limits specified.

304.2.3.6 Failing Tests

Procedures for failing test results are outlined in Sec 304.4. (http://www.modot.org/business/standards_and_specs/SpecbookEPG.pdf#page=6)

304.2.4 Trimmed Base

Trimmed base may be reused as base material but must be checked for specification compliance prior to use. The material should be stockpiled and held pending testing. Material not meeting gradation can be reconditioned. Material that has been contaminated to such an extent that it no longer complies with the specification cannot be used.

304.3 Laboratory Testing for Sec 304

For aggregate base course, refer to Laboratory Testing for Sec 1007 for testing and reporting of standard compaction samples.

Retrieved from "https://epg.modot.org/index.php?title=Category:304_Aggregate_Base_Course&oldid=50183"

This page was last edited on 1 October 2021, at 07:40.

106.3.2.35 TM-35, Moisture Offset Factor for a Nuclear Gauge

This test determines the moisture offset factor to be applied to the calibration curve values for moisture content determinations by nuclear gauges in soil, soil-aggregate and crushed stone bases.

106.3.2.35.1 Equipment

(a) Nuclear moisture-density gauges meeting the apparatus and precision requirements of AASHTO T310.

(b) Equipment specified by AASHTO T205, paragraphs 2.2, 2.3 and 2.4.



Crew takes a soil sample on an interstate to determine soil conditions and how much rock is beneath the surface.

106.3.2.35.2 Procedure

A correction factor for use with the moisture calibration curve shall be determined as follows:

(1) No fewer than four tests^a are required to establish a moisture offset factor. These tests should be obtained from material typical of that to be tested and should be randomly selected over the largest practical area of material positively identifiable as the material to be tested. For soils, the tests may be performed in cuts behind the earth movers.

^a The required number of tests is based upon statistical considerations which include a selected confidence level of 99%, a selected confidence interval of 0.5 pcf and a standard deviation of 0.35 pcf for nuclear moisture test values as determined by Research Study 74-2.

(2) At each random site, perform a nuclear wet density and moisture test in accordance with AASHTO T310 Direct Transmission and obtain a moisture sample for heat drying. Obtain the moisture sample and heat dry as follows:

- a. Select the sample from that material located between source and detectors during the nuclear determinations.
- b. The moisture sample should weigh from 1000 g (2.2 lb) to 1500 g (3.3 lb). The higher weight sample should be obtained when particles larger than 1/4 in. are present. The sample should be obtained to a depth of 5 in. (127 mm) except that the depth should be reduced so as to not exceed the thickness of any layer under test. (Note: The nuclear meter has not been evaluated in crushed stone bases where the lift was less than 4 in. thick.)

c. Determine the moisture content of the total sample by heat drying at $110^{\circ}\text{C} \pm 5^{\circ}\text{C}$ ($230^{\circ}\text{F} \pm 9^{\circ}\text{F}$).

106.3.2.35.3 Calculations

(a) Determine the moisture offset factor from the average results of the 4 tests, as follows from Troxler Manual:

$$K = 1000 \times \frac{\%M_{LAB} - \%M_{GAUGE}}{100 + \%M_{GAUGE}}$$

Where:

K = Moisture Offset Factor

% M_{LAB} = Percent moisture of heat dried sample

% M_{GAUGE} = Percent moisture of nuclear gauge

(b) Enter moisture offset factor (K) into gauge as outlined in the Operator's Manual.

(c) The offset factor can be ignored if 0.5 pcf or less.

106.3.2 Material Inspection Test Methods

Retrieved from "https://epg.modot.org/index.php?title=106.3.2.35_TM-35_Moisture_Offset_Factor_for_a_Nuclear_Gauge&oldid=56485"

This page was last edited on 26 June 2025, at 10:17.

**Intentionally Left Blank-
Notes if Needed**

MOISTURE OFFSET

The 3430 measures moisture by determining the hydrogen content of the soil and relating this to the water content. In some soils, there are compounds other than water that contain hydrogen as well as compounds that absorb neutrons. Both types of material will result in gauge readings that are different from the true soil moisture. If these compounds are suspected to be present in the soil, the gauge is equipped with a Moisture Offset for adjusting the readings.

The offset factor (K) is determined by comparing the moisture value of a laboratory sample with the moisture determined by a gauge reading. Use the following procedure:

1. Use laboratory methods to determine the moisture content of a sample taken at the measurement site.
2. Take a gauge reading at the site. Record the readings.
3. Calculate the offset factor (K).

$$K = \frac{\%M_{LAB} - \%M_{GAUGE}}{100 + \%M_{GAUGE}} \times 1000$$

Multiple samples and measurements may be taken. Calculate the average moisture of the samples and the gauge readings. These average values should be used for the offset factor calculation.

NOTE: If the "K" value is negative, a minus sign (-) may be entered by pressing the "Down" arrow prior to entering the first digit.

To perform a Moisture offset, press **SPECIAL**.

Press the "Down" arrow one (1) time and then press **ENTER** for the display:

Offset Density
(11 OF ENTER)

Press the "Down" arrow one (1) time and press **ENTER**.

Moist Offset Off
Want to enable?

Press **YES**.

K= 0.0
(11 OF ENTER)

Use the "Up" and "Down" arrows to change the numeric value.

NOTE: To input a minus (-) sign (for a negative offset), press the "Down" arrow first!

Press the **ENTER** key to change fields and exit.

The display will be:

Moist Offset ON

After the count time has elapsed, the display will be:

Wet Density

WD: xxxxx
(Use ↑ ↓ keys)

Use the "Up" and "Down" keys to view the data.

Dry Density and Percent % Proctor

DD: xxxxx
% PR: xxxxx %

Moisture and % Moisture

Moist: xxxxx
% Moist: xxx %

%M_{GAUGE}

Air Void and Void Ratio

Air Void: xxx %
Void Ratio: xxx

Refer to the following page for the formulae used in calculating the above values.

% AIR VOIDS =
where:

$100 (1 - (V_s/V_t) - (V_w/V_t))$
V_s = Volume of Soil
V_t = Total Volume
V_w = Volume of Water

where:

$= 100 (1 - (DD / SG(D_w)) - (M / (D_w)))$
D_w = Density of Water

VOID RATIO

= Volume of Voids / Volume of Soil
= (SG(D_w) - DD) / DD

Continue pressing the "Down" arrow for:

Moisture and Density Count Ratio

MOIST CR: xxx
DENS CR: xxx

Moisture and Density Counts

M Count: xxx
D Count: xxx

**Intentionally Left Blank-
Notes if Needed**

MoDOT TM 35: Moisture Offset Factor for A Nuclear Gauge PROFICIENCY CHECKLIST

Applicant: _____

Employer: _____

Trial#	1	2
1. Select at least 4 testing sites for each aggregate type.		
2. Ensure that moisture offset is disabled or turned off in the machine.		
3. Perform field nuclear wet density and moisture tests.		
4. Record readings obtained and Avg. (%M _{gauge}).		
5. At each test site obtain sample for moisture, retrieving material between source and detectors 2.2 lb. (1,000 g) for ≤ ¼", 3.3 lb. (1,500 g) > ¼".		
6. Dry sample per AASHTO T 265.		
7. Record and Avg. (%M _{lab}).		
8. Calculate "K" factor: $K = \frac{(\%M_{lab} - \%M_{gauge})}{(100 + \%M_{gauge})} \times 1,000$		

PASS PASS

FAIL FAIL

Examiner: _____ Date: _____

Appendix



Calibration of Measure AASHTO T 19

★ Volume of Mold

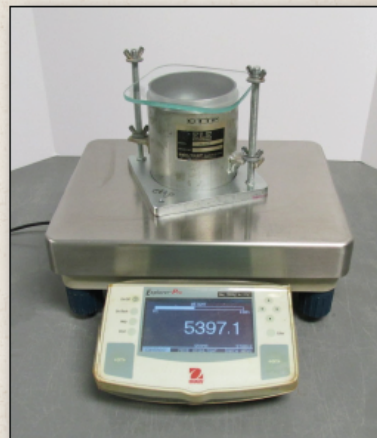
- ✓ Place a thin layer of grease on upper and lower mold rims
- ✓ Assemble mold and base plate
 - Clean and dry
- ✓ Weigh glass plate and mold assembly



Calibration of Measure AASHTO T 19

★ Volume of Mold

- ✓ Fill mold with water and cover with glass plate
 - Eliminate bubbles and excess water
 - Dry mold assembly and glass plate
- ✓ Weigh mold, water and glass plate



Calibration of Measure AASHTO T 19

★ Volume of Mold

✓ Measure temperature of water to nearest 1° F

✓ Determine the density of the water at the measured temperature

- AASHTO Table 3
- Interpolate

✓ Calculate the volume of the mold

° F	lb/ft ³	° F	lb/ft ³
65	62.336	74	62.269
66	62.329	75	62.261
67	62.322	76	62.252
68	62.315	77	62.243
69	62.308	78	62.234
70	62.301	79	62.225
71	62.293	80	62.216
72	62.285	81	62.206
73	62.277	82	62.196

Calibration of Measure AASHTO T 19

★ Volume of Mold

$$V = \frac{(Full - Empty)}{Density\ of\ Water}$$

★ Calculate the volume of the mold

✓ Mold + Plate	2.427 lb	Density of
✓ Mold + Water + Plate	4.500 lb	Water @ 76°
✓ Temperature	76 °F	62.252 lb/ft ³

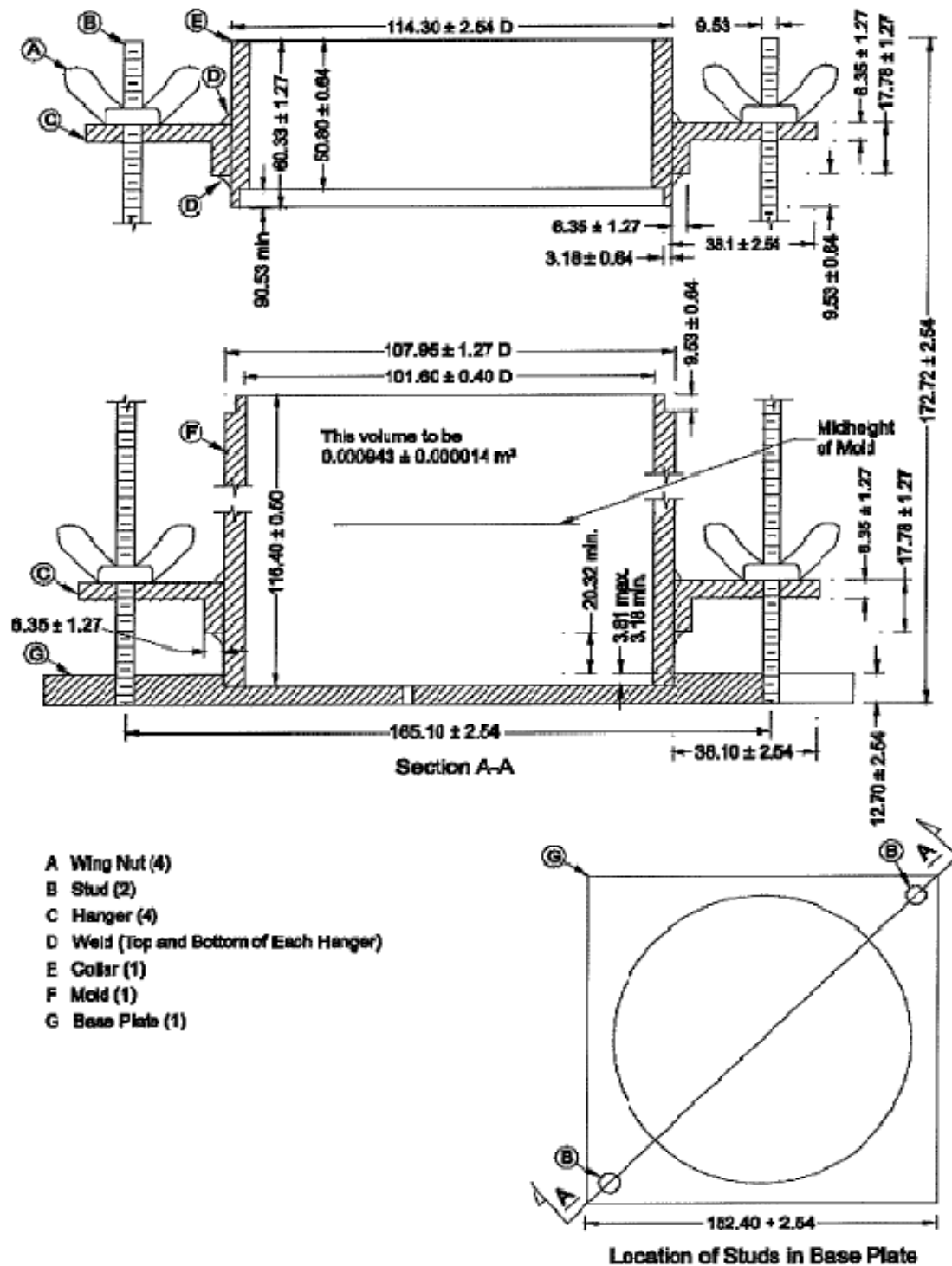
$$V = \frac{(4.500\ lb - 2.427\ lb)}{62.252\ lb/ft^3} = 0.0333\ ft^3$$

Mold Assembly (Mold, Collar, and Base Plate)—Molds shall be solid-wall, metal cylinders manufactured with dimensions and capacities shown in [Sections 3.1.1, 3.1.2, and Figures 1 and 2](#). They shall have a detachable collar approximately 60 mm (2.375 in.) in height, to permit preparation of compacted specimens of soil-water mixtures of the desired height and volume. The mold and collar shall be so constructed that it can be fastened firmly to a detachable base plate made of the same material ([Note 2](#)). The base plate shall be plane to 0.005 in. as shown in [Figures 1 and 2](#).

Note 2—Alternate types of mold assemblies with capacities as stipulated herein may be used, provided the test results are correlated with those of the solid-wall mold on several soil types and the same moisture-density results are obtained. Records of such correlation shall be maintained and readily available for inspection, when alternate types of molds are used.

Molds having a volume of $0.000943 \pm 0.000014 \text{ m}^3$ ($0.0333 \pm 0.0005 \text{ ft}^3$) shall have an inside diameter of $101.60 \pm 0.40 \text{ mm}$ ($4.000 \pm 0.016 \text{ in.}$) and a height of $116.40 \pm 0.50 \text{ mm}$ ($4.584 \pm 0.018 \text{ in.}$) ([Figure 1](#)). Determine the mold volume in accordance with the "Calibration of Measure" section of T 19M/T 19 for Unit Mass of Aggregate.

Molds having a volume of $0.002124 \pm 0.000025 \text{ m}^3$ ($0.07500 \pm 0.0009 \text{ ft}^3$) shall have an inside diameter of $152.40 \pm 0.70 \text{ mm}$ ($6.000 \pm 0.026 \text{ in.}$) and a height of $116.40 \pm 0.50 \text{ mm}$ ($4.584 \pm 0.018 \text{ in.}$) ([Figure 2](#)). Determine mold volume in accordance with the "Calibration of Measure" section of T 19M/T 19 for Unit Mass of Aggregate.



- Notes:
1. All dimensions shown in millimeters unless otherwise noted.
 2. Hanger on the mold portion only cannot extend above the midheight line.
 3. Figure 1 is to be used for all compaction molds purchased after the publication of the 21st edition (HDM-21).

Figure 1 – Cylindrical Mold and Base Plate (101.6 – mm Mold)

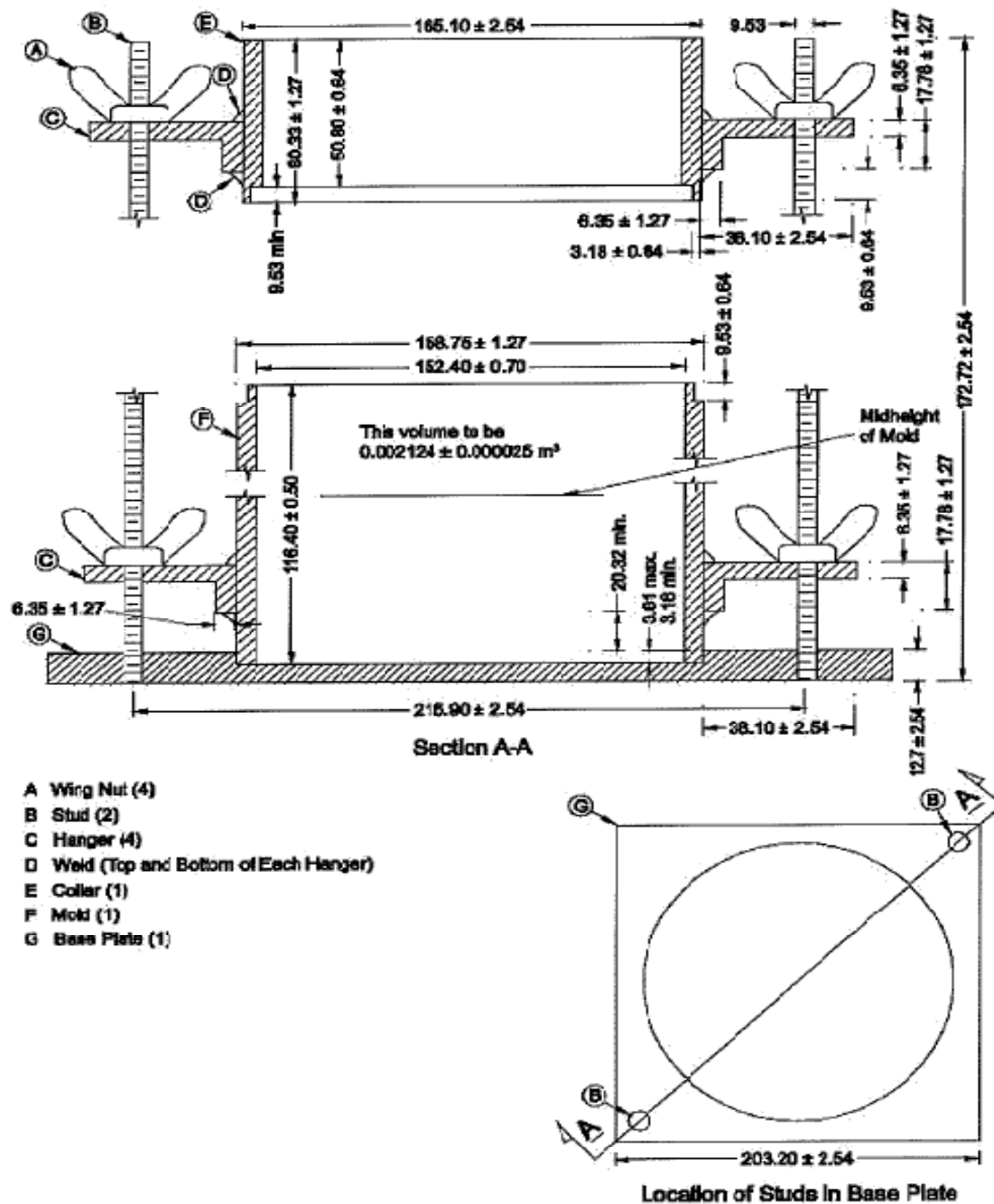


Figure 2 – Cylindrical Mold and Base Plate (152.4 – mm Mold)

Figure 2—Cylindrical Mold and Base Plate (152.4-mm Mold)**Table 1**—Dimensional Equivalents for [Figure 1](#)

mm	in.	mm	in.
3.18 ± 0.64	0.125 ± 0.025	50.80 ± 0.64	2.000 ± 0.025
3.81	0.150	60.33 ± 1.27	2.375 ± 0.050
6.35 ± 1.27	0.250 ± 0.050	101.60 ± 0.41	4.000 ± 0.016
7.62	0.300	107.95 ± 1.27	4.250 ± 0.050
9.53 ± 0.64	0.375 ± 0.025	114.30 ± 2.54	4.500 ± 0.100
12.70 ± 2.54	0.500 ± 0.100	116.43 ± 0.13	4.584 ± 0.005
17.78 ± 1.27	0.700 ± 0.050	152.40 ± 2.54	6.000 ± 0.100
20.32	0.800	165.10 ± 2.54	6.500 ± 0.100
38.10 ± 2.54	1.500 ± 0.100	172.72 ± 2.54	6.800 ± 0.100
0.000943 ± 0.000009 m ³		0.0333 ± 0.0005 ft ³	

Table 2—Dimensional Equivalents for [Figure 2](#)

mm	in.	mm	in.
3.18 ± 0.64	0.125 ± 0.025	50.80 ± 0.64	2.000 ± 0.025
3.81	0.150	60.33 ± 1.27	2.375 ± 0.050
6.35 ± 1.27	0.250 ± 0.050	116.43 ± 0.13	4.584 ± 0.005
7.62	0.300	152.40 ± 0.66	6.000 ± 0.026
9.53 ± 0.64	0.375 ± 0.025	158.75 ± 1.27	6.250 ± 0.050
12.70 ± 2.54	0.500 ± 0.100	165.10 ± 2.54	6.500 ± 0.100
17.78 ± 1.27	0.700 ± 0.050	172.72 ± 2.54	6.800 ± 0.100
20.32	0.800	203.23 ± 2.54	8.000 ± 0.100
38.10 ± 2.54	1.500 ± 0.100	215.90 ± 2.54	8.500 ± 0.100
0.002124 ± 0.000025 m ³		0.0750 ± 0.0009 ft ³	

3.2. *Rammer:*

3.2.1. *Manually Operated*—Metal rammer with a mass of 2.495 ± 0.009 kg (5.5 ± 0.02 lb), and having a flat circular face of 50.80-mm (2.000-in.) diameter with a manufacturing tolerance of ± 0.25 mm (0.01 in.). The in-service diameter of the flat circular face shall be not less than 50.42 mm (1.985 in.). The rammer shall be equipped with a suitable-guide sleeve to control the height of drop to a free fall of 305 ± 2 mm (12.00 ± 0.06 in.) above the elevation of the soil. The guide sleeve shall have at least four vent holes, no smaller than 9.5-mm (3/8-in.) diameter spaced approximately 90 degrees (1.57 rad) apart and approximately 19 mm (3/4 in.) from each end; and shall provide sufficient clearance so the free fall of the rammer shaft and head is unrestricted.

3.2.2. *Mechanically Operated*—A metal rammer that is equipped with a device to control the height of drop to a free fall of 305 ± 2 mm (12.00 ± 0.06 in.) above the elevation of the soil and uniformly distributes such drops to the soil surface ([Note 3](#)). The rammer shall have a mass of 2.495 ± 0.009 kg (5.5 ± 0.02 lb), and have a flat circular face of 50.80-mm (2.000-in.) diameter with a manufactured tolerance of ± 0.25 mm (0.01 in.). The in-service diameter of the flat circular face shall be not less than 50.42 mm (1.985 in.). The mechanical rammer shall be calibrated by ASTM D2168.

Note 3—It may be impractical to adjust the mechanical apparatus so the free fall is 305 mm (12 in.) each time the rammer is dropped, as with the manually operated rammer. To make the

adjustment of free fall, the portion of loose soil to receive the initial blow should be slightly compressed with the rammer to establish the point of impact from which the 305-mm drop is determined. Subsequent blows on the layer of soil being compacted may all be applied by dropping the rammer from a height of 305 mm above the initial-setting elevation; or, when the mechanical apparatus is designed with a height adjustment for each blow, all subsequent blows should have a rammer free fall of 305 mm measured from the elevation of the soil as compacted by the previous blow. A more detailed calibration procedure for laboratory mechanical-rammer soil compactors can be found in ASTM D2168.

Rammer Face—The circular face rammer shall be used, but a sector face may be used as an alternative, provided the report shall indicate type of face used other than the 50.8-mm (2-in.) circular face, and it shall have an area equal to that of the circular face rammer. The in-service area of sector face rammers shall be standardized and yield a surface area within 1.5 percent of the area of the 50.8-mm (2-in.) circular face rammer.

Sample Extruder (for Solid-Walled Molds Only)—A jack, lever, frame, or other device adopted for the purpose of extruding compacted specimens from the mold.

Balances and Scales—A balance or scale conforming to the requirements of M 231, Class G 5. Also, a balance conforming to the requirements of M 231, Class G 2.

Note 4—The capacity of the metric balance or scale should be approximately 11.5 kg (25 lb) when used to determine the mass of the 152-mm (6-in.) mold and compacted, moist soil; however, when the 102-mm (4-in.) mold is used, a balance or scale of lesser capacity than 11.5 kg may be used, if the sensitivity and readability are 1 g.

Drying Oven—A thermostatically controlled drying oven capable of maintaining a temperature of $110 \pm 5^\circ\text{C}$ ($230 \pm 9^\circ\text{F}$) for drying moisture samples.

Straightedge—A hardened-steel straightedge at least 250 mm (10 in.) in length. It shall have one beveled edge, and at least one longitudinal surface (used for final trimming) shall be plane within 0.250 mm per 250 mm (0.01 in. per 10 in.) (0.1 percent) of length within the portion used for trimming the soil ([Note 5](#)).

Note 5—The beveled edge may be used for final trimming if the edge is true within a tolerance of 0.250 mm per 250 mm (0.1 percent) of length; however, with continued use, the cutting edge may become excessively worn and not suitable for trimming the soil to the level of the mold. The straightedge should not be so flexible that trimming the soil with the cutting edge will cause a concave soil surface.

Sieves—50-mm (2-in.), 19.0-mm (3/4-in.), and 4.75-mm (No. 4) sieves conforming to the requirements of ASTM E11.

Mixing Tools—Miscellaneous tools such as mixing pan, spoon, trowel, spatula, etc., or a suitable mechanical device for thoroughly mixing the sample of soil with increments of water.

Containers—Suitable containers made of material resistant to corrosion and not subject to change in mass or disintegration on repeated heating and cooling. Containers shall have close-fitting lids to prevent loss of moisture from samples before initial mass determination and to prevent absorption of moisture from the atmosphere following drying and before final mass determination. One container is needed for each moisture content determination.

**Intentionally Left Blank-
Notes if Needed**

Glossary



Soils Glossary of Terms

Background Count – The naturally occurring radiation from lights, the sun, and many other sources.

Compaction – The reduction of voids in a soil mass. The densification of the soil mass by applying a force such as that delivered by the rammer.

Compaction Effort – The force applied to achieve compaction of a soil mass.

Density – The mass of the soil divided by the volume.

Dry Density – The density of the soil corrected for moisture content.

Fast Neutron Detector – An electronic device that counts neutrons as they pass through a special gas.

Fast Neutron Source – Each atom has a nucleus comprised of varying numbers of protons and neutrons. When a high-energy electron strikes a nuclei, one or more protons or neutrons are released. These neutrons are used to measure moisture content by a nuclear gauge.

Gamma Detector – An electronic device that converts electronic pulses caused by high energy electrons, passing through a special gas enclosed in a tube, into a numerical count.

Gamma Source – A radioactive material that emits high energy electron radiation, similar to x-rays commonly used in hospitals. The radiation is invisible and capable of passing through many millimeters of wood, soil or other material.

Homogenous – Of uniform structure and composition throughout.

Maximum Density – The dry density corresponding to the peak of the moisture-density curve. The highest density that can be achieved for a particular soil using a particular compactive effort.

Meniscus – The curved concave upper surface of a column of liquid in a tube.

Moisture Content – The ratio, expressed as a percentage, of the mass of the water in a given soil mass to the mass of the solid particles.

Moisture Density Curve – A smooth line connecting the points obtained from AASHTO T99 when plotted on a graph with moisture on the x-axis and density on the y-axis.

Moisture-Density Relationships – The interrelationship between density and changing moisture contents in a soil.

Optimum Moisture Content – The percent of free moisture at which a soil can reach its maximum density with a standard compactive effort.

Organic – Vegetable matter included in soil.

Percent Compaction – The ratio, expressed as a percentage, of the density of a soil to its maximum density.

Soil Mechanics – The study of engineering properties and behavior of soils.