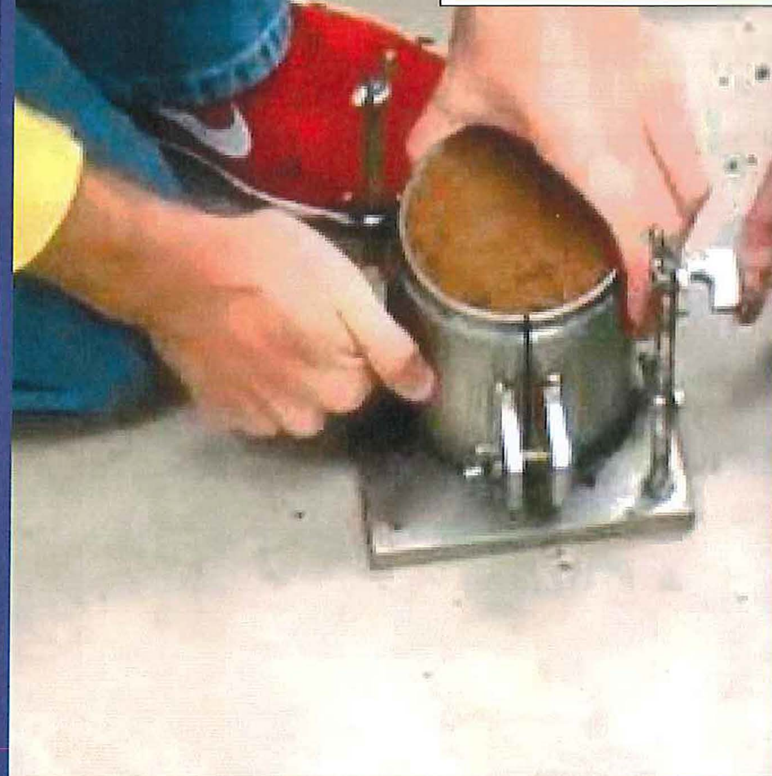
**2022 Edition**



# SOIL DENSITY

MoDOT

# Soil Density Technician

## 2020 – Updates

- **AUDIT NOTIFICATION SLIDE ADDED TO ALL MANUALS:** To all material testers, who work on Missouri Highways, this includes Consultants, Contractors, City, County, and MoDOT workers; you will be audited by **MoDOT IAS Inspectors** and sometimes **FHWA** personnel.
- **No Significant changes in Methods for 2020.**

# 2021 and 2022 – No updates

# 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** | |

MoDOT

# AASHTO T 265

## Laboratory Determination Of Moisture Content of Soils

## 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 till the end of the year.
- **Provide Proof;** when audited, present a MoDOT Certification Card, or a MoDOT Letter.

# AASHTO T 265

**LABORATORY DETERMINATION**

**OF**

**MOISTURE CONTENT OF SOILS**

10/22/2019
No Change

## SCOPE

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

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

Informational

- 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.

5

Informational

- 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.

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

# 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 ± 9°F (110 ± 5°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.

8

# EQUIPMENT

- **Scale** – readable to 0.1% of the sample mass or better.
- **Oven** – 230 ± 9°F (110 ± 5°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.

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

## PROCEDURE

1. Preheat oven and allow the temperature to stabilize to 230 ± 9°F (110 ± 5°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

Procedure

4. Remove the lid and place the container with the moist sample and lid in the drying oven at 230 ± 9°F (110 ± 5°C).


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).


12

Procedure

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%**

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).

14

Notes

- 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.

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

Calculations

- Another way to understand the equation:

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

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

**EXERCISE #1:**

ANSWER

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

$$w = 20.459 = 20.5\%$$

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

**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

**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

# 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**)<br><br>**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:______________

# AASHTO T 99

## Moisture-Density Relations of Soils

(Standard 4 – Point Proctor Test)

MoDOT

# AASHTO T 99

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

Rev 10/22/2019
AASHTO = No Change

1

## SCOPE

- 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

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

| Method | A | B | C | D |
|---|---|---|---|---|
| Mold Size | 4 inch | 6 inch | 4 inch | 6 inch |
| Material Size | Passing No. 4 Sieve | Passing No. 4 Sieve | Passing ¾" Sieve | Passing ¾" Sieve |
| Blows per Layer | 25 | 56 | 25 | 56 |
| Minimum Mass for Testing | 3,000g (7lb.) | 7,000g (16lb.) | 5,000g (11lb.) | 11,000g (25lb.) |
| Standard (T99) | 3 layers,12 inch drop of a 5.5 lb. Rammer, total compaction depth 5" | | | |

Scope

- The method to be used should be indicated in the specifications for the material being tested. If no method is specified, the provisions of Method A shall govern.

5

Scope

- This test method applies to soil mixtures that have the following criteria:
  - When **40%** or less retained on the **No. 4** sieve use **Method A or B**.
  - When **30%** or less retained on the **¾"** sieve, use **Method C or D**.
    - Material retained on these sieves shall be defined as **oversized particles** (coarse particles)

6

## Oversized Particles

Scope

- If the test specimen contains oversized particles, dry density and moisture corrections must be made in accordance with **Annex A1**. (Slides 65-71)
- If no minimum percentage is specified by MoDOT, the correction for the oversized particles shall be applied to material containing more than **5% by weight** of oversized particles.

7

Scope

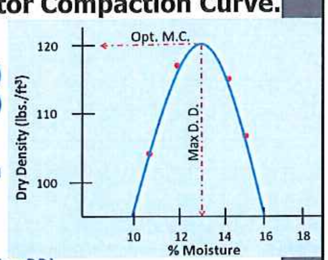
- This method creates a Proctor Compaction Curve using the data from each sample compacted.
- The data is then used to create a graph with a curve going through the Proctor points to determine **Optimum Moisture** and **Maximum Dry Density**.

8

## Example of a Proctor Compaction Curve.

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

Draw Proctor Curve
- Decide ≈ 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./$ft^3$
- Optimum MC: Nearest 0.1%

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## TERMINOLOGY

Terminology

- **Maximum Dry Density:** Proctor value entered into 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.

10

Terminology

- **Percent Compaction**: Comparison between the compaction actually 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".

11

Terminology

- **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.

12

# EQUIPMENT

13

Equipment

- **Sieves**
  - #4 or ¾″
- **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
- **Sample Containers**
- **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

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# SAMPLE PREPARATION

1. Obtaining a Representative Sample
2. Drying
3. Sieving & Oversized Particles
4. Reducing
5. Adding Moisture

15

## 1. Obtaining a Representative Sample

Sample Preparation

- **Method A:** This sample must be large enough that when the oversized particles (retained on the No. 4 sieve) are removed 3,000 g (7 lb.) or more of the sample remains.
- **Method C:** This sample must be large enough that when the oversized particles (retained on the ¾" sieve) are removed 5,000 g (11 lb.) or more of the sample remains.

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## 2. Drying the Sample

Sample Preparation

**Method A** and **Method C**

- Place the sample in a drying pan.
- Dry the sample in air or by use of an oven not to exceed 140°F (60°C) until it becomes friable under a trowel.
- Thoroughly break up the large clods of soil by hand, without reducing the natural size of individual particles.

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## 3. Sieving & Oversized Particles

Sample Preparation

- **Method A:** Sieve the soil over a No. 4 sieve.
  - When the sample has oversized particles, retained on the No.4 sieve, refer to Annex A1.
- **Method C:** Sieve the soil over a ¾" sieve.
  - When the sample has oversized particles, retained on the ¾" sieve, refer to Annex A1.

**Note:** When a sample has **30%** or more material retained on a ¾" sieve, it may be too rocky to test.

18

- For **Method C**, in order to adjust densities of soil or soil aggregate with 5.1-30% retained on the ¾" sieve, use AASHTO T 99 **Annex A1** calculations.
- If less than 5% is retained on the ¾" sieve, no adjustment is necessary when using **Method C**.

If necessary for **Method C**, determine the amount of:

$M_{DF}$ = Mass of material for fine particles (Passing the ¾" sieve).

$M_{DC}$ = Mass of material for coarse particles (Retained on the ¾" sieve).

Sample Preparation 19

## 4. Reducing Samples

- **Method A:** Reduce the sample to a mass of 3,000 g or 7 lb. or more in accordance with AASHTO R 76.
- **Method C:** Reduce the sample to a mass of 5,000 g or 11 lb. or more in accordance with AASHTO R 76.

Sample Preparation 20

## 5. 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.

**Hint:** A good starting point for the lowest moisture content is **6%** below the Plastic Limit (**PL**) moisture level.

Sample Preparation 21

First Point Moisture

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

22

Sample Preparation

- **Average 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, $\mathbf{W_1}$ per $ft^3$ of the compacted soil, perform one more determination for a **minimum of two** determinations over optimum moisture.

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Sample Preparation

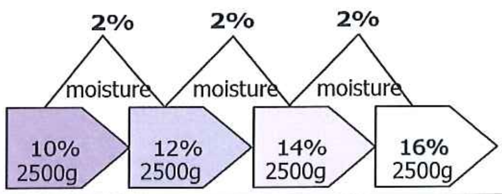
- **Heavy Clay Soils or Organic Soils:**
  - To handle **Clayey** or **Organic** fragile type soils that may be difficult to incorporate water into, perform the following:
    - Mix a separate sample for each compaction test.
    - Each test will increase in 2% - 4% max moisture increments from the previous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

**Note: Clayey Soil will have ≈ LL greater than 50**

24

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

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




Sample Preparation

25

- 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: 14%/100 = 0.14

Sample Preparation

26

- **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

27

## Sample Preparation

- **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)

28

## Practice Calculation

**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.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## Answer

5,000 x 0.15 = 750 ml
2.5/100 = 0.025
5,000 x 0.025 = 125 ml increments of water

ml = milliliters


30

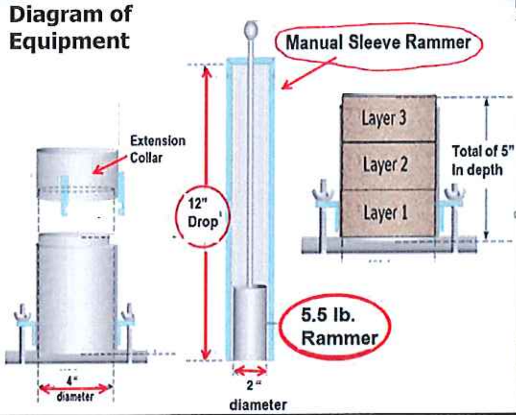
# PROCEDURE

Standard Proctor Test

**Method A**
4 inch Mold
25 blows
12 inch drop
3 Layers

31

**Diagram of Equipment**




Procedure

32

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

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

Procedure

33

**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

34

**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.

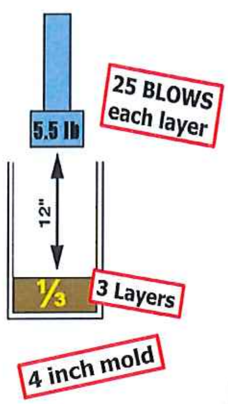
**Note:** The 12" drop is from the bottom side of the rammer face to the surface of the soil and shall uniformly distribute the blows over the entire surface area of the sample in the mold assembly.

Procedure

35

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

**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

36

Procedure

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

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

37

Procedure

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.

38

Procedure

**9.** Clean off the mold base before weighing.


**10.** Weigh mold and base with sample.

- For **lb./ft$^3$**, record to the nearest **0.005 lb.**
- For kg/m$^3$, record to the nearest 1 gram.

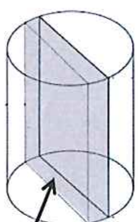
39

**11.** Extract the compacted sample

Procedure

40

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



Shaded area illustrates a representative moisture content sample.

Procedure

41

**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 %

Procedure

42

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



43

Procedure

**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 : **¾"** (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.

44

Procedure

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.**

45

**16.**

- 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 46

**17. CALCULATIONS**

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

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

$W_1$ = 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 47

**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 48

- **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

49

### 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

**Report Percent Moisture to the nearest 0.1%**

Calculations

50

- 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./ft$^3$

**w** = Moisture content of sample in %

$W_1$ = Wet Density in lbs./ft$^3$

**Report to the nearest 0.1 lbs./ft$^3$**

Calculations

51

- **Example**
- Calculate the **Dry Density** when Moisture Content ($w$), is 18.5%, and Wet Density ($W_1$) is 108.0 lbs/ft$^3$?

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

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

$$W = \frac{108.0}{118.5} \times 100$$

Dry Density

$W = 91.1$ lb./ft$^3$

Calculations

52

## 18. 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

53

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

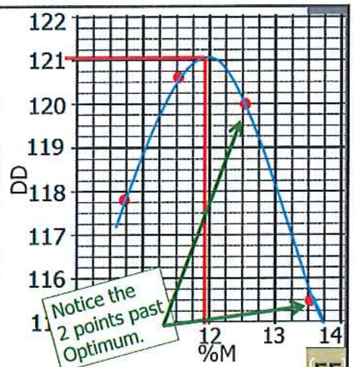
**Maximum Dry Density is a proctor value entered into the nuclear gage.**

Calculations-graph

54

## Proctor Curve Example

| Moisture Content % | Dry Density (lb./ft³) |
|---|---|
| 10.7 | 117.8 |
| 11.5 | 120.6 |
| 12.5 | 120.0 |
| 13.5 | 115.4 |




55

**Max DD = 121.1 lb./ft³**
**Optimum Moisture Content = 11.8%**

## 19. 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

56

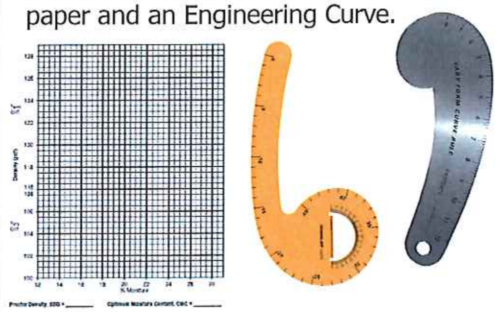
## Reporting for Oversized Particles

- 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

57

- 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

58

## 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

59

### 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 | Nearest |
| C. | Wt. of wet Soil in mold = A-B | | | | | 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 | | | | | 0.1 |
| G. | % Moisture = (F ÷ E) x 100 | | | | | 0.1 |
| H. | Dry Wt./Cu. Ft. = [(C x 30) / (100 + G )] x 100 | | | | | 0.1 |

% Optimum Moisture= ____ 0.1

lbs./ft$^3$ Maximum Density = ____ 0.1

Calculations-graph

60

## Practice Calculation

Answer

| | | | | | | |
|---|---|---|---|---|---|---|
| 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 | Nearest |
| C. | Wt. of wet Soil in mold = A-B | 3.690 | 3.830 | 4.020 | 3.950 | 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 | 98.3 | 110.1 | 125.5 | 132.0 | 0.1 |
| G. | % Moisture = (F ÷ E) x 100 | 20.2 | 21.6 | 24.8 | 27.0 | 0.1 |
| H. | Dry Wt./Cu. Ft. = [(C x 30) / (100 + G )] x 100 | 92.1 | 94.5 | 96.6 | 93.3 | 0.1 |

% Optimum Moisture= 24.2 % 0.1

lbs./ft$^3$ Maximum Density = 96.8 lbs./ft$^3$ 0.1

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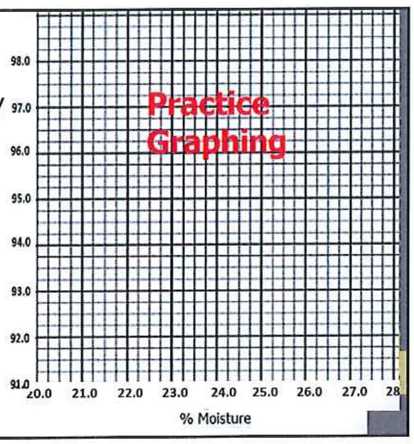
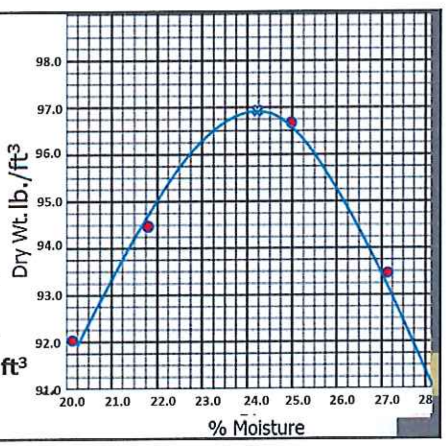
**Numbering And Spacing**

Create an x & y number scale that includes your results.

5 squares between each point is OK to use, but 10 squares per point would be even better for graphing.




Practice Graphing Answers

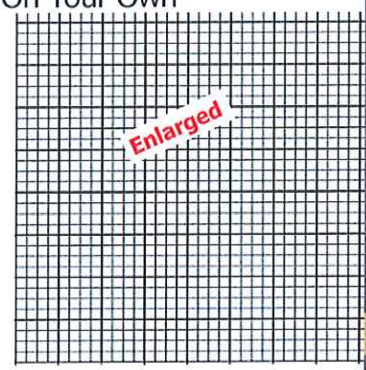



Optimum Moisture is **24.2%.**

Maximum Dry Density Is **96.8 lb/ft$^3$**

## Graphing – On Your Own

Hand in your work to the instructor for approval.




Calculations-graph

64

## ANNEX 1

(Mandatory Information)

**Correction for Densities With Oversized Particles**

Annex-Correction for Densities

65

## 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 **¾"** sieve is between 5.1% and maximum allowed, 30% or as specified.
  - When material retained on the **¾"** sieve exceeds specified maximum, material is deemed "Too Rocky to Test".

Annex-Correction for Densities

66

$$MC_T = \frac{(MC_F \times P_f)+(MC_C \times P_C)}{100}$$

*$MC_T$ = Corrected Optimum Moisture Content of total sample (combined fine and oversize particles) to the nearest 0.1%*

*$P_f$ = Percent of fine particles of sieve used*

*$P_c$ = Percent of oversize particles of sieve used*

*$MC_F$ = Optimum moisture content of fine particles expressed as a decimal.*

*(small w from test calculations)*

*$MC_C$ = Moisture content of the oversized particles expressed as a decimal (0.02 assumed per method)*

Annex-Moisture Correction

67

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

**$D_d$** = Corrected Maximum Dry Density of total sample (combined fine and oversize particles) **(nearest 0.1 pcf)**

**$D_f$** = Maximum dry density of fine particles (pcf) (Big W from test calculations)

**$P_c$** = Percent of oversized particles of sieve used

**$P_f$** = Percent of fine particles of sieve used

**k** = 62.4 pcf x Bulk Specific Gravity ($G_{sb}$)(oven-dry basis)(pcf) **Use 2.600 for Bulk SpG. today**

**k = 62.4** x **2.600** = 162.24

Annex-Density Correction

68

- For moisture content of the plus **¾"** material, assume 2%. ($MC_C$ = 0.02)
  - This is acceptable according to the test method.
- Either determine the specific gravity of the plus **¾"** material or assume **2.600**.

[Bulk Specific Gravity ($G_{sb}$)used in determining "**k**"]

- This is acceptable according to the test method.

Annex Corrections

69

## Example Calculation

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

Enlarged

- Given:
  - $P_f$ = 93 percent
  - $P_c$ = 7 percent
  - $MC_C$ = 0.02
  - $G_{sb}$ = 2.600
  - $MC_F = 0.11$
  - $D_f = 108.0$
  - *Calculate k*

From gradation or as determined.
Assumed per test method or as determined.
*Determined for each point from test.*

Annex-Calculations

70

- Calculations are performed for each differing moisture content of fine particles (¾" minus).
- The percentage of coarse particles (¾" plus) by weight and moisture content of the coarse particles along with the bulk specific gravity are kept constant through out the different trials.

Annex-Calculations

71

**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.

Common Testing Errors

72

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

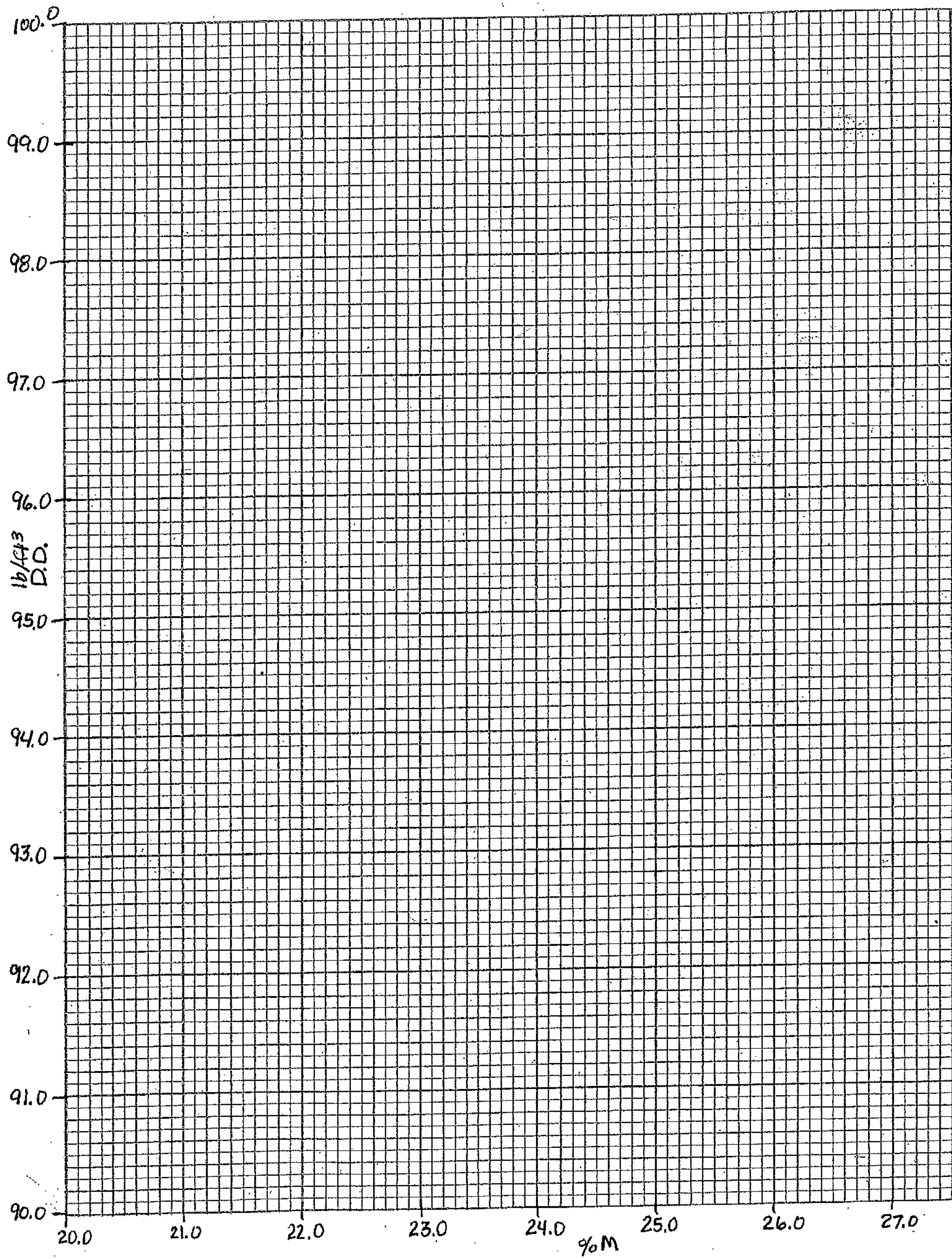
* Show your work to the Instructor for approval.

## Practice Calculation

Enlarged

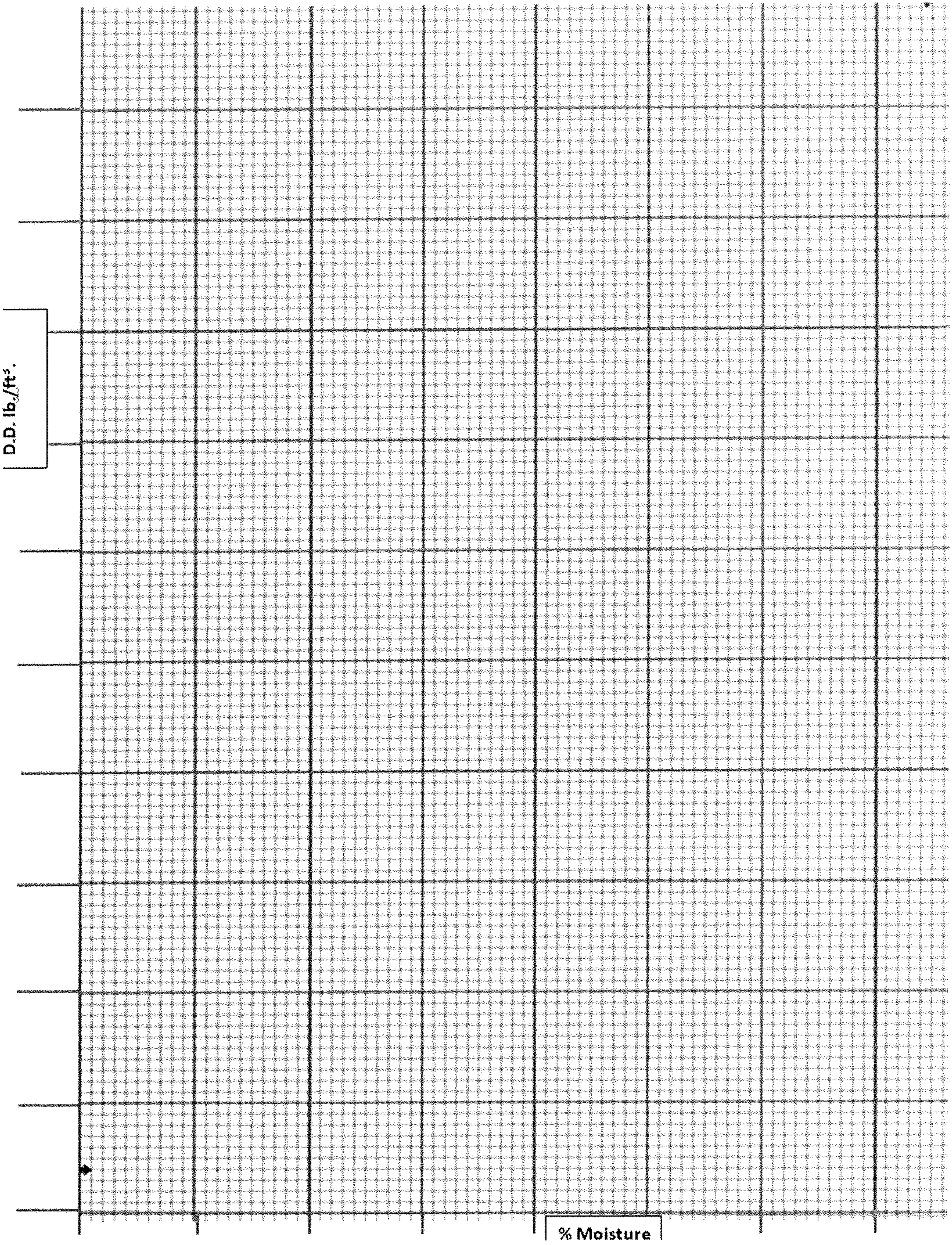
| | | | | | | |
|---|---|---|---|---|---|---|
| **A.** | Mold & Wet Soil, in lbs. | 8.910 | 9.050 | 9.240 | 9.170 | |
| **B.** | Wt. of Mold, in lbs. | 5.220 | 5.220 | 5.220 | 5.220 | Nearest |
| **C.** | Wt. of wet Soil in mold = A-B | | | | | 0.005 |
| **Moisture Determination** | | | | | | |
| **D.** | 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 | | | | | 0.1 |
| **G.** | % Moisture = (F ÷ E) x 100 | | | | | 0.1 |
| **H.** | Dry Wt./Cu. Ft. = [(C x 30) / (100 + G )] x 100 | | | | | 0.1 |

| | | |
|---|---|---|
| % Optimum Moisture= | | 0.1 |
| lbs./ft$^3$ Maximum Density = | | 0.1 |


100.0
99.0
98.0
97.0
96.0
lb/ft3
D.D.
95.0
94.0
93.0
92.0
91.0
90.0
20.0
21.0
22.0
23.0
24.0
25.0
26.0
27.0
%M

D.D. lb./ft$^3$.

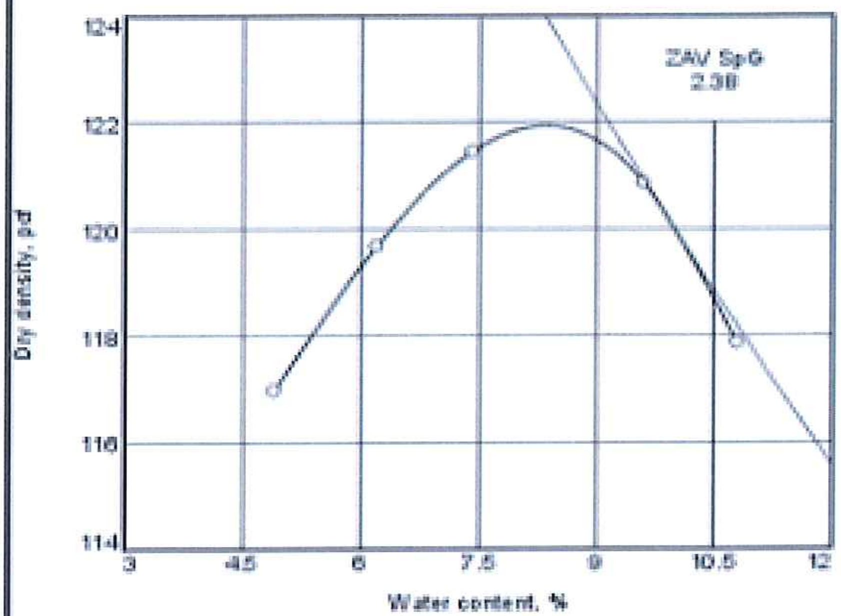
% Moisture



D.D. lb./ft³.
% Moisture

# COMPACTION TEST REPORT

Curve No. C-281




| | |
|---|---|
| Preparation Method | |
| Hammer: Wt. 5.5 lb. | Drop 12 in. |
| Type | |
| Layers: No. three | Blows per 56 |
| Mold Size | 0.075 cu. ft. |
| Test Performed on Material Passing 3/4 in. Sieve | |
| % >3/4 in. 12.4 | % <No. 200 4.9 |
| Atterberg (D 4318): LL 52 | PI 32 |
| NM (D 2216) 14 | Sp.G. (D 854) 2.65 |
| USCS (D 2487) | CL |
| AASHTO (M 145) | 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 D Standard
AASHTO T 224-01 Oversize Correction Applied to Final Results

| | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| WM + WS | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | |
| WM | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | |
| WW + T #1 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | |
| WD + T #1 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | |
| TARE #1 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | |
| WW + T #2 | | | | | | |
| WD + T #2 | | | | | | |
| TARE #2 | | | | | | |
| MOIST. | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | |
| DRY DENS. | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | |

SIEVE TEST RESULTS

| Opening Size | % Passing | Specs. |
|---|---|---|
| | | |

ROCK CORRECTED TEST RESULTS

Maximum dry density = 126.3 pcf

Optimum moisture = 8.3 %

Material Description

Dark Brown Sandy Lean Clay w/ Organics & Rubble

Remarks:

T-112=0.0% SE=6? Soundness=1.8%

Project No. PP1003-24 Client: County of Berthoud

Project: Berthoud County Landfill Expansion

○ Source: Boring B-3 Depth: 0-5' Sample No.: S-1

Checked by: ERK

Title:

**ALV ENGINEERS**

Figure F-22

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

**Given:**

$P_f = 93\ percent$ $MC_F = 0.11$

$P_c = 7\ percent$ $MC_c = 0.02$

$D_f = 108.0\ pcf$ $G_{sb} = 2.600$

$k = 62.4 \times Gsb$

| Corrected Moisture Content of Total Sample: | Corrected Dry Density of Total Sample: |
|---|---|
| $MC_T = \frac{(MC_F \times P_f) + (MC_c \times P_c)}{100}$ | $D_d = \frac{(100 \times D_f \times k)}{(D_f \times P_c) + (k \times P_f)}$ |

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

Applicant: ______________________________

Employer: ______________________________

| Trial # | 1 | 2 |
|---|---|---|
| **Sample Preparation** | | |
| 1. If damp, sample dried in air or drying apparatus not exceeding 140°F (60°C). | | |
| 2. Thoroughly broke up sample and adequate amount sieved over #4 (4.75mm) sieve (Method A) or ¾" (19.0mm) sieve (Method C). | | |
| 3. Material retained on No. 4 sieve, discarded if less than 5.0% (Method A). If 5.1% or more retained on No. 4, revert to Method C and see Annex A1 for oversize particles. | | |
| 4. Sample passing #4 sieve weighs 7 lb. (3 kg) or more (Method A). | | |
| Sample passing ¾" sieve weighs 11 lb. (5 kg) or more (Method C). | | |
| 5. Sample mixed with water to approximately 4% to 8% below optimum moisture. **Clayey Soils:** Samples mixed with water varying by approx. 2% to 2.5% max 4% for increments of moisture, samples placed in covered containers and allowed to stand for at least 12 hours. | | |
| **Procedure for Method A** (4 inch mold) | | |
| 1. Weighed the mold and base plate (w/o the collar), <u>recorded to the nearest 0.005 lb. (1g)</u> | | |
| 2. Attached collar to the mold and placed on a stable foundation. | | |
| 3. Layer of soil placed in mold distributed evenly to yield approximately 1/3 full after compaction (2/3 or 3/3 full). | | |
| 4. Soil lightly tamped with manual rammer of 2 inch diameter until it is not in a loose state. | | |
| 5. Applied 25 blows for 4 inch mold, with a 5.5 lb. rammer, 12 inch drop. | | |
| 6. Following compaction trimmed away any excess soil on mold walls evenly on top of layer (trimmed soil may be included with additional soil for next layer). | | |
| 7. Repeat steps 3 – 6, for 3 equal layers, last lift is slightly above the top of the mold. | | |
| 8. Removed the collar, soil sample trimmed to top of the mold with a straight edge, filled coarse aggregate holes on surface, patched with smaller sized material. | | |
| 9. Cleaned off the mold and base plate before weighing. | | |
| 10. Weighed the mold, base, and contents, <u>recorded to nearest 0.005 lb. (1g).</u> | | |
| 11. Sample extracted from the mold. | | |
| 12. Sliced vertically through the center for moisture content sample. | | |
| 13. Moisture content sample removed from the slice, placed in a pre-weighed sample container, and weighed immediately, <u>recorded wet weight to nearest 0.1g.</u> Need approximately: **Method A** 100g, **Method C** 500g | | |
| 14. Sample dried and % moisture determined according to AASHTO T 265 , <u>reported *w* to 0.1%.</u> | | |
| 15. Remainder of material from mold broken up to pass a #4 size sieve and added to the remainder of original test sample. Samples mixed with water varying by 1-2% (2.5% max) increments of moisture and mixed thoroughly. | | |

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

| Trial # | 1 | 2 |
|---|---|---|
| 16. Repeat the compaction process: (Steps 2 through 15) for each increment of water added and the process continued until wet density either decreases or stabilizes, need 2 points pass Optimum Density<br>**Note:** Non-cohesive drainable soils, only one additional determination over optimum moisture is sufficient. | | |
| 17. Calculated: Wet Density, Dry Density and Percent Moisture calculated for each sample.<br>$W_1 = (M_{ms} - M_m) \times \text{Constant}$<br>Wet Density<br>$W = \frac{W_1}{w + 100} \times 100$<br>Dry Density<br>$w = \left[\frac{(W_1 - W_2)}{(W_2 - W_c)}\right] \times 100$<br>Percent Moisture | | |
| 18. Dry density mass plotted on y-axis, % Moisture plotted on x-axis and points connected with curve either manually or by computer program.<br>**Note:** (Method C): Calculate adjusted density for oversized particles on each point prior to plotting curve. | | |
| 19. Report:<br>***Percent Moisture** at peak of curve taken as Optimum Moisture reported to nearest 0.1%.<br>***Dry Density** mass at Optimum percent moisture reported as maximum dry density to the nearest 0.1 lb./ft³.<br>***Method Used** A, B, C, D.<br>*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)

# MoDOT TM 40

## (AASHTO T 272)

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

Rev 11/05/2019

## SUMMARY

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

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

- 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

## 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.

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•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

•Sandy or silty soils fit on the curves with higher maximum densities, while clay soils fit those curves with lower densities.

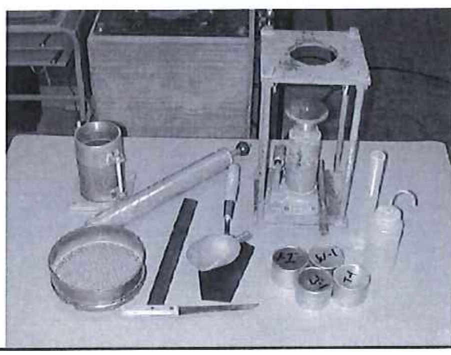
•Since sands do not hold water, the optimum moisture for sand will be much lower than for a soil that contains more fines.

Background

7

## EQUIPMENT

Same as AASHTO T99



8

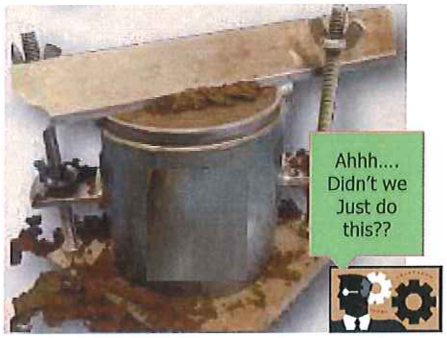
- **Sieves**
  - #4 or ¾"
- **Scales**
  - Readable to 1g
  - Readable to 0.1g (MC)
- **Oven**
  - 230 ± 9°F (110 ± 5°C)
  - 140°F (60°C)
- **Mold Assembly**
  - 4" or 6"
- **Sample Extruder**
- **Mixing Tools**
- **Straight Edge**
  - 10" steel with beveled edge
- **Moisture Tins**
- **Rammer** (Mechanical 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

## PROCEDURE




Procedure

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

---

## 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.

12

Method A Procedure

- 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

13

Method A Procedure

- 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.

14

Method A Procedure

- 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.

15

Method A Procedure

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.

16

Method A Procedure

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.

17

Method A Procedure

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).

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

## 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

Calculate the Dry Density

$$W = \frac{W_1}{w + 100} \text{X } 100$$

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

## Method "C"
## PROCEDURE

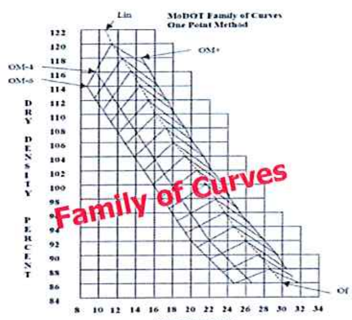
- Method C is the same as Method A, with the following exceptions:
  - Sample size is 11 lb. (5 kg)
  - Material must pass the ¾"(19.0 mm) sieve

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

Method C Procedure

22

## ONE-POINT MOISTURE-DENSITY




One Point Moisture-Density

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

## 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

One Point Moisture-Density

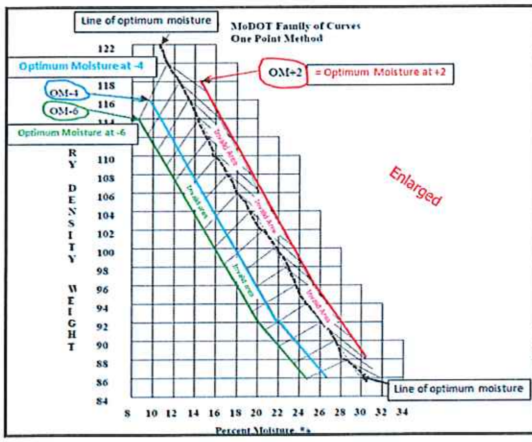
- Plot the values of dry density and moisture content calculated previously on the Family of Curves.
- If the point falls on one of the curves and within the allowable range, **(Optimum to 4% below Optimum)**, the maximum density and optimum moisture for that curve shall be used.

26

One Point Moisture-Density

- 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.

27




One Point Moisture-Density

28

# Classroom Exercise

## MoDOT TM 40

*Enlarged*

**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.

One Point Moisture-Density

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).

Report

30

## TYPICAL TEST RESULTS

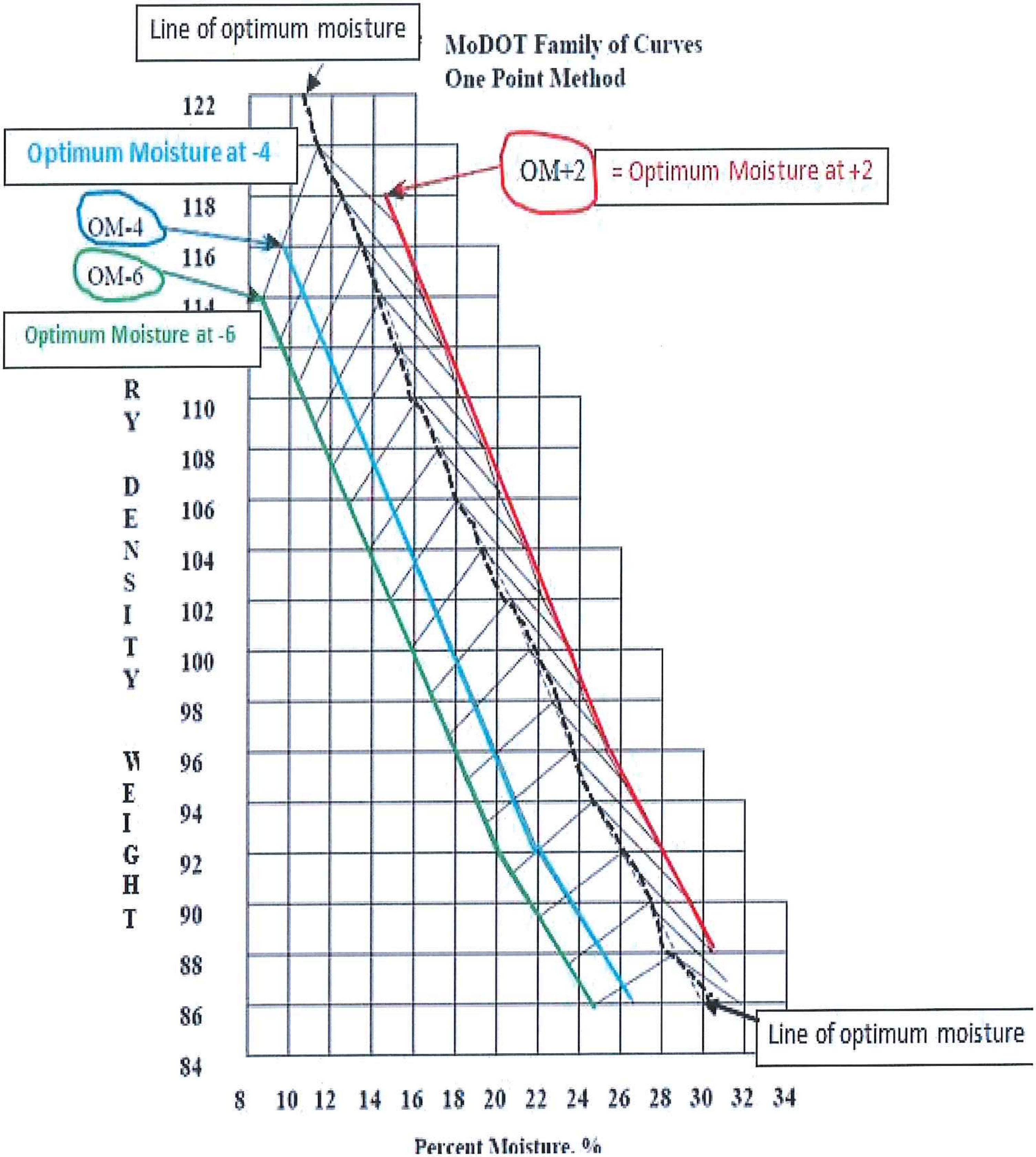
- MoDOT TM 40 will give the same range of results as AASHTO T 99, moisture-density relations of soil using a 5.5 lb. (2.5 kg) rammer and 12" (305 mm) drop.
- This method can be used for any soil that develops a classic parabolic "Proctor" curve.
  - This method is <u>not applicable</u> to free *draining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

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


Line of optimum moisture
MoDOT Family of Curves
One Point Method
Optimum Moisture at -4
OM+2
= Optimum Moisture at +2
OM-4
OM-6
Optimum Moisture at -6
122
118
116
110
108
106
104
102
100
98
96
94
92
90
88
86
84
RY DENSITY WEIGHT
8 10 12 14 16 18 20 22 24 26 28 30 32 34
Line of optimum moisture
Percent Moisture, %

# Family of Curves Exercise

## MoDOT TM40

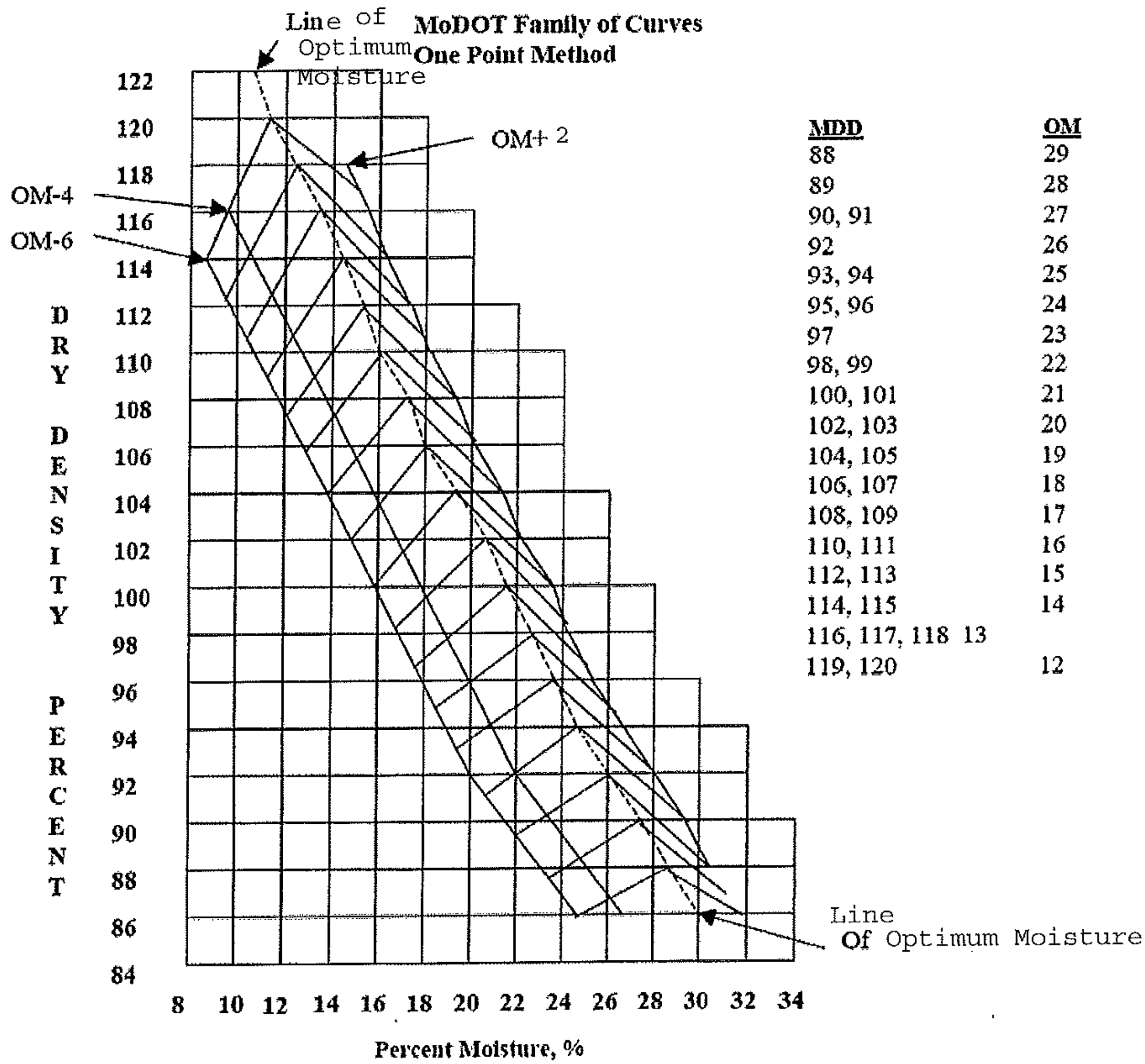
Use the Family of Curves to determine the Maximum Dry Density and Optimum Moisture using the data below. State whether the test is valid or not valid.

| 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 | | | | |

# 106.3.2.40 TM-40, A One-Point Moisture-Density Relations Test for Soils

## From Engineering Policy Guide

MoDOT TM-40 is identical to AASHTO T272-86 (2000) except that the family of curves provided in the figure below shall be used.




| MDD | OM |
|---|---|
| 88 | 29 |
| 89 | 28 |
| 90, 91 | 27 |
| 92 | 26 |
| 93, 94 | 25 |
| 95, 96 | 24 |
| 97 | 23 |
| 98, 99 | 22 |
| 100, 101 | 21 |
| 102, 103 | 20 |
| 104, 105 | 19 |
| 106, 107 | 18 |
| 108, 109 | 17 |
| 110, 111 | 16 |
| 112, 113 | 15 |
| 114, 115 | 14 |
| 116, 117, 118 | 13 |
| 119, 120 | 12 |

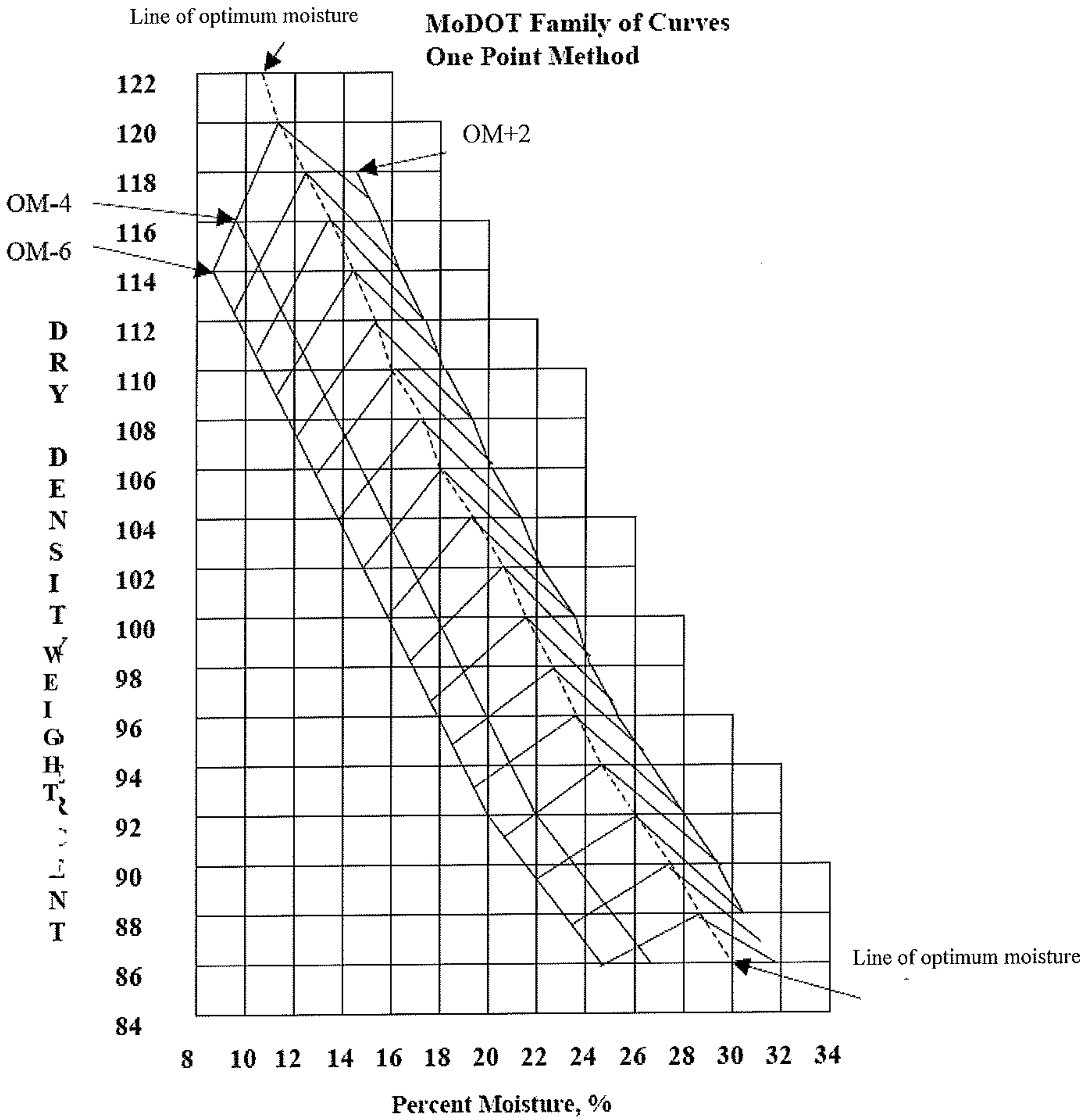

Line of optimum moisture
MoDOT Family of Curves
One Point Method
OM+2
OM-4
OM-6
122
120
118
116
114
112
110
108
106
104
102
100
98
96
94
92
90
88
86
84
8 10 12 14 16 18 20 22 24 26 28 30 32 34
Line of optimum moisture
Percent Moisture, %

Figure 1

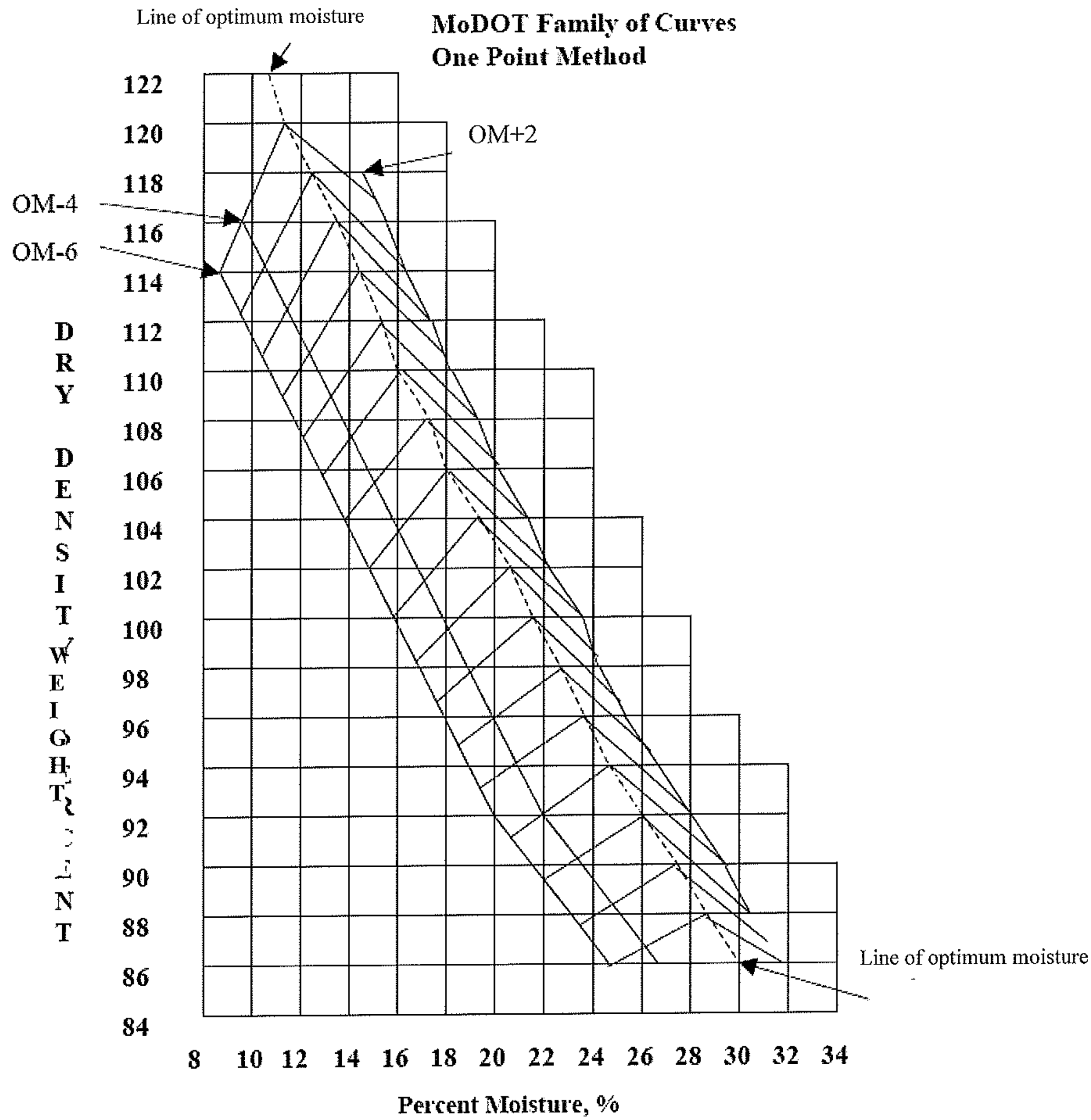

Line of optimum moisture
MoDOT Family of Curves
One Point Method
OM+2
OM-4
OM-6
122
120
118
116
114
112
110
108
106
104
102
100
98
96
94
92
90
88
86
84
DRY DENSITY WEIGHT PERCENT
8 10 12 14 16 18 20 22 24 26 28 30 32 34
Percent Moisture, %
Line of optimum moisture

Figure 1

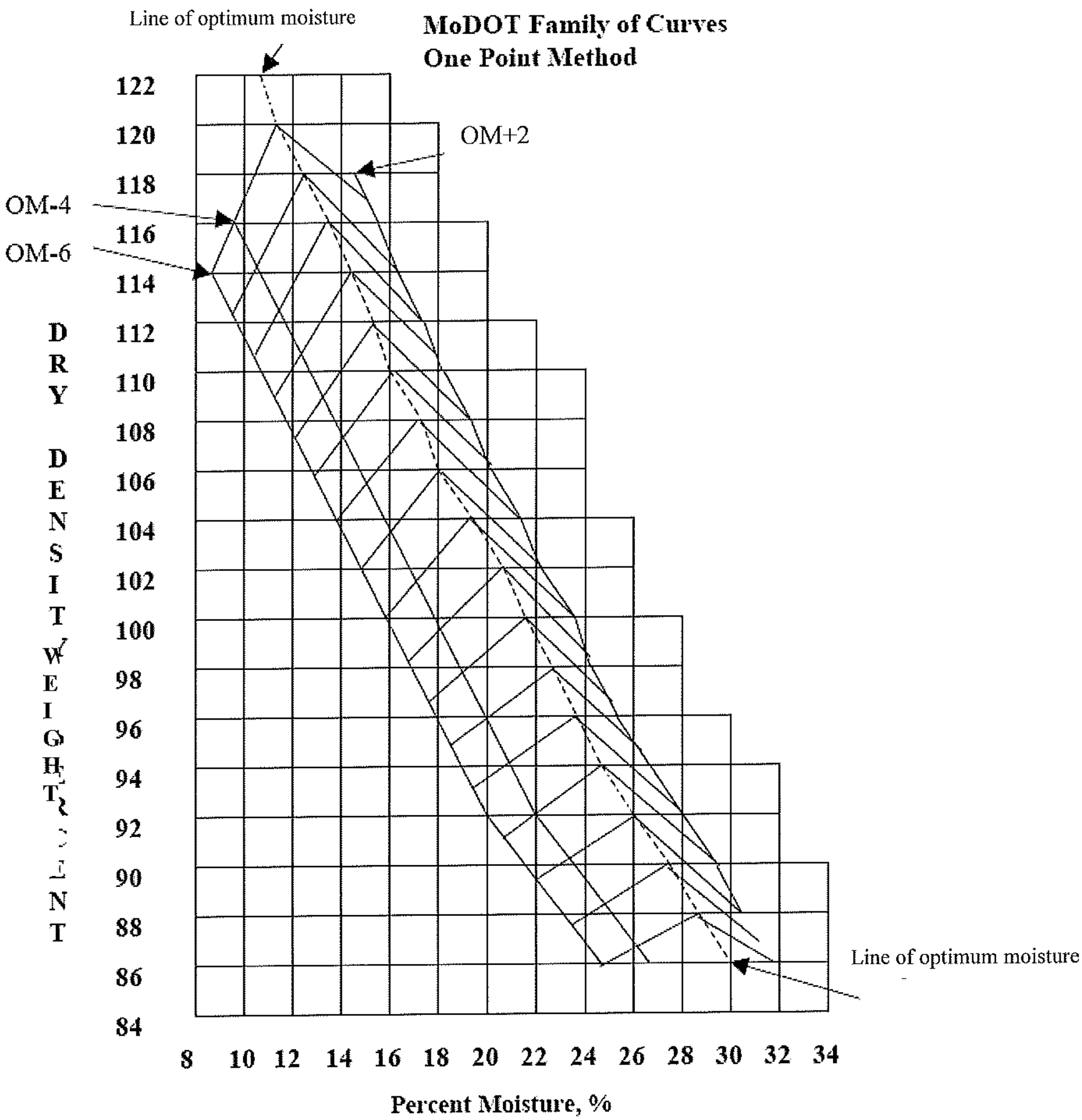

MoDOT Family of Curves
One Point Method
Line of optimum moisture
OM+2
OM-4
OM-6
Line of optimum moisture
DRY DENSITY WEIGHT
122
120
118
116
114
112
110
108
106
104
102
100
98
96
94
92
90
88
86
84
8 10 12 14 16 18 20 22 24 26 28 30 32 34
Percent Moisture, %

Figure 1

# 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: ____________________

# AASHTO T 310

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

(Shallow Depth)

# AASHTO T 310

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

1

Rev 11/05/19

## 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

Scope

- 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
  2. Backscatter
  3. Backscatter/Air-Gap Ratio Method - Not covered in this certification.

3

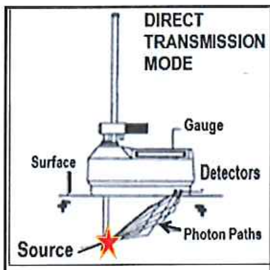
Scope

- The moisture of the material is determined only from measurements taken at the surface of the soil (i.e., backscatter).

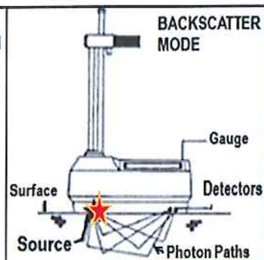
- **Density** – The total of wet density of soil and soil-rock mixtures is determined by the attenuation of gamma radiation where the source or detector is placed at a known depth up to 12 inches while the detector(s) or source remains on the surface (Direct Transmission Method) or the source and detector(s) remain on the surface (Backscatter Method).

4

Scope




**Direct Transmission**
**Measures the density of the material between the source and the surface.**




**Backscatter**
**Measures the density of the material close to the surface (80% in top 2").**

5

Scope

- **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.

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

Significance

- 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.

8

Significance

- 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.

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

Interferences

- 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.
- Other radioactive sources should be **30 ft.** from the gauge in operation.

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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 sources must not be within **30 ft.** of the gauge in operation.

12

## 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

Safety

**Radiation poisoning is very serious.**

Always practice the "**ALARA**" principles to minimize exposure.

(**A**s **L**ow **A**s **R**easonably **A**chievable)

Four important facts to remember:

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

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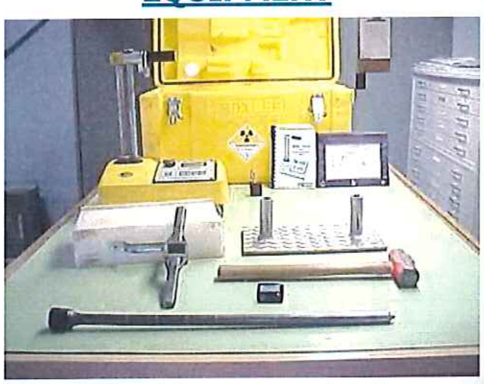
## EQUIPMENT



15

## Equipment

- 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)

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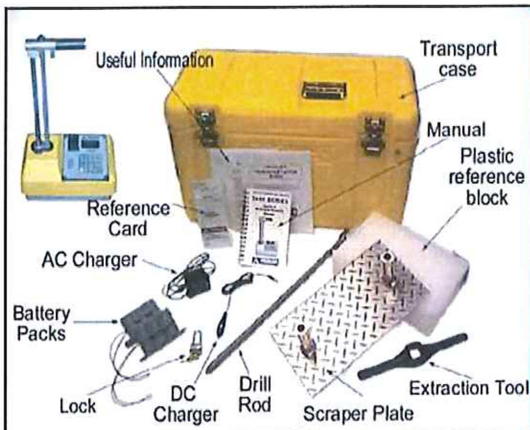
## Equipment

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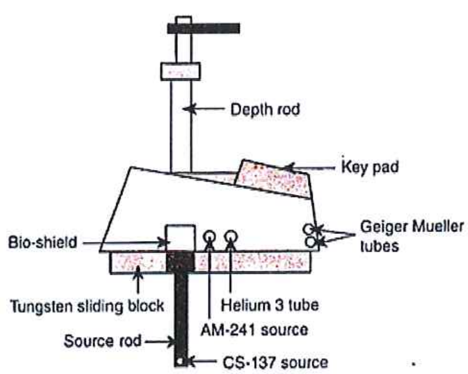
## Nuclear Gauge

Nuclear Gauge Diagram



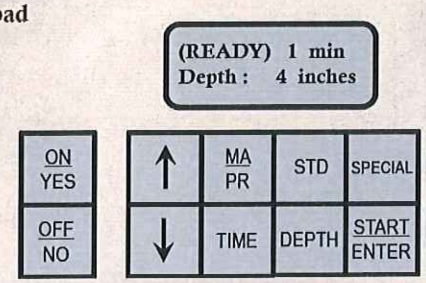

18

## Nuclear Gauge Keypad

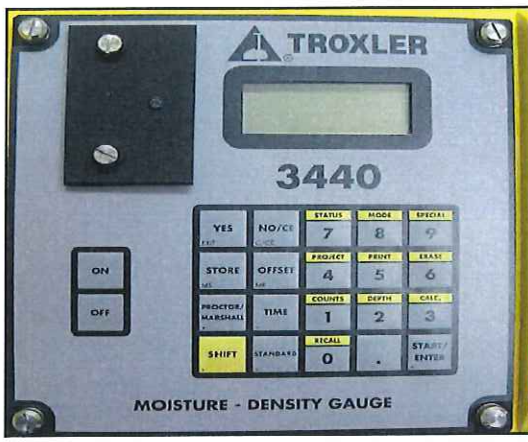
Nuclear Gauge

**Troxler 3430**

⭑**Keypad**




19




Nuclear Gauge

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.

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## How it Works

Nuclear Gauge-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.

22

Nuclear Gauge-How it Works

- 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.

23

## CALIBRATION

- AASHTO T 310 requires that the gauge read within ± **1 lb./ft³** on a standard block(s) of material(s) with established density and moisture content.
- Calibration is performed by the Central Lab for MoDOT owned gauges.
- Calibration is performed by the manufacturer for industry owned gauges.
- Gauges will be calibrated once a year or when a gauge is not working correctly and/or giving irregular readings.

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 ≥100 lb/ft$^3$.

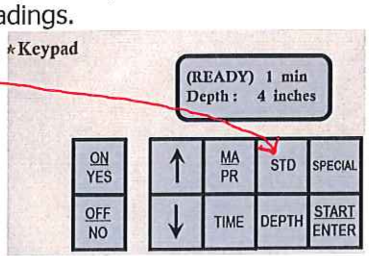
25

## Standard Count


Nuclear Gauge-Standardization

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.




Nuclear Gauge-Standardization

27

- 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 Ns taken prior to usage

$F$ = factory pre-scale factor, provided with the gauge (16 for a Troxler standard count)

Nuclear Gauge-Standardization

28

## 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 todays readings in the range of previous readings recorded in the Field Book?

Nuclear Gauge-Standardization

29

## 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**

Nuclear Gauge-Standardization

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

---

- $N_s$ = 2757 ± (1.96 $\sqrt{(2757/16)}$
- Step One: (2757/16)= 172.3
- Step Two: $\sqrt{172.3}$ = 13.1
- Step Three: 1.96 x 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

Density Calculation Steps

**The Range is 2731 to 2783**

Nuclear Gauge-Standardization

32

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## 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

## 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

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## 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

- 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 contaminates, correct moisture using (K) offset MoDOT TM 35.

Moisture Offset

36

## Trench Offset

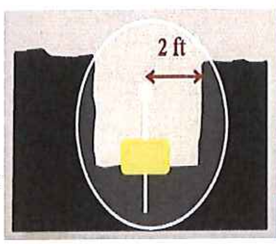
Trench Offset

- 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.

37

Trench Offsets

- 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.




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

## PROCEDURE

40

## Density Testing Outline

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

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

## 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

## 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

Site Preparation

- The maximum void beneath the gauge should not be more than **⅛**″ (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

## 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

**2.** Drilling the hole.

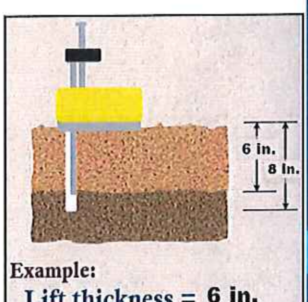
- Place the scraper plate on prepared site.
- Attach extraction tool and insert drill rod.
- Step firmly on the plate and hammer the drill rod perpendicular to the surface.

Direct Transmission Procedure

47

- 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

## ⋆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

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

Direct Transmission Procedure 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

**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

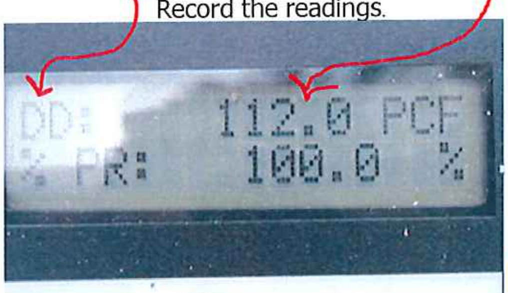
**7.** Take one or more 1-minute readings to determine:

- % Compaction
- Dry Density
- % Moisture


Direct Transmission Procedure

53

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




Direct Transmission Procedure

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.

Direct Transmission Procedure

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.

Direct Transmission Procedure

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.


Backscatter Procedure

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

## CALCULATIONS

- Direct Measurements
  - ✓ Wet Density
  - ✓ Moisture Content

- Calculated Values
  - ✓ Dry Density

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

  - ✓ % Compaction

$$\% PR = \frac{Gauge\ DD}{Proctor\ DD} \, x\, 100\%$$

59

Calculation of Results

- 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./ft$^3$ (kg/m$^3$) of moisture from the lb./ft$^3$ (kg/m$^3$) of wet density, and obtain dry density in lb./ft$^3$ (kg/m$^3$).

60

- 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./ft$^3$ (kg/m$^3$)** |
| $m$ = | **Wet density in lb./ft$^3$ (kg/m$^3$)** |
| w = | **Water as a percent of dry mass** |

Calculation of Results

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- **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.

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

Calculation of Results

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/m$^3$) or unit weights in lb./ft$^3$.
- 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

## 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 contaminates, without correcting moisture using (K) offset MoDOT TM35

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

# MISSOURI DEPARTMENT OF TRANSPORTATION
## DENSITY-MOISTURE TEST DATA NUCLEAR

A – Consecutive, by material per project
B – Reading on display must match probe position
C – Read direct from display – Daily Standard
D – Read direct from display – Daily Standard
E – Record correction for current material
(Reference page 3–4 Troxler Manual

F – Record from display for current test
G - Record from display for current test
H – Provided by Materials for current material
I – Record from display for current test
J – Provided in contract documents or specifications
K – Record from display for current test
L – Provided form Materials for current material

## 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

# 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

# MISSOURI DEPARTMENT OF TRANSPORTATION
## DENSITY-MOISTURE TEST DATA NUCLEAR

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

## 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

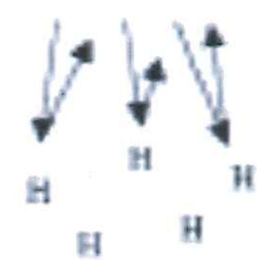
Technical Advice: 573-526-4628

# Offsets

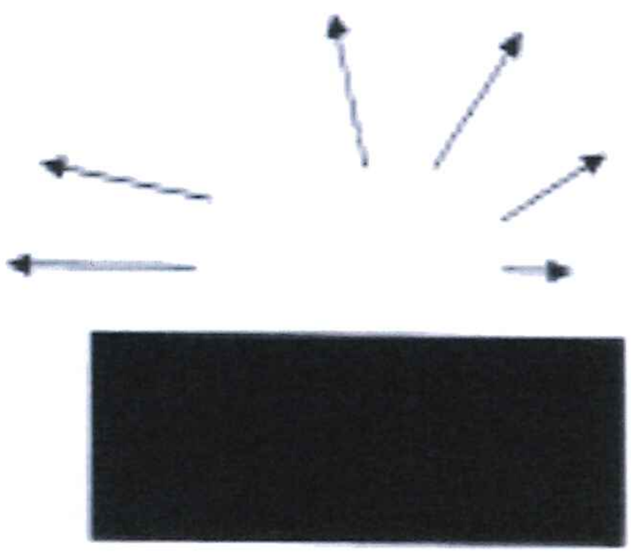
- Moisture Offset
  - When measuring materials containing hydrogen not in the form of water or containing neutron absorbers a moisture offset may be necessary.
- Trench Offset
  - When performing moisture and density measurements in a trench or near a large object the density or moisture may be effected 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.

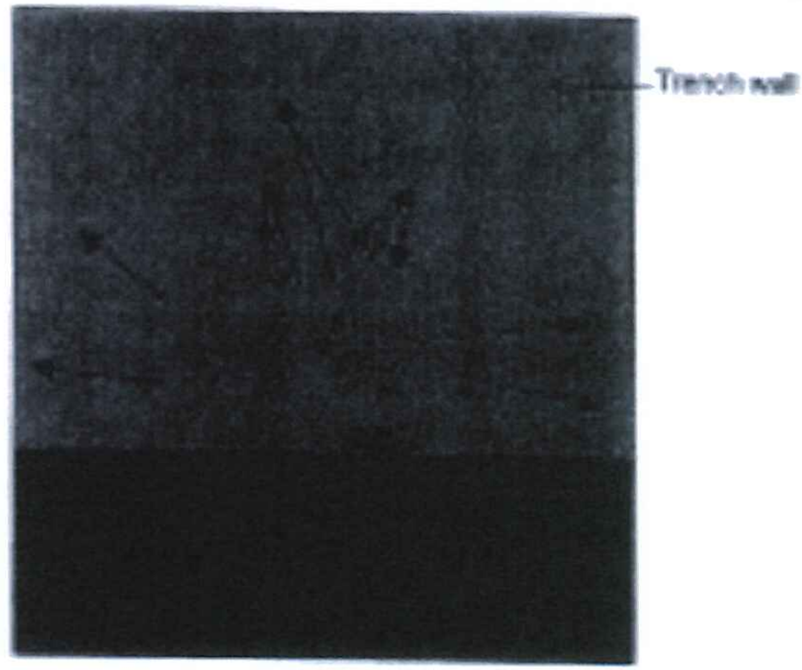
# Moisture Offset

- 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
    - gypsum
    - lime
    - mica
    - organic material (coal, shells, etc.)
    - fly ash
    - phosphates
  - Common neutron absorbers
    - 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):

| | Gauge Measured Dens. | Core dens. | Difference |
|---|---|---|---|
| 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

# MoDOT TM 35

## Moisture Offset (K) Factor for a Nuclear Gauge

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

## 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

## EQUIPMENT

- Nuclear gauge
- Air tight sample container and other sample collection equipment
- Oven capable of 230 ± 9°F (110 ± 5°C)
- Scale capable of weighing 2 kg
- Other drying equipment - pans, gloves, brushes, etc.

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.

(**A**s **L**ow **A**s **R**easonably **A**chievable)

- 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

## 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 $\%M_{gauge}$ for each sample.

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.

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)

- 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)

## Classroom Exercise

Calculations

- Example:

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

- Calculate *K* Factor to the nearest tenth:

(10)

## Classroom Exercise

*Calculations*

- Proficiency

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

Enlarged

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

$K =$

Calculations

(11)

## Moisture Offset

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

  **<u>Can be ignored if ± 0.5 pcf or less.</u>**

- 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.

(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

## 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 air tight sample container to transport sample to lab
- Not drying sample to oven-dry condition
- Mixing soil/aggregate types

14

# 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. |

$$K =$$

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 SiteManager 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. 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. 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.

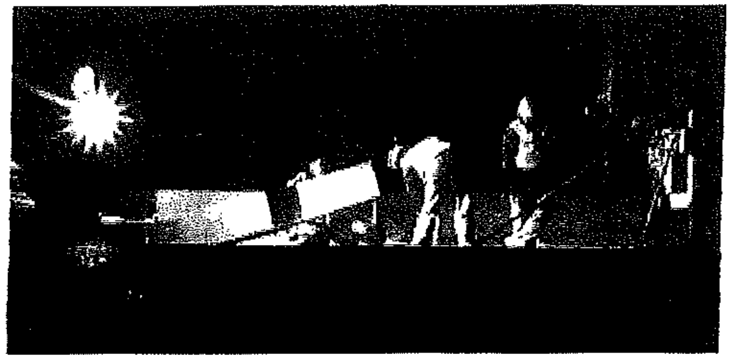
### 304.2.4 Trimmed Base

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

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

**From Engineering Policy Guide**

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.



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

## 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.

## 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°C ± 5°C (230°F ± 9° 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.

## 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. ($\%M_{LAB}$)

2. Take a gauge reading at the site. Record the readings. ($\%M_{GAUGE}$)

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
(↑ ↓ or ENTER)
```

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

```
Moist Offset OFF
Want to enable?
```

Press **YES**.

```
K= 0.0
(↑ ↓ or 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 <u>first!</u>

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: xxxx  %
```

$\%M_{GAUGE}$

Air Void and Void Ratio

```
Air Void:  xxxx %
Void Ratio: xxxx
```

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



% AIR VOIDS = 100 (1 - (Vs/Vt) - (Vw/Vt) )

where:
Vs = Volume of Soil
Vt = Total Volume
Vw = Volume of Water

= 100 (1 - (DD / SG(Dw)) - (M / (Dw) ) )

where:
Dw = Density of Water

VOID RATIO = Volume of Voids / Volume of Soil
= ( SG(Dw) - DD ) / DD

Continue pressing the "Down" arrow for:

Moisture and Density Count Ratio

```
MOIST CR:  xxxx
DENS. CR:  xxxx
```

Moisture and Density Counts

```
M Count:  xxxx
D Count:  xxxx
```

# 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

# MISSOURI DEPARTMENT OF TRANSPORTATION
## DENSITY-MOISTURE TEST DATA NUCLEAR

A – Consecutive, by material per project
B – Reading on display must match probe position
C – Read direct from display – Daily Standard
D – Read direct from display – Daily Standard
E – Record correction for current material
(Reference page 3–4 Troxler Manual

F – Record from display for current test
G - Record from display for current test
H – Provided by Materials for current material
I – Record from display for current test
J – Provided in contract documents or specifications
K – Record from display for current test
L – Provided form Materials for current material

## 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: Paul Hilchen 573-526-4628

# 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 <u>thin</u> 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/ft³ |
|---|---|
| 65 | 62.336 |
| 66 | 62.329 |
| 67 | 62.322 |
| 68 | 62.315 |
| 69 | 62.308 |
| 70 | 62.301 |
| 71 | 62.293 |
| 72 | 62.285 |
| 73 | 62.277 |

| °F | lb/ft³ |
|---|---|
| 74 | 62.269 |
| 75 | 62.261 |
| 76 | 62.252 |
| 77 | 62.243 |
| 78 | 62.234 |
| 79 | 62.225 |
| 80 | 62.216 |
| 81 | 62.206 |
| 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
  - ✓ Mold + Water + Plate 4.500 lb
  - ✓ Temperature 76 °F

Density of Water @ 76° 62.252 lb/ft³

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

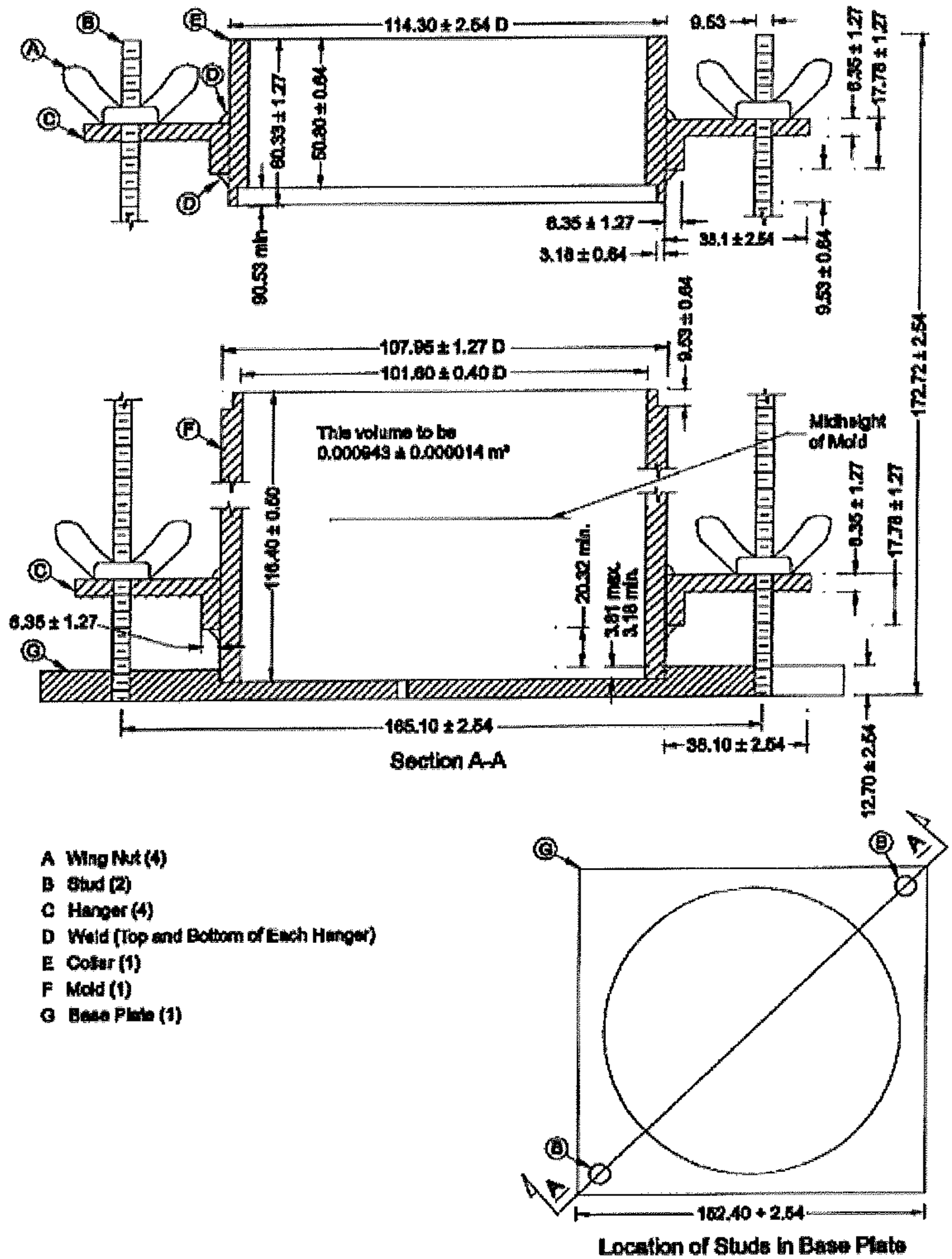
## APPARATUS

*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.

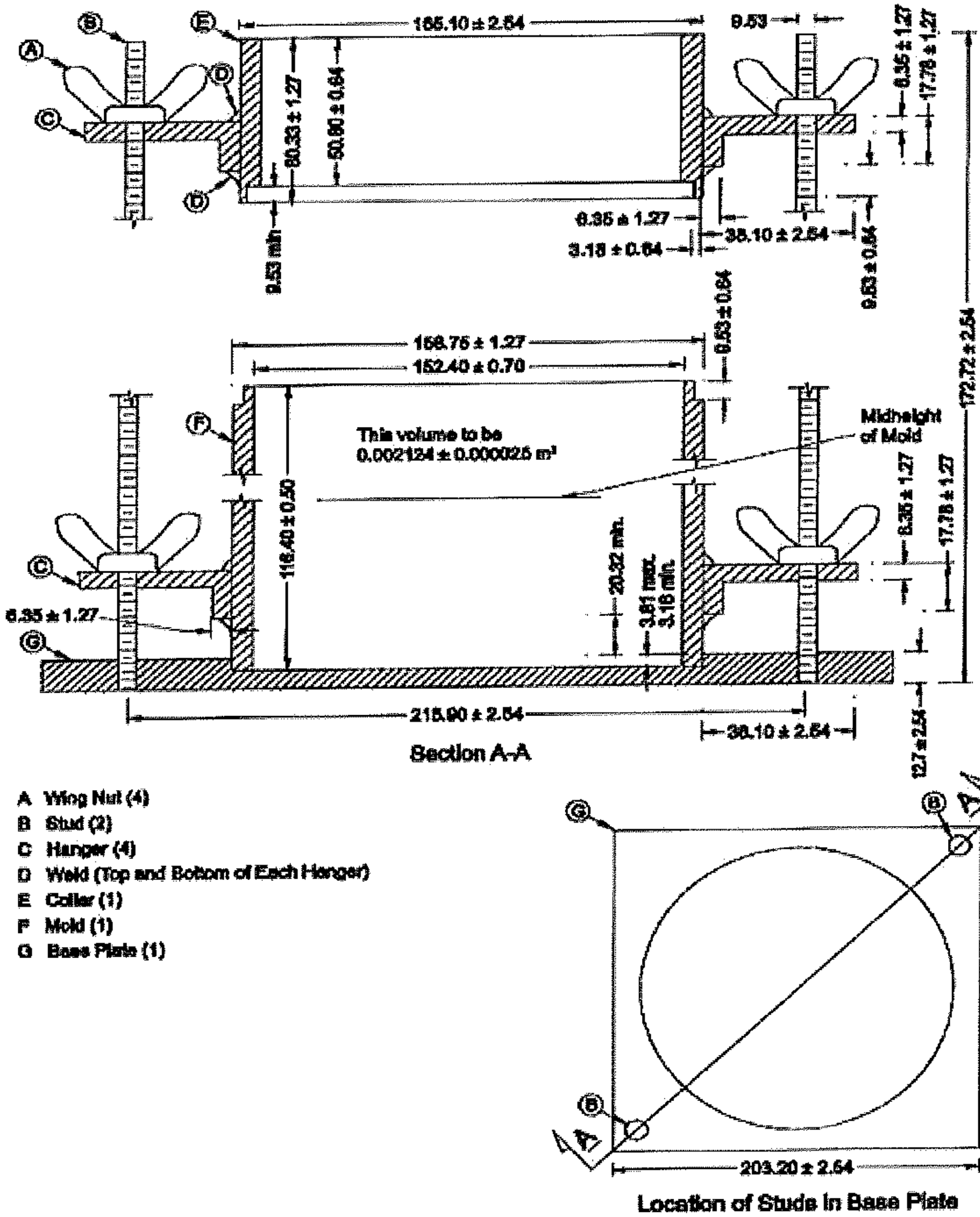
Molds having a volume of 0.000943 ± 0.000014 m3 ( 0.0333 ± 0.0005 ft3) shall have an inside diameter of 101.60 ± 0.40 mm (4.000 ± 0.016 in.) and a height of 116.40 ± 0.50 mm (4.584 ± 0.018 in.) (Figure 1).Determine the mold volume in accordance with the "Calibration of Measure" section of T 19M/T 19 for Unit Mass of Aggregate.

Molds having a volume of 0.002124 ± 0.000025 m3 ( 0.07500 ± 0.0009 ft3) shall have an inside diameter of 152.40 ± 0.70 mm (6.000 ± 0.026 in.) and a height of 116.40 ± 0.50 mm (4.584 ± 0.018 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 (HM-21).

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




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 2 is to be used for all compaction molds purchased after the publication of the 21st edition (HM-21).

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 m³ | 0.0333 ± 0.0005 ft³ | | |

**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 m³ | 0.0750 ± 0.0009 ft³ | | |

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 ± 5°C (230 ± 9°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.

# Glossary

MoDOT

# 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, on 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 pluses 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.