

**APPENDIX A  
FIELD OPERATING PROCEDURES – SHORT FORM**

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**TOTAL EVAPORABLE MOISTURE CONTENT OF AGGREGATE BY DRYING  
FOP FOR AASHTO T 255  
LABORATORY DETERMINATION OF MOISTURE CONTENT OF SOILS  
FOP FOR AASHTO T 265**

**Scope**

This procedure covers the determination of moisture content of aggregate and soil in accordance with AASHTO T 255-22 and AASHTO T 265-22. It may also be used for other construction materials.

**Overview**

Moisture content is determined by comparing the wet mass of a sample and the mass of the sample after drying to constant mass. The term constant mass is used to define when a sample is dry.

*Constant mass* – the state at which a mass does not change more than a given percent, after additional drying for a defined time interval, at a required temperature.

**Apparatus**

- Balance or scale: capacity sufficient for the principal sample mass, accurate to 0.1 percent of sample mass or readable to 0.1 g, and meeting the requirements of AASHTO M 231
- Containers: clean, dry, and capable of being sealed
- Suitable drying container
  - For soils: container requires close-fitting lid
  - For aggregate: container lid is optional
- Microwave safe container with ventilated lid (for drying aggregate only)
- Heat source, thermostatically controlled, capable of maintaining  $110 \pm 5^{\circ}\text{C}$  ( $230 \pm 9^{\circ}\text{F}$ ).
  - Forced draft oven (preferred)
  - Ventilated oven
  - Convection oven
- Heat source, uncontrolled, for use when allowed by the agency, will not alter the material being dried, and close control of the temperature is not required:
  - Infrared heater/heat lamp, hot plate, fry pan, or any other device/method allowed by the agency .
  - Microwave oven (900 watts minimum)
- Utensils such as spoons
- Hot pads or gloves

**Sample Preparation**

Obtain a representative sample according to the FOP for AASHTO R 90 in its existing condition. If necessary, reduce the sample to moisture content sample size according to the FOP for AASHTO R 76.

For aggregate, the moisture content sample size is based on Table 1 or other information that may be specified by the agency.

**TABLE 1**  
**Sample Sizes for Moisture Content of Aggregate**

<b>Nominal Maximum Size* mm (in.)</b>	<b>Minimum Sample Mass g (lb)</b>
150 (6)	50,000 (110)
100 (4)	25,000 (55)
90 (3 1/2)	16,000 (35)
75 (3)	13,000 (29)
63 (2 1/2)	10,000 (22)
50 (2)	8000 (18)
37.5 (1 1/2)	6000 (13)
25.0 (1)	4000 (9)
19.0 (3/4)	3000 (7)
12.5 (1/2)	2000 (4)
9.5 (3/8)	1500 (3.3)
4.75 (No. 4)	500 (1.1)

\* One sieve larger than the first sieve to retain more than 10 percent of the material using an agency specified set of sieves based on cumulative percent retained. Where large gaps in specification sieves exist, intermediate sieve(s) may be inserted to determine nominal maximum.

For soils the moisture content sample size is based on Table 2 or other information that may be specified by the agency.

**TABLE 2**  
**Sample Sizes for Moisture Content of Soil**

<b>Maximum Particle Size mm (in.)</b>	<b>Minimum Sample Mass g</b>
50 (2)	1000
25.0 (1)	500
12.5 (1/2)	300
4.75 (No. 4)	100
0.425 (No. 40)	10

Immediately seal or cover moisture content samples to prevent any change in moisture content or follow the steps in “Procedure.”

**Procedure**

Determine and record the sample masses as follows:

- For aggregate, determine and record all masses to the nearest 0.1 percent of the sample mass or to the nearest 0.1 g.
- For soil, determine and record all masses to the nearest 0.1 g.

When determining the mass of hot samples or containers or both, place and tare a buffer between the sample container and the balance. This will eliminate damage to or interference with the operation of the balance or scale.

1. Determine and record the mass of the container .
  - a. For soils: the container includes the mass of the close-fitting lid.
  - b. For aggregate: the lid is optional unless drying with a microwave then a ventilated lid is required.
2. Place the wet sample in the container.
3. Determine and record the total mass of the container and wet sample.
  - a. For oven(s), hot plates, infrared heaters, etc.: Spread the sample in the container.
  - b. For microwave oven: Heap sample in the container; cover with ventilated lid.
4. Determine and record the wet mass of the sample ( $M_w$ ) by subtracting the container mass determined in Step 1 from the mass of the container and sample determined in Step 3.
5. Place the sample in one of the following drying apparatuses:
  - a. For aggregate –
    - i. Controlled heat source (oven): at  $110 \pm 5^\circ\text{C}$  ( $230 \pm 9^\circ\text{F}$ ).
    - ii. Uncontrolled heat source (Hot plate, infrared heater, or other heat source as allowed by the agency): Stir frequently to avoid localized overheating.

b. For soil – controlled heat source (oven): at  $110 \pm 5^{\circ}\text{C}$  ( $230 \pm 9^{\circ}\text{F}$ ).

**Note 1:** Soils containing gypsum or significant amounts of organic material require special drying. For reliable moisture contents dry these soils at  $60^{\circ}\text{C}$  ( $140^{\circ}\text{F}$ ). For more information see AASHTO T 265, Note 2.

6. Dry until sample appears moisture free.
7. Determine mass of sample and container.
8. Determine and record the mass of the sample by subtracting the container mass determined in Step 1 from the mass of the container and sample determined in Step 7.
9. Return sample and container to the heat source for the additional time interval.
  - a. Drying intervals for aggregate –
    - i. Controlled heat source (oven): 30 minutes
    - ii. Uncontrolled heat source (Hot plate, infrared heater, or other heat source as allowed by the agency): 10 minutes
    - iii. Uncontrolled heat source (Microwave oven): 2 minutes

**Caution:** Some minerals in the sample may cause the aggregate to overheat, crack, and explode; altering the aggregate gradation.

b. Drying interval for soil – controlled heat source (oven): 1 hour

10. Determine mass of sample and container.
11. Determine and record the mass of the sample by subtracting the container mass determined in Step 1 from the mass of the container and sample determined in Step 10.
12. Determine percent change by subtracting the new mass determination ( $M_n$ ) from the previous mass determination ( $M_p$ ), dividing by the previous mass determination ( $M_p$ ), and multiplying by 100.
13. Continue drying, performing steps 9 through 12, until there is less than a 0.10 percent change after additional drying time.
14. Constant mass has been achieved; sample is defined as dry.
15. Allow the sample to cool. Immediately determine and record the total mass of the container and dry sample.
16. Determine and record the dry mass of the sample ( $M_D$ ) by subtracting the mass of the container determined in Step 1 from the mass of the container and sample determined in Step 15.
17. Determine and record percent moisture ( $w$ ) by subtracting the final dry mass determination ( $M_D$ ) from the initial wet mass determination ( $M_W$ ), dividing by the final dry mass determination ( $M_D$ ), and multiplying by 100.

**Table 3**  
**Methods of Drying**

<b>Aggregate</b>		
<b>Heat Source</b>	<b>Specific Instructions</b>	<b>Drying intervals to achieve constant mass (minutes)</b>
<b>Controlled:</b>		
Forced draft (preferred), ventilated, or convection oven	110 ±5°C (230 ±9°F)	30
<b>Uncontrolled:</b>		
Hot plate, infrared heater, or any other device/method allowed by the agency	Stir frequently	10
Microwave	Heap sample and cover with ventilated lid	2
<b>Soil</b>		
<b>Heat Source</b>	<b>Specific Instructions</b>	<b>Drying interval to achieve constant mass</b>
<b>Controlled:</b>		
Forced draft (preferred), ventilated, or convection oven	110 ±5°C (230 ±9°F)	1 hour

### Calculation

#### Constant Mass

Calculate constant mass using the following formula:

$$\% \text{ Change} = \frac{M_p - M_n}{M_p} \times 100$$

Where:

$M_p$  = previous mass measurement

$M_n$  = new mass measurement

#### Example:

Mass of container:	1232.1 g
Mass of container and sample after first drying cycle:	2637.2 g
Mass, $M_p$ , of possibly dry sample:	$2637.2 \text{ g} - 1232.1 \text{ g} = 1405.1 \text{ g}$
Mass of container and sample after second drying cycle:	2634.1 g
Mass, $M_n$ , of sample:	$2634.1 \text{ g} - 1232.1 \text{ g} = 1402.0 \text{ g}$

$$\% \text{ Change} = \frac{1405.1 \text{ g} - 1402.0 \text{ g}}{1405.1 \text{ g}} \times 100 = 0.22\%$$

*0.22 percent is not less than 0.10 percent, so continue drying.*

Mass of container and sample after third drying cycle: 2633.0 g

Mass,  $M_n$ , of sample:  $2633.0 \text{ g} - 1232.1 \text{ g} = 1400.9 \text{ g}$

$$\% \text{ Change} = \frac{1402.0 \text{ g} - 1400.9 \text{ g}}{1402.0 \text{ g}} \times 100 = 0.08\%$$

*0.08 percent is less than 0.10 percent, so constant mass has been reached.*



### Moisture Content:

Calculate the moisture content, as a percent, using the following formula:

$$w = \frac{M_W - M_D}{M_D} \times 100$$

where:

w = moisture content, percent

M<sub>W</sub> = wet mass

M<sub>D</sub> = dry mass

Example:

Mass of container: 1232.1 g

Mass of container and wet sample: 2764.7 g

Mass, M<sub>W</sub>, of wet sample: 2764.7 g - 1232.1 g = 1532.6 g

Mass of container and dry sample (COOLED): 2633.5 g

Mass, M<sub>D</sub>, of dry sample: 2633.5 g - 1232.1 g = 1401.4 g

$$w = \frac{1532.6 \text{ g} - 1401.4 \text{ g}}{1401.4 \text{ g}} \times 100 = \frac{131.2 \text{ g}}{1401.4 \text{ g}} \times 100 = 9.36\% \text{ report } 9.4\%$$

### Report

- On forms approved by the agency
- Sample ID
- M<sub>W</sub>, wet mass
- M<sub>D</sub>, dry mass
- w, moisture content to the nearest 0.1 percent

EMBANKMENT AND BASE  
IN-PLACE DENSITY

WAQTC/IDAHO

FOP AASHTO T 255 / T 265 (23)

### PERFORMANCE EXAM CHECKLIST

#### TOTAL EVAPORABLE MOISTURE CONTENT OF AGGREGATE BY DRYING FOP FOR AASHTO T 255

#### LABORATORY DETERMINATION OF MOISTURE CONTENT OF SOILS FOP FOR AASHTO T 265

Participant Name \_\_\_\_\_ Exam Date \_\_\_\_\_

Record the symbols “P” for passing or “F” for failing on each step of the checklist.

Procedure Element	Trial 1	Trial 2
1. Representative sample of appropriate mass obtained?	_____	_____
2. Mass of container determined to 0.1 g?	_____	_____
3. Sample placed in container and mass determined to 0.1 g?	_____	_____
4. Test sample mass conforms to the required mass?	_____	_____
5. Wet sample mass determined to 0.1 g?	_____	_____
6. Loss of moisture avoided prior to mass determination?	_____	_____
7. Sample dried by a suitable heat source?	_____	_____
a. Describe suitable heat sources for aggregate?	_____	_____
b. Describe suitable heat sources for soils?	_____	_____
8. If aggregate heated by means other than a controlled oven, is sample stirred to avoid localized overheating?	_____	_____
9. For microwave, aggregate heaped and covered with a ventilated lid?	_____	_____
10. For aggregate, heated for the additional, specified time?	_____	_____
a. Forced draft, ventilated, convection ovens – 30 minutes		
b. Microwave – 2 minutes		
c. Other – 10 minutes		
11. For soil:		
a. Heated for at least 1 hour additional drying time using a controlled heat source?	_____	_____
12. Mass determined and compared to previous mass - showing less than 0.10 percent loss?	_____	_____
13. Sample cooled, dry mass determined and recorded to the nearest 0.1 percent?	_____	_____
14. Moisture content calculated correctly and recorded to the nearest 0.1 percent?	_____	_____

OVER

EMBANKMENT AND BASE  
IN-PLACE DENSITY

WAQTC/IDAHO

FOP AASHTO T 255/T 265 (18)

Comments:      First attempt:    Pass\_\_\_\_Fail\_\_\_\_      Second attempt:    Pass\_\_\_\_Fail\_\_\_\_

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Examiner Signature \_\_\_\_\_ WAQTC #: \_\_\_\_\_

**MOISTURE-DENSITY RELATIONS OF SOILS:  
USING A 2.5 KG (5.5 LB) RAMMER AND A 305 MM (12 IN.) DROP**

**FOP FOR AASHTO T 99**

**USING A 4.54 KG (10 LB) RAMMER AND A 457 MM (18 IN.) DROP**

**FOP FOR AASHTO T 180**

**Scope**

This procedure covers the determination of the moisture-density relations of soils and soil-aggregate mixtures in accordance with two similar test methods:

- AASHTO T 99-22: Methods A, B, C, and D
- AASHTO T 180-22: Methods A, B, C, and D

This test method applies to soil mixtures having 40 percent or less retained on the 4.75 mm (No. 4) sieve for methods A or B, or 30 percent or less retained on the 19 mm ( $\frac{3}{4}$  in.) sieve with methods C or D. The retained material is defined as oversize (coarse) material. If no minimum percentage is specified, 5 percent will be used. Samples that contain oversize (coarse) material that meet percent retained criteria should be corrected by using *Annex A, Correction of Maximum Dry Density and Optimum Moisture for Oversized Particles*. Samples of soil or soil-aggregate mixture are prepared at several moisture contents and compacted into molds of specified size, using manual or mechanical rammers that deliver a specified quantity of compactive energy. The moist masses of the compacted samples are multiplied by the appropriate factor to determine wet density values. Moisture contents of the compacted samples are determined and used to obtain the dry density values of the same samples. Maximum dry density and optimum moisture content for the soil or soil-aggregate mixture is determined by plotting the relationship between dry density and moisture content.

**Apparatus**

- Mold – Cylindrical mold made of metal with the dimensions shown in Table 1 or Table 2. If permitted by the agency, the mold may be of the “split” type, consisting of two half-round sections, which can be securely locked in place to form a cylinder. Determine the mold volume according to *Annex B, Standardization of the Mold*.
- Mold assembly – Mold, base plate, and a detachable collar.
- Rammer – Manually or mechanically operated rammers as detailed in Table 1 or Table 2. A manually operated rammer shall be equipped with a guide sleeve to control the path and height of drop. The guide sleeve shall have at least four vent holes no smaller than 9.5 mm ( $\frac{3}{8}$  in.) in diameter, spaced approximately 90 degrees apart and approximately 19 mm ( $\frac{3}{4}$  in.) from each end. A mechanically operated rammer will uniformly distribute blows over the sample and will be calibrated with several soil types, and be adjusted, if necessary, to give the same moisture-density results as with the manually operated rammer. For additional information concerning calibration, see AASHTO T 99 and T 180.
- Sample extruder – A jack, lever frame, or other device for extruding compacted specimens from the mold quickly and with little disturbance.

- Balance(s) or scale(s) of the capacity and sensitivity required for the procedure used by the agency.
  - A balance or scale with a capacity of 11.5 kg (25 lb) and a sensitivity of 1 g for obtaining the sample, meeting the requirements of AASHTO M 231, Class G 5.
  - A balance or scale with a capacity of 2 kg and a sensitivity of 0.1 g is used for moisture content determinations done under both procedures, meeting the requirements of AASHTO M 231, Class G 2.
- Drying apparatus – A thermostatically controlled drying oven, capable of maintaining a temperature of  $110 \pm 5^{\circ}\text{C}$  ( $230 \pm 9^{\circ}\text{F}$ ) for drying moisture content samples in accordance with the FOP for AASHTO T 255/T 265.
- Straightedge – A steel straightedge at least 250 mm (10 in.) long, with one beveled edge and at least one surface plane within 0.1 percent of its length, used for final trimming.
- Sieve(s) – 4.75 mm (No. 4) and/or 19.0 mm (3/4 in.), meeting the requirements of FOP for AASHTO T 27/T 11.
- Mixing tools – Miscellaneous tools such as a mixing pan, spoon, trowel, spatula, etc., or a suitable mechanical device, for mixing the sample with water.
- Containers with close-fitting lids to prevent gain or loss of moisture in the sample.

**Table 1**  
**Comparison of Apparatus, Sample, and Procedure – Metric**

	<b>T 99</b>	<b>T 180</b>
Mold Volume, m <sup>3</sup>	Methods A, C: 0.000943 ±0.000014	Methods A, C: 0.000943 ±0.000014
	Methods B, D: 0.002124 ±0.000025	Methods B, D: 0.002124 ±0.000025
Mold Diameter, mm	Methods A, C: 101.60 ±0.40	Methods A, C: 101.60 ±0.4
	Methods B, D: 152.40 ±0.70	Methods B, D: 152.40 ±0.70
Mold Height, mm	116.40 ±0.50	116.40 ±0.50
Detachable Collar Height, mm	50.80 ±0.64	50.80 ±0.64
Rammer Diameter, mm	50.80 ±0.25	50.80 ±0.25
Rammer Mass, kg	2.495 ±0.009	4.536 ±0.009
Rammer Drop, mm	305 ±2	457 ±2
Layers	3	5
Blows per Layer	Methods A, C: 25	Methods A, C: 25
	Methods B, D: 56	Methods B, D: 56
Material Size, mm	Methods A, B: 4.75 minus	Methods A, B: 4.75 minus
	Methods C, D: 19.0 minus	Methods C, D: 19.0 minus
Test Sample Size, kg	Method A: 3 Method C: 5 (1)	Method B: 7 Method D: 11(1)
Energy, kN-m/m <sup>3</sup>	592	2,693

(1) This may not be a large enough sample depending on your nominal maximum size for moisture content samples.

**Table 2**  
**Comparison of Apparatus, Sample, and Procedure – English**

	<b>T 99</b>	<b>T 180</b>
Mold Volume, ft <sup>3</sup>	Methods A, C: 0.0333 ±0.0005	Methods A, C: 0.0333 ±0.0005
	Methods B, D: 0.07500 ±0.0009	Methods B, D: 0.07500 ±0.0009
Mold Diameter, in.	Methods A, C: 4.000 ±0.016	Methods A, C: 4.000 ±0.016
	Methods B, D: 6.000 ±0.026	Methods B, D: 6.000 ±0.026
Mold Height, in.	4.584 ±0.018	4.584 ±0.018
Detachable Collar Height, in.	2.000 ±0.025	2.000 ±0.025
Rammer Diameter, in.	2.000 ±0.025	2.000 ±0.025
Rammer Mass, lb	5.5 ±0.02	10 ±0.02
Rammer Drop, in.	12 ±0.06	18 ±0.06
Layers	3	5
Blows per Layer	Methods A, C: 25	Methods A, C: 25
	Methods B, D: 56	Methods B, D: 56
Material Size, in.	Methods A, B: No. 4 minus	Methods A, B: No.4 minus
	Methods C, D: 3/4 minus	Methods C, D: 3/4 minus
Test Sample Size, lb	Method A: 7 Method C: 12 <sub>(1)</sub>	Method B: 16 Method D: 25 <sub>(1)</sub>
Energy, lb-ft/ft <sup>3</sup>	12,375	56,250

(1) This may not be a large enough sample depending on your nominal maximum size for moisture content samples.

## Sample

If the sample is damp, dry it until it becomes friable under a trowel. Drying may be in air or by use of a drying apparatus maintained at a temperature not exceeding 60°C (140°F). Thoroughly break up aggregations in a manner that avoids reducing the natural size of individual particles.

Obtain a representative test sample of the mass required by the agency by passing the material through the sieve required by the agency. See Table 1 or Table 2 for test sample mass and material size requirements.

In instances where the material is prone to degradation, i.e., granular material, a compaction sample with differing moisture contents should be prepared for each point.

If the sample is plastic (clay types), it should stand for a minimum of 12 hours after the addition of water to allow the moisture to be absorbed. In this case, several samples at different moisture contents should be prepared, put in sealed containers, and tested the next day.

*Note 1:* Both T 99 and T 180 have four methods (A, B, C, D) that require different masses and employ different sieves.

## Procedure

During compaction, rest the mold firmly on a dense, uniform, rigid, and stable foundation, or base. This base shall remain stationary during the compaction process.

1. Determine the mass of the clean, dry mold. Include the base plate but exclude the extension collar. Record the mass to the nearest 1 g (0.005 lb).
2. Thoroughly mix the selected representative sample with sufficient water to dampen it to approximately 4 to 8 percentage points below optimum moisture content. For many materials, this condition can be identified by forming a cast by hand.
  - a. Prepare individual samples of plastic or degradable material, increasing moisture contents 1 to 2 percent for each point.
  - b. Allow samples of plastic soil to stand for 12 hrs.
3. Form a specimen by compacting the prepared soil in the mold assembly in approximately equal layers. For each layer:
  - a. Spread the loose material uniformly in the mold.

*Note 2:* It is recommended to cover the remaining material with a non-absorbent sheet or damp cloth to minimize loss of moisture.

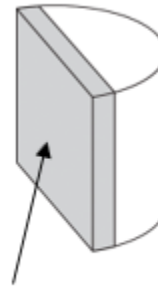
- b. Lightly tamp the loose material with the manual rammer or other similar device, this establishes a firm surface.
- c. Compact each layer with uniformly distributed blows from the rammer. See Table 1 for mold size, number of layers, number of blows, and rammer specification for the various test methods. Use the method specified by the agency.
- d. Trim down material that has not been compacted and remains adjacent to the walls of the mold and extends above the compacted surface.



4. Remove the extension collar. Avoid shearing off the sample below the top of the mold. The material compacted in the mold should not be over 6 mm (1/4 in.) above the top of the mold once the collar has been removed.
5. Trim the compacted soil even with the top of the mold with the beveled side of the straightedge.
6. Clean soil from exterior of the mold and base plate.
7. Determine and record the mass of the mold, base plate, and wet soil to the nearest 1 g (0.005 lb).
8. Determine and record the wet mass ( $M_w$ ) of the sample by subtracting the mass in Step 1 from the mass in Step 7.
9. Calculate the wet density ( $\rho_w$ ), in  $\text{kg/m}^3$  ( $\text{lb/ft}^3$ ), by dividing the wet mass by the measured volume ( $V_m$ ).
10. Extrude the material from the mold. For soils and soil-aggregate mixtures, slice vertically through the center and remove one of the cut faces for a representative moisture content sample. For granular materials, a vertical face will not exist. Take a representative sample ensuring that all layers are represented. This sample must meet the sample size requirements of the test method used to determine moisture content.



**Extruded material**



**Representative moisture  
content sample**

**Note 3:** When developing a curve for free-draining soils such as uniform sands and gravels, where seepage occurs at the bottom of the mold and base plate, taking a representative moisture content from the mixing bowl may be preferred in order to determine the amount of moisture available for compaction.

11. Determine and record the moisture content ( $w$ ) of the sample in accordance with the FOP for AASHTO T 255 / T 265.
12. If the material is degradable or plastic, return to Step 3 using a prepared individual sample. If not, continue with Steps 13 through 15.
13. Thoroughly break up the remaining portion of the molded specimen until it will again pass through the sieve, as judged by eye, and add to the remaining portion of the sample being tested.
14. Add sufficient water to increase the moisture content of the remaining soil by 1 to 2 percentage points and repeat steps 3 through 11.

15. Continue determinations until there is either a decrease or no change in the wet mass. There will be a minimum of three points on the dry side of the curve and two points on the wet side. For non-cohesive, drainable soils, one point on the wet side is sufficient.

## Calculations

### Wet Density

$$\rho_w = \frac{M_w}{V_m}$$

Where:

$$\begin{aligned} \rho_w &= \text{wet density, kg/m}^3 \text{ (lb/ft}^3\text{)} \\ M_w &= \text{wet mass} \\ V_m &= \text{volume of the mold, Annex B} \end{aligned}$$

### Dry Density

$$\rho_d = \left( \frac{\rho_w}{w + 100} \right) \times 100 \quad \text{or} \quad \rho_d = \frac{\rho_w}{\left( \frac{w}{100} \right) + 1}$$

Where:

$$\begin{aligned} \rho_d &= \text{dry density, kg/m}^3 \text{ (lb/ft}^3\text{)} \\ w &= \text{moisture content, as a percentage} \end{aligned}$$

### Example for 4-inch mold, Methods A or C

$$\begin{aligned} \text{Wet mass, } M_w &= 1.928 \text{ kg (4.25 lb)} \\ \text{Moisture content, } w &= 11.3\% \\ \text{Measured volume of the mold, } V_m &= 0.000946 \text{ m}^3 \text{ (0.0334 ft}^3\text{)} \end{aligned}$$

### Wet Density

$$\rho_w = \frac{1.928 \text{ kg}}{0.000946 \text{ m}^3} = 2038 \text{ kg/m}^3 \quad \rho_w = \frac{4.25 \text{ lb}}{0.0334 \text{ ft}^3} = 127.2 \text{ lb/ft}^3$$

### Dry Density

$$\rho_d = \left( \frac{2038 \text{ kg/m}^3}{11.3 + 100} \right) \times 100 = 1831 \text{ kg/m}^3 \quad \rho_d = \left( \frac{127.2 \text{ lb/ft}^3}{11.3 + 100} \right) \times 100 = 114.3 \text{ lb/ft}^3$$

Or

$$\rho_d = \left( \frac{2038 \text{ kg/m}^3}{\frac{11.3}{100} + 1} \right) = 1831 \text{ kg/m}^3 \quad \rho_d = \left( \frac{127.2 \text{ lb/ft}^3}{\frac{11.3}{100} + 1} \right) = 114.3 \text{ lb/ft}^3$$

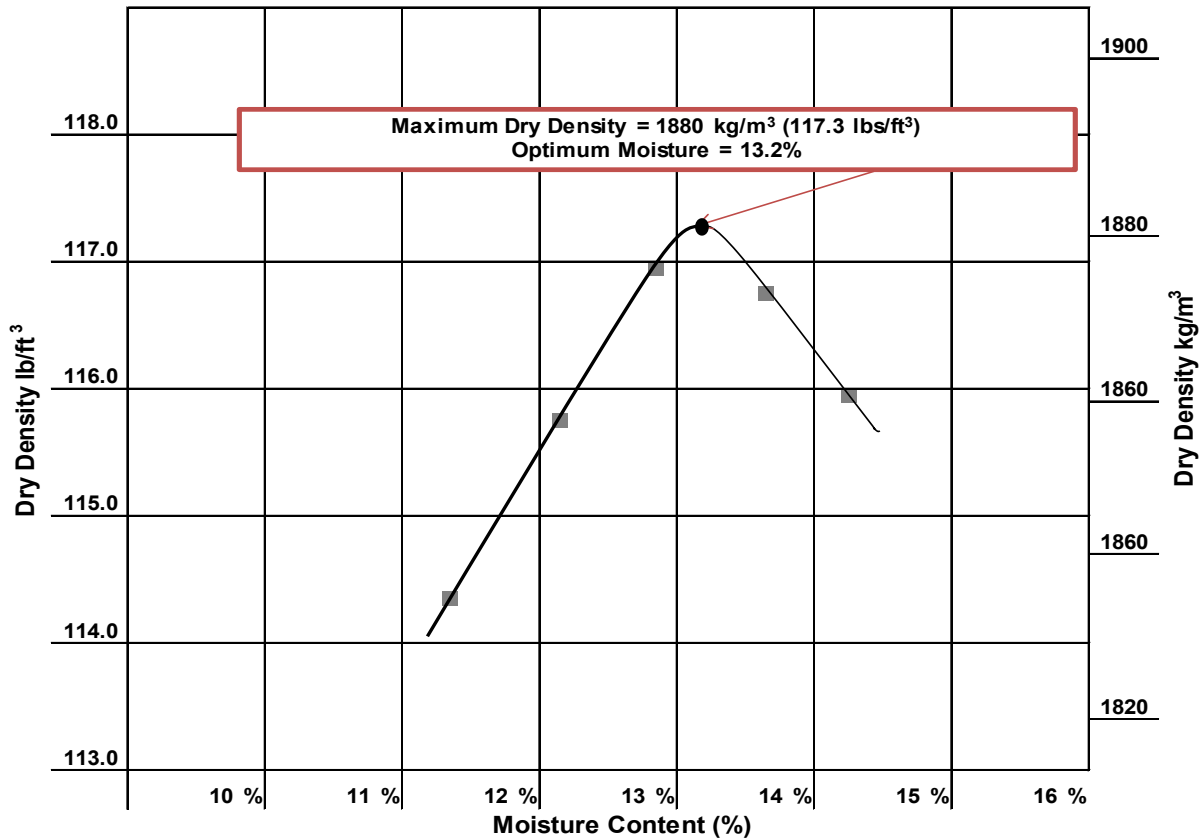
### Moisture-Density Curve Development

When dry density is plotted on the vertical axis versus moisture content on the horizontal axis and the points are connected with a smooth line, a moisture-density curve is developed. The coordinates of the peak of the curve are the maximum dry density, or just “maximum density,” and the “optimum moisture content” of the soil.

#### Example

Given the following dry density and corresponding moisture content values develop a moisture-density relations curve and determine maximum dry density and optimum moisture content.

Dry Density		Moisture Content, %
kg/m <sup>3</sup>	lb/ft <sup>3</sup>	
1831	114.3	11.3
1853	115.7	12.1
1873	116.9	12.8
1869	116.7	13.6
1857	115.9	14.2



In this case, the curve has its peak at:

Maximum dry density = 1880 kg/m<sup>3</sup> (117.3 lb/ft<sup>3</sup>)  
Optimum moisture content = 13.2%

Note that both values are approximate since they are based on sketching the curve to fit the points.

### Report

- Results on forms approved by the agency
- Sample ID
- Maximum dry density to the nearest 1 kg/m<sup>3</sup> (0.1 lb/ft<sup>3</sup>)
- Optimum moisture content to the nearest 0.1 percent

## ANNEX A

### CORRECTION OF MAXIMUM DRY DENSITY AND OPTIMUM MOISTURE FOR OVERSIZED PARTICLES

(Mandatory Information)

This section corrects the maximum dry density and moisture content of the material retained on the 4.75 mm (No. 4) sieve, Methods A and B; or the material retained on the 19 mm (¾ in.) sieve, Methods C and D. The maximum dry density, corrected for oversized particles and total moisture content, are compared with the field-dry density and field moisture content.

This correction can be applied to the sample on which the maximum dry density is performed. A correction may not be practical for soils with only a small percentage of oversize material. The agency shall specify a minimum percentage below which the method is not needed. If not specified, this method applies when more than 5 percent by weight of oversize particles is present.

Bulk specific gravity ( $G_{sb}$ ) of the oversized particles is required to determine the corrected maximum dry density. Use the bulk specific gravity as determined using the FOP for AASHTO T 85 in the calculations. For construction activities, an agency established value or specific gravity of 2.600 may be used.

This correction can also be applied to the sample obtained from the field while performing in-place density.

#### Procedure

1. Use the sample from this procedure or a sample obtained according to the FOP for AASHTO T 310.
2. Sieve the sample on the 4.75 mm (No. 4) sieve for Methods A and B or the 19 mm (¾ in.) sieve, Methods C and D.
3. Determine the dry mass of the oversized and fine fractions ( $M_{DC}$  and  $M_{DF}$ ) by one of the following:
  - a. Dry the fractions, fine and oversized, in air or by use of a drying apparatus that is maintained at a temperature not exceeding 60°C (140°F).
  - b. Calculate the dry masses using the moisture samples.

To determine the dry mass of the fractions using moisture samples.

1. Determine the moist mass of both fractions, fine ( $M_{Mf}$ ) and oversized ( $M_{Mc}$ ):
2. Obtain moisture samples from the fine and oversized material.
3. Determine the moisture content of the fine particles ( $MC_f$ ) and oversized particles ( $MC_c$ ) of the material by FOP for AASHTO T 255/T 265 or agency approved method.
4. Calculate the dry mass of the oversize and fine particles.

$$M_D = \frac{M_m}{1 + MC}$$

Where:

$M_D$  = mass of dry material (fine or oversize particles)

$M_m$  = mass of moist material (fine or oversize particles)

MC = moisture content of respective fine or oversized, expressed as a decimal

5. Calculate the percentage of the fine ( $P_f$ ) and oversized ( $P_c$ ) particles by dry weight of the total sample as follows: See Note 2.

$$P_f = \frac{100 \times M_{DF}}{M_{DF} + M_{DC}} \quad \frac{100 \times 15.4 \text{ lb}}{15.4 \text{ lbs} + 5.7 \text{ lb}} = 73\% \quad \frac{100 \times 6.985 \text{ kg}}{6.985 \text{ kg} + 2.585 \text{ kg}} = 73\%$$

And

$$P_c = \frac{100 \times M_{DC}}{M_{DF} + M_{DC}} \quad \frac{100 \times 5.7 \text{ lb}}{15.4 \text{ lbs} + 5.7 \text{ lb}} = 27\% \quad \frac{100 \times 2.585 \text{ kg}}{6.985 \text{ kg} + 2.585 \text{ kg}} = 27\%$$

Or for  $P_c$ :

$$P_c = 100 - P_f$$

Where:

$P_f$  = percent of fine particles, of sieve used, by weight

$P_c$  = percent of oversize particles, of sieve used, by weight

$M_{DF}$  = mass of dry fine particles

$M_{DC}$  = mass of dry oversize particles

### Optimum Moisture Correction Equation

1. Calculate the corrected moisture content as follows:

$$MC_T = \frac{(MC_F \times P_f) + (MC_C \times P_c)}{100} = \frac{(13.2\% \times 73.0\%) + (2.1\% \times 27.0\%)}{100} = 10.2\%$$

$MC_T$  = corrected moisture content of combined fines and oversized particles, expressed as a % moisture

$MC_F$  = moisture content of fine particles, as a % moisture

$MC_C$  = moisture content of oversized particles, as a % moisture

**Note 1:** Moisture content of oversize material can be assumed to be two (2) percent for most construction applications.

**Note 2:** In some field applications agencies will allow the percentages of oversize and fine materials to be determined with the materials in the wet state.

### Density Correction Equation

2. Calculate the corrected dry density ( $\rho_d$ ) of the total sample (combined fine and oversized particles) as follows:

$$\rho_d = \frac{100\%}{\left[\left(\frac{P_f}{\rho_f}\right) + \left(\frac{P_c}{k}\right)\right]}$$

Where:

$\rho_d$  = corrected total dry density (combined fine and oversized particles)  
kg/m<sup>3</sup> (lb/ft<sup>3</sup>)

$\rho_f$  = dry density of the fine particles kg/m<sup>3</sup> (lb/ft<sup>3</sup>), determined in the lab

$P_c$  = percent of dry oversize particles, of sieve used, by weight.

$P_f$  = percent of dry fine particles, of sieve used, by weight.

$k$  = Metric: 1,000 \* Bulk Specific Gravity ( $G_{sb}$ ) (oven dry basis)  
of coarse particles (kg/m<sup>3</sup>).

$k$  = English: 62.4 \* Bulk Specific Gravity ( $G_{sb}$ ) (oven dry basis)  
of coarse particles (lb/ft<sup>3</sup>)

**Note 3:** If the specific gravity is known, then this value will be used in the calculation. For most construction activities the specific gravity for aggregate may be assumed to be 2.600.

## Calculation

### Example

- Metric:

Maximum laboratory dry density ( $\rho_p$ ):	1880 kg/m <sup>3</sup>
Percent coarse particles ( $P_c$ ):	27%
Percent fine particles ( $P_f$ ):	73%
Mass per volume coarse particles ( $k$ ):	(2.697) (1000) = 2697 kg/m <sup>3</sup>

$$\rho_d = \frac{100\%}{\left[ \left( \frac{P_f}{\rho_f} \right) + \left( \frac{P_c}{k} \right) \right]}$$

$$\rho_d = \frac{100\%}{\left[ \left( \frac{73\%}{1880 \text{ kg/m}^3} \right) + \left( \frac{27\%}{2697 \text{ kg/m}^3} \right) \right]}$$

$$\rho_d = \frac{100\%}{[0.03883 \text{ kg/m}^3 + 0.01001 \text{ kg/m}^3]}$$

$$\rho_d = 2047.5 \text{ kg/m}^3 \text{ report } 2048 \text{ kg/m}^3$$



English:

Maximum laboratory dry density ( $\rho_f$ ): 117.3 lb/ft<sup>3</sup>

Percent coarse particles ( $P_c$ ): 27%

Percent fine particles ( $P_f$ ): 73%

Mass per volume of coarse particles (k): (2.697) (62.4) = 168.3 lb/ft<sup>3</sup>

$$\rho_d = \frac{100\%}{\left[\left(\frac{P_f}{\rho_f}\right) + \left(\frac{P_c}{k}\right)\right]}$$

$$\rho_d = \frac{100\%}{\left[\left(\frac{73\%}{117.3 \text{ lb/ft}^3}\right) + \left(\frac{27\%}{168.3 \text{ lb/ft}^3}\right)\right]}$$

$$\rho_d = \frac{100\%}{[0.6223 \text{ lb/ft}^3 + 0.1604 \text{ lb/ft}^3]}$$

$$\rho_d = \frac{100\%}{0.7827 \text{ lb/ft}^3}$$

$$\rho_d = 127.76 \text{ lb/ft}^3 \quad \text{Report } 127.8 \text{ lb/ft}^3$$

## Report

- On forms approved by the agency
- Sample ID
- Corrected maximum dry density to the nearest 1 kg/m<sup>3</sup> (0.1 lb/ft<sup>3</sup>)
- Corrected optimum moisture to the nearest 0.1 percent

## **ANNEX B**

### **STANDARDIZATION OF THE MOLD**

(Mandatory Information)

Standardization is a critical step to ensure accurate test results when using this apparatus. Failure to perform the standardization procedure as described herein will produce inaccurate or unreliable test results.

#### **Apparatus**

- Mold and base plate
- Balance or scale – Accurate to within 45 g (0.1 lb) or 0.3 percent of the test load, whichever is greater, at any point within the range of use.
- Cover plate – A piece of plate glass, at least 6 mm (1/4 in.) thick and at least 25 mm (1 in.) larger than the diameter of the mold.
- Thermometers – Standardized liquid-in-glass, or electronic digital total immersion type, accurate to 0.5°C (1°F)

#### **Procedure**

1. Create a watertight seal between the mold and base plate.
2. Determine and record the mass of the dry sealed mold, base plate, and cover plate.
3. Fill the mold with water at a temperature between 16°C and 29°C (60°F and 85°F) and cover with the cover plate in such a way as to eliminate bubbles and excess water.
4. Wipe the outside of the mold, base plate, and cover plate dry, being careful not to lose any water from the mold.
5. Determine and record the mass of the filled mold, base plate, cover plate, and water.
6. Determine and record the mass of the water in the mold by subtracting the mass in Step 2 from the mass in Step 5.
7. Measure the temperature of the water and determine its density from Table B1, interpolating, as necessary.
8. Calculate the volume of the mold,  $V_m$ , by dividing the mass of the water in the mold by the density of the water at the measured temperature.

**Calculations**

$$V_m = \frac{M}{\rho_{water}}$$

Where:

$V_m$  = volume of the mold

$M$  = mass of water in the mold

$\rho_{water}$  = density of water at the measured temperature

**Example**

Mass of water in mold = 0.94367 kg (2.0800 lb)

$\rho_{water}$  at 23°C (73.4°F) = 997.54 kg/m<sup>3</sup> (62.274 lb/ft<sup>3</sup>)

$$V_m = \frac{0.94367 \text{ kg}}{997.54 \text{ kg/m}^3} = 0.000946 \text{ m}^3 \quad V_m = \frac{2.0800 \text{ lb}}{62.274 \text{ lb/ft}^3} = 0.0334 \text{ ft}^3$$

**Table B1**  
**Unit Mass of Water**  
**15°C to 30°C**

°C	(°F)	kg/m <sup>3</sup>	(lb/ft <sup>3</sup> )	°C	(°F)	kg/m <sup>3</sup>	(lb/ft <sup>3</sup> )
15	(59.0)	999.10	(62.372)	23	(73.4)	997.54	(62.274)
15.6	(60.0)	999.01	(62.366)	23.9	(75.0)	997.32	(62.261)
16	(60.8)	998.94	(62.361)	24	(75.2)	997.29	(62.259)
17	(62.6)	998.77	(62.350)	25	(77.0)	997.03	(62.243)
18	(64.4)	998.60	(62.340)	26	(78.8)	996.77	(62.227)
18.3	(65.0)	998.54	(62.336)	26.7	(80.0)	996.59	(62.216)
19	(66.2)	998.40	(62.328)	27	(80.6)	996.50	(62.209)
20	(68.0)	998.20	(62.315)	28	(82.4)	996.23	(62.192)
21	(69.8)	997.99	(62.302)	29	(84.2)	995.95	(62.175)
21.1	(70.0)	997.97	(62.301)	29.4	(85.0)	995.83	(62.166)
22	(71.6)	997.77	(62.288)	30	(86.0)	995.65	(62.156)

## Report

- Mold ID
- Date Standardized
- Temperature of the water
- Volume,  $V_m$ , of the mold to the nearest  $0.000001 \text{ m}^3$  ( $0.0001 \text{ ft}^3$ )

## DEVELOPING A FAMILY OF CURVES FOP FOR AASHTO R 75

### Scope

This procedure provides a method to develop a family of curves in accordance with AASHTO R 75-16 using multiple moisture-density relationships developed using the same method, A, B, C, or D, from the FOP for AASHTO T 99/T 180.

All curves used in a family must be developed using a single Method: A, B, C, or D of a procedure for AASHTO T 99 or T 180. See the FOP for AASHTO T 99/T 180.

### Terminology

*family of curves* — a group of soil moisture-density relationships (curves) determined using AASHTO T 99 or T 180, which reveal certain similarities and trends characteristic of the soil type and source.

*spine* — smooth line extending through the point of maximum density and optimum moisture content of a family of moisture-density curves.

### Procedure

1. Sort the curves by Method (A, B, C, or D of the FOP for T 99/T 180). At least three curves are required to develop a family.
2. Select the highest and lowest maximum dry densities from those selected to assist in determining the desired scale of the subsequent graph.
3. Plot the maximum density and optimum moisture points of the selected curves on the graph.
4. Draw a smooth, “best fit,” curved line through the points creating the spine of the family of curves.
5. Remove maximum density and optimum moisture points that were not used to establish the spine.
6. Add the moisture-density curves associated with the points that were used to establish the spine. It is not necessary to include the portion of the curves over optimum moisture.

*Note 1*—Intermediate curves using slopes similar to those of the original moisture-density curves may be included when maximum density points are more than 2.0 lb/ft<sup>3</sup> apart. Intermediate curves are indicated by a dashed line.

7. Plot the 80 percent of optimum moisture range when desired:
  - a. Using the optimum moisture of an existing curve, calculate 80 percent of optimum moisture and plot this value on the curve. Repeat for each curve in the family.
  - b. Draw a smooth, “best fit,” curved line connecting the 80 percent of optimum moisture points plotted on the curves that parallel the spine.

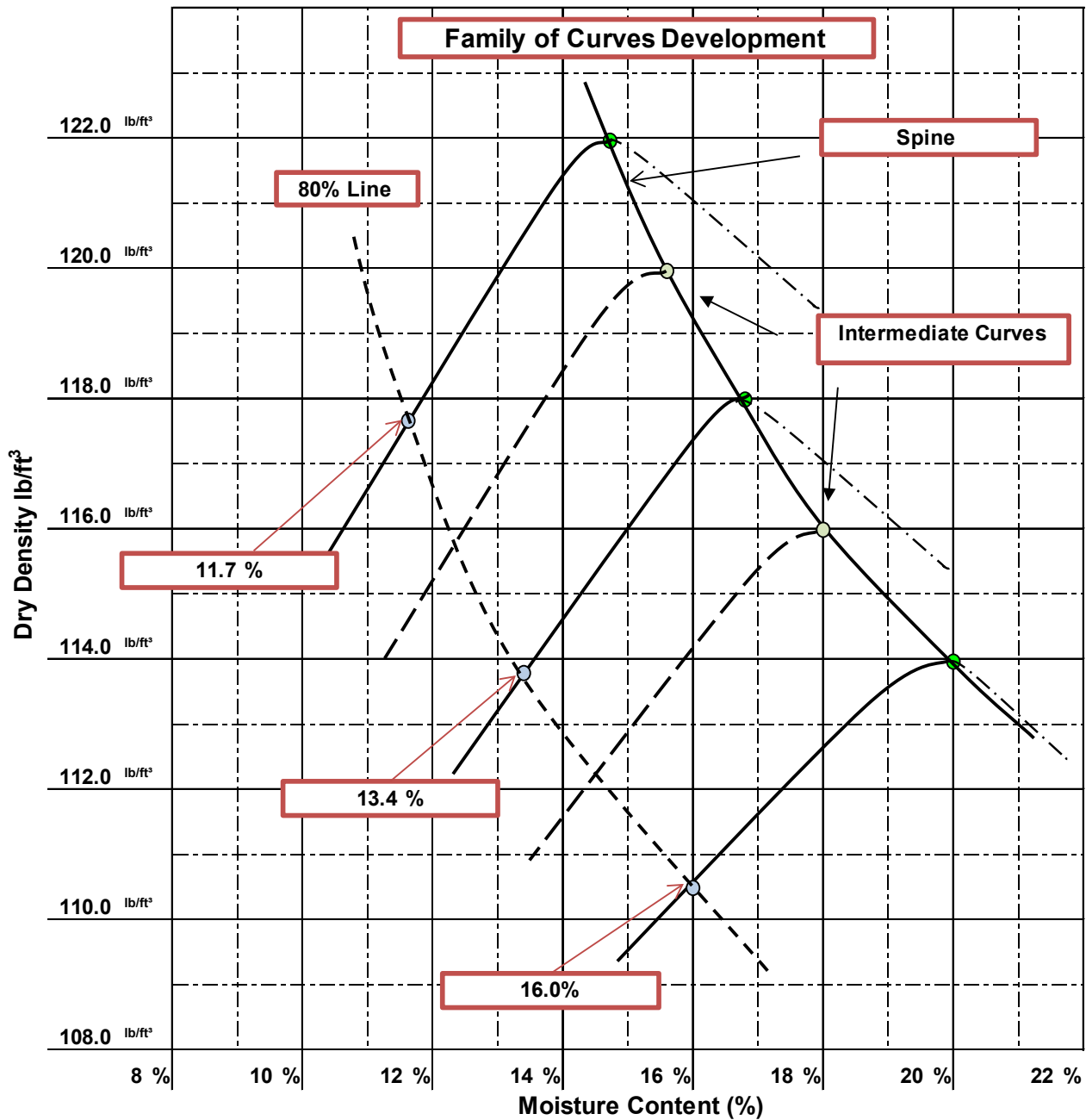
### Calculations

Calculate 80 percent of optimum moisture of each curve:

Example:

Optimum moisture of the highest density curve = 14.6%

$$80\% \text{ point} = \frac{80}{100} \times 14.6\% = 11.7\%$$



## **ONE-POINT METHOD FOR DETERMINING MAXIMUM DRY DENSITY AND OPTIMUM MOISTURE FOP FOR AASHTO T 272**

### **Scope**

This procedure provides for a rapid determination of the maximum dry density and optimum moisture content of a soil sample, using a one-point determination in accordance with AASHTO T 272-18. This procedure is related to the FOPs for AASHTO T 99/T 180 and R 75.

One-point determinations are made by compacting the soil in a mold of a given size with a specified rammer dropped from a specified height and then compared to an individual moisture-density curve (FOP for AASHTO T 99 or T 180) or a family of curves (FOP for AASHTO R 75). Four alternate methods – A, B, C, and D – are used and correspond to the methods described in the FOP for AASHTO T 99/T 180. The method used in AASHTO T 272 must match the method used for the reference curve or to establish the family of curves. For example, when moisture-density relationships as determined by T 99 - Method C are used to form the family of curves or an individual moisture density curve, then T 99 - Method C must be used to for the one-point determination.

### **Apparatus**

See the FOP for AASHTO T 99/T 180.

### **Sample**

Sample size determined according to the FOP for AASHTO T 310. In cases where the existing individual curve or family cannot be used a completely new curve will need to be developed and the sample size will be determined by the FOP for AASHTO T 99/T 180.

1. If the sample is damp, dry it until it becomes friable under a trowel. Drying may be in air or by use of a drying apparatus maintained at a temperature not exceeding 60°C (140°F).
2. Thoroughly break up aggregations in a manner that avoids reducing the natural size of individual particles.
3. Pass the material through the appropriate sieve.

### **Procedure**

Use the method matching the individual curve or Family of Curves. Refer to Table 1 of the FOP for AASHTO T 99 / T 180 for corresponding mold size, number of layers, number of blows, sieve size, and rammer specification for the various test methods.

1. Determine the mass of the clean, dry mold. Include the base plate but exclude the extension collar. Record the mass to the nearest 1 g (0.005 lb).
2. Thoroughly mix the sample with sufficient water to adjust moisture content to 80 to 100 percent of the anticipated optimum moisture.

3. Form a specimen by compacting the prepared soil in the mold (with collar attached) in approximately equal layers. For each layer:

- a. Spread the loose material uniformly in the mold.

*Note 1:* It is recommended to cover the remaining material with a non-absorbent sheet or damp cloth to minimize loss of moisture.

- b. Lightly tamp the loose material with the manual rammer or other similar device, this establishes a firm surface.

- c. Compact each layer with uniformly distributed blows from the rammer.

- d. Trim down material that has not been compacted and remains adjacent to the walls of the mold and extends above the compacted surface.

4. Remove the extension collar. Avoid shearing off the sample below the top of the mold. The material compacted in the mold should not be over 6 mm (¼ in.) above the top of the mold once the collar has been removed.

5. Trim the compacted soil even with the top of the mold with the beveled side of the straightedge.

6. Clean soil from exterior of the mold and base plate.

7. Determine the mass of the mold and wet soil to the nearest 1 g (0.005 lb).

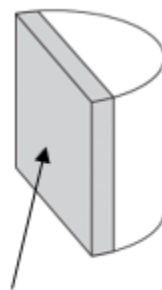
8. Determine the wet mass of the sample by subtracting the mass in Step 1 from the mass in Step 7.

9. Calculate the wet density ( $\rho_w$ ) as indicated below under “Calculations.”

10. Extrude the material from the mold. For soils and soil-aggregate mixtures, slice vertically through the center and remove one of the cut faces for a representative moisture content sample. For granular materials, a vertical face will not exist. Take a representative sample ensuring that all layers are represented. This sample must meet the sample size requirements of the test method used to determine moisture content.



**Extruded material**



**Representative moisture  
content sample**

11. Determine the moisture content ( $w$ ) of the sample in accordance with the FOP for AASHTO T 255 / T 265.



### Calculations

1. Calculate the wet density, in  $\text{kg/m}^3$  ( $\text{lb/ft}^3$ ), by dividing the wet mass by the measured volume of the mold (T 19).

Example – Methods A or C mold:

Wet mass = 2.0055 kg (4.42 lb)

Measured volume of the mold = 0.0009469  $\text{m}^3$  (0.0334  $\text{ft}^3$ )

$$\rho_w = \frac{2.0055 \text{ kg}}{0.0009469 \text{ m}^3} = 2118 \text{ kg/m}^3$$

$$\rho_w = \frac{4.42 \text{ lb}}{0.0334 \text{ ft}^3} = 132.2 \text{ lb/ft}^3$$

Where:

$$\rho_w = \text{Wet density, kg/m}^3 \text{ (lb/ft}^3\text{)}$$

2. Calculate the dry density as follows.

$$\rho_d = \left( \frac{\rho_w}{w + 100} \right) \times 100 \quad \text{or} \quad \rho_d = \frac{\rho_w}{\left( \frac{w}{100} \right) + 1}$$

Where:

$$\rho_d = \text{Dry density, kg/m}^3 \text{ (lb/ft}^3\text{)}$$

w = Moisture content, as a percentage

Example:

$$\rho_w = 2118 \text{ kg/m}^3 \text{ (132.2 lb/ft}^3\text{)}$$

$$w = 13.5\%$$

$$\rho_d = \left( \frac{2118 \text{ kg/m}^3}{13.5 + 100} \right) \times 100 = 1866 \text{ kg/m}^3 \quad \rho_d = \left( \frac{132.2 \text{ lb/ft}^3}{13.5 + 100} \right) \times 100 = 116.5 \text{ lb/ft}^3$$

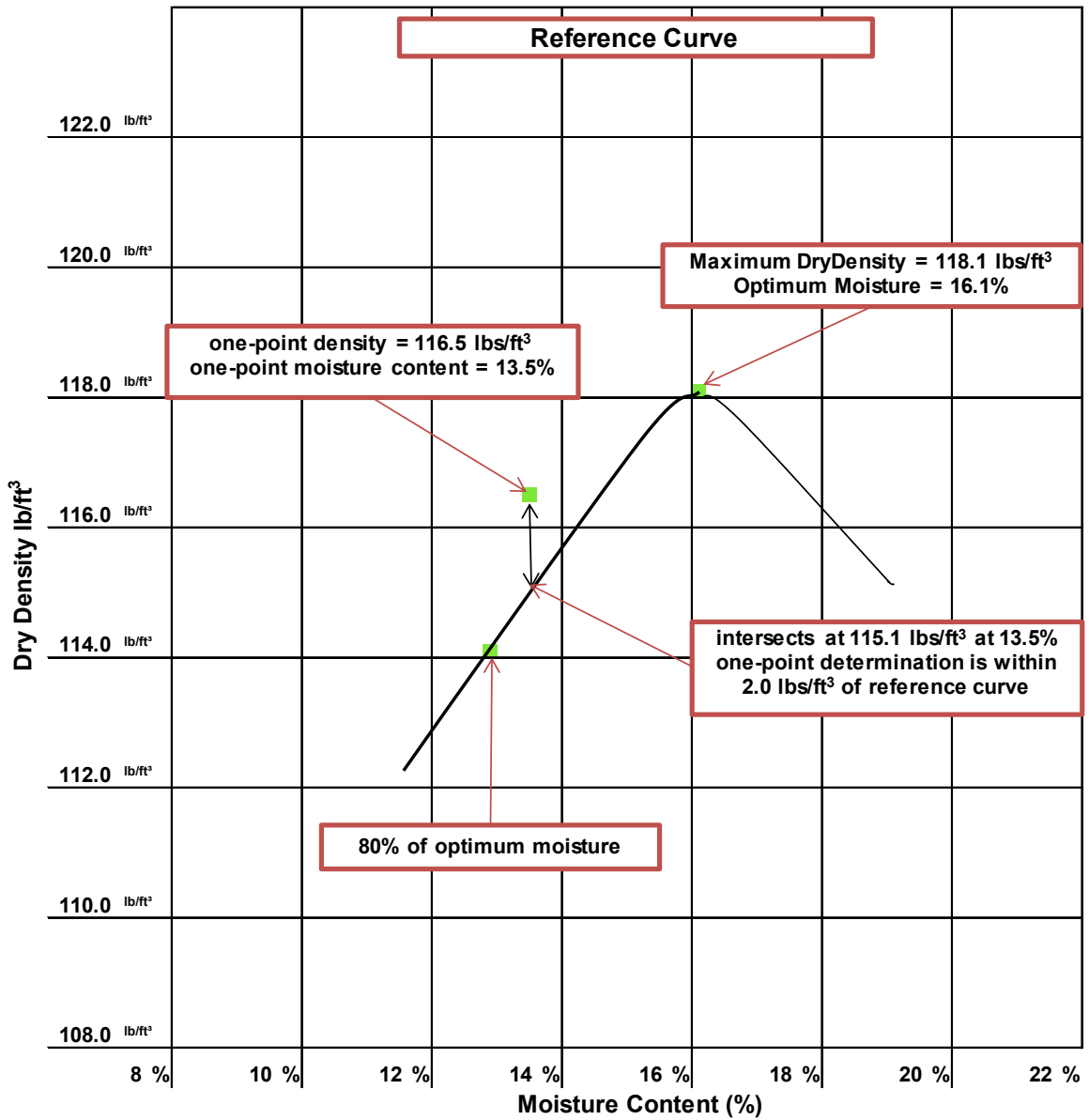
or

$$\rho_d = \left( \frac{2118 \text{ kg/m}^3}{\frac{13.5}{100} + 1} \right) = 1866 \text{ kg/m}^3 \quad \rho_d = \left( \frac{132.2 \text{ lb/ft}^3}{\frac{13.5}{100} + 1} \right) = 116.5 \text{ lb/ft}^3$$

### **Maximum Dry Density and Optimum Moisture Content Determination Using an Individual Moisture - Density Curve**

1. The moisture content must be within 80 to 100 percent of optimum moisture of the reference curve. Compact another specimen, using the same material, at an adjusted moisture content if the one-point does not fall in the 80 to 100 percent of optimum moisture range.
2. Plot the one-point, dry density on the vertical axis and moisture content on the horizontal axis, on the reference curve graph.
3. If the one-point falls on the reference curve or within  $\pm 2.0$  lbs/ft<sup>3</sup>, use the maximum dry density and optimum moisture content determined by the curve.
4. Use the FOP for AASHTO T 99/T 180 Annex A to determine corrected maximum dry density and optimum moisture content if oversize particles have been removed.
5. Perform a full moisture-density relationship if the one-point does not fall on or within  $\pm 2.0$  lbs/ft<sup>3</sup> of the reference curve at 80 to 100 percent optimum moisture.

**Example**



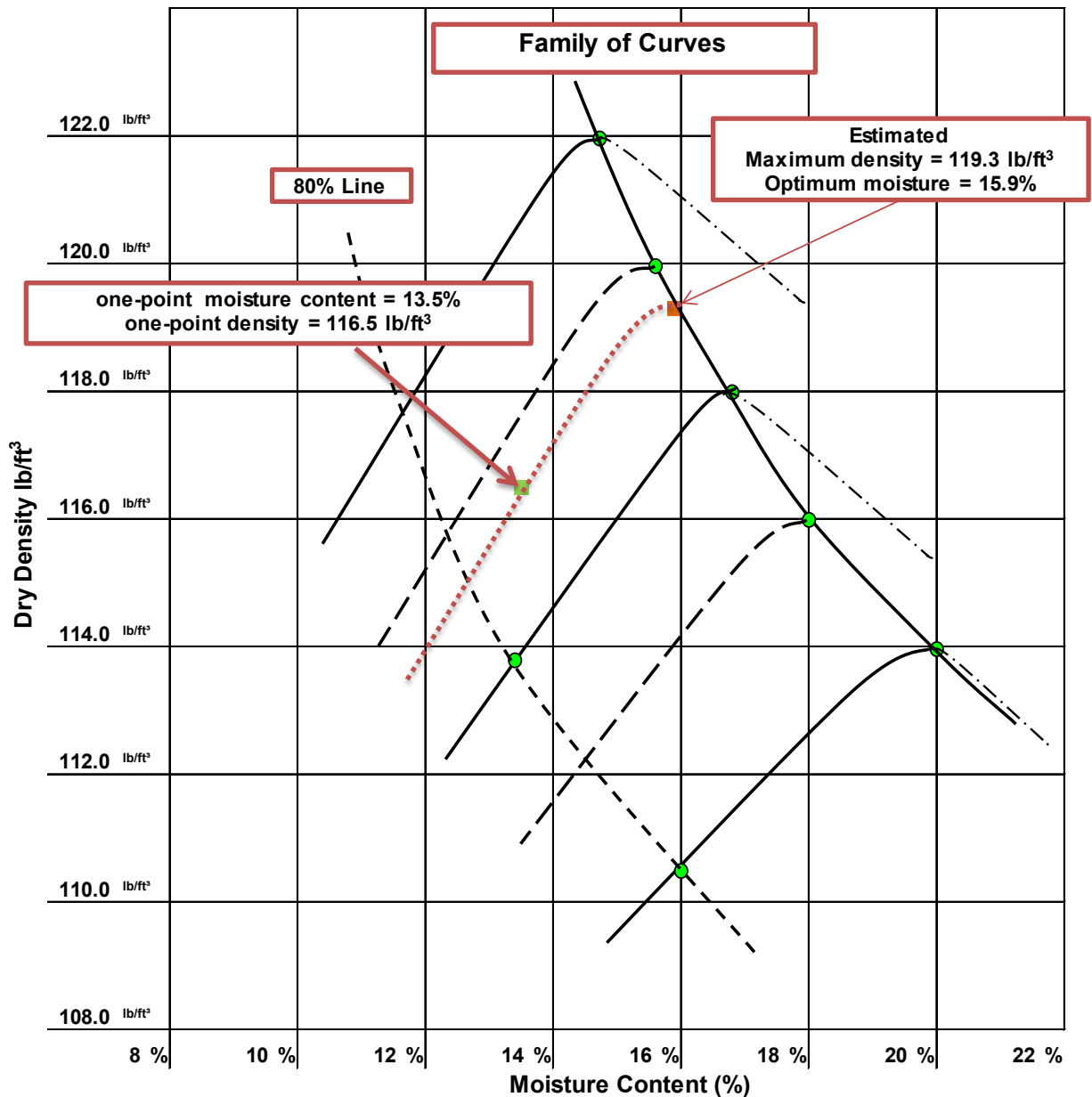
The results of a one-point determination were 116.5 lb/ft<sup>3</sup> at 13.5 percent moisture. The point was plotted on the reference curve graph. The one-point determination is within 2.0 lb/ft<sup>3</sup> of the point on the curve that corresponds with the moisture content.

### **Maximum Dry Density and Optimum Moisture Content Determination Using a Family of Curves**

1. Plot the one-point, dry density on the vertical axis and moisture content on the horizontal axis, on the reference family of curves graph.
2. If the moisture-density one-point falls on one of the curves in the family of curves, use the maximum dry density and optimum moisture content defined by that curve.
3. If the moisture-density one-point falls within the family of curves but not on an existing curve, draw a new curve through the plotted single point, parallel and in character with the nearest existing curve in the family of curves. Use the maximum dry density and optimum moisture content as defined by the new curve.
  - a. The one-point must fall either between or on the highest or lowest curves in the family. If it does not, then a full curve must be developed.
  - b. If the one-point plotted within or on the family of curves does not fall in the 80 to 100 percent of optimum moisture content, compact another specimen, using the same material, at an adjusted moisture content that will place the one point within this range.
4. Use the FOP for AASHTO T 99/T 180 Annex A to determine corrected maximum dry density and optimum moisture content if oversize particles have been removed.
5. If the new curve through a one-point is not well defined or is in any way questionable, perform a full moisture-density relationship to correctly define the new curve and verify the applicability of the family of curves.

**Note 2:** New curves drawn through plotted single point determinations shall not become a permanent part of the family of curves until verified by a full moisture-density procedure following the FOP for AASHTO T 99/T 180.

Example



The results of a one-point determination were 116.5 lb/ft<sup>3</sup> at 13.5 percent moisture. The point was plotted on the reference curve graph. The point was plotted on the appropriate family between two previously developed curves near and intermediate curve.

The “dotted” curve through the moisture-density one-point was sketched between the existing curves. A maximum dry density of 119.3 lb/ft<sup>3</sup> and a corresponding optimum moisture content of 15.9 percent were estimated.

## Report

- On forms approved by the agency
- Sample ID
- Maximum dry density to the nearest  $1 \text{ kg/m}^3$  ( $0.1 \text{ lb/ft}^3$ )
- Corrected maximum dry density (if applicable)
- Optimum moisture content to the nearest 0.1 percent
- Corrected optimum moisture content (if applicable)
- Reference curve or Family of Curves used

**PERFORMANCE EXAM CHECKLIST**

**ONE-POINT METHOD  
FOP FOR AASHTO T 272 (T 99)**

Participant Name \_\_\_\_\_ Exam Date \_\_\_\_\_

Record the symbols “P” for passing or “F” for failing on each step of the checklist.

Procedure Element	Trial 1	Trial 2
1. One-point determination of dry density and corresponding moisture content made in accordance with the FOP for AASHTO T 99?	_____	_____
a. Correct size (4.75 mm / No. 4 or 19.0 mm / 3/4 in.) material used?	_____	_____
2. If necessary, sample dried until friable in air or drying apparatus, not exceeding 60°C (140°F)?	_____	_____
3. Sample broken up and an adequate amount sieved over the appropriate sieve (4.75 mm / No. 4 or 19.0 mm / 3/4 in.) to determine oversize (coarse particle) percentage?	_____	_____
4. Sample passing the sieve has appropriate mass?	_____	_____
5. Moisture content adjusted if needed?	_____	_____
6. Determine mass of clean, dry mold without collar to nearest 1 g (0.005 lb.)?	_____	_____
7. Mold placed on rigid and stable foundation?	_____	_____
8. Layer of soil (approximately one third compacted depth) placed in mold with collar attached, loose material lightly tamped?	_____	_____
9. Soil compacted with appropriate number of blows (25 or 56)?	_____	_____
10. Material adhering to the inside of the mold trimmed?	_____	_____
11. Layer of soil (approximately two thirds compacted depth) placed in mold with collar attached, loose material lightly tamped?	_____	_____
12. Soil compacted with appropriate number of blows (25 or 56)?	_____	_____
13. Material adhering to the inside of the mold trimmed?	_____	_____
14. Mold filled with soil such that compacted soil will be above the mold, loose material lightly tamped?	_____	_____
15. Soil compacted with appropriate number of blows (25 or 56)?	_____	_____
16. Collar removed without shearing off sample?	_____	_____
17. Approximately 6 mm (1/4 in.) of compacted material above the top of the mold (without the collar)?	_____	_____
18. Soil trimmed to top of mold with the beveled side of the straightedge?	_____	_____
19. Remove soil from exterior surface of mold and base plate?	_____	_____
20. Mass of mold and contents determined to appropriate precision?	_____	_____

**OVER**

Procedure Element	Trial 1	Trial 2
21. Wet density calculated from the wet mass?	_____	_____
22. Soil removed from mold using a sample extruder if needed?	_____	_____
23. Soil sliced vertically through center (non-granular material)?	_____	_____
24. Moisture sample removed ensuring all layers are represented?	_____	_____
25. Moist mass determined immediately to 0.1 g?	_____	_____
26. Moisture sample mass of correct size?	_____	_____
27. Sample dried and water content determined according to the FOP for T 255/T 265?	_____	_____
28. One-point plotted on family of curves supplied?	_____	_____
a. One-point falls within 80 to 100 percent of optimum moisture content in order to be valid?	_____	_____
b. If one-point does not fall within 80 to 100 percent of optimum moisture content, another one-point determination with an adjusted water content is made?	_____	_____
c. Maximum dry density and corresponding optimum moisture content correctly estimated?	_____	_____
29. One-point plotted on a single reference curve?	_____	_____
a. Does one-point plot within 2 lb/ft <sup>3</sup> in order to be valid?	_____	_____
b. Does one-point fall within 80 to 100 percent of optimum moisture content in order to be valid?	_____	_____
c. Maximum dry density and corresponding optimum moisture content determined from single reference curve?	_____	_____

Comments:      First attempt: Pass\_\_\_\_Fail\_\_\_\_      Second attempt: Pass\_\_\_\_Fail\_\_\_\_

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Examiner Signature \_\_\_\_\_ WAQTC #: \_\_\_\_\_



### PERFORMANCE EXAM CHECKLIST

#### ONE-POINT METHOD FOP FOR AASHTO T 272 (T 180)

Participant Name \_\_\_\_\_ Exam Date \_\_\_\_\_

Record the symbols “P” for passing or “F” for failing on each step of the checklist.

Procedure Element	Trial 1	Trial 2
1. One-point determination of dry density and corresponding moisture content made in accordance with the FOP for AASHTO T 180?	_____	_____
a. Correct size (4.75 mm / No. 4 or 19.0 mm / 3/4 in.) material used?	_____	_____
2. If necessary, sample dried until friable in air or drying apparatus, not exceeding 60°C (140°F)?	_____	_____
3. Sample broken up and an adequate amount sieved over the appropriate sieve (4.75 mm / No. 4 or 19.0 mm / 3/4 in.) to determine oversize (coarse particle) percentage?	_____	_____
4. Sample passing the sieve has appropriate mass?	_____	_____
5. Moisture content adjusted if needed?	_____	_____
6. Determine mass of clean, dry mold without collar to nearest 1 g (0.005 lb.)?	_____	_____
7. Mold placed on rigid and stable foundation?	_____	_____
8. Layer of soil (approximately one fifth compacted depth) placed in mold with collar attached, loose material lightly tamped?	_____	_____
9. Soil compacted with appropriate number of blows (25 or 56)?	_____	_____
10. Material adhering to the inside of the mold trimmed?	_____	_____
11. Layer of soil (approximately two fifths compacted depth) placed in mold with collar attached, loose material lightly tamped?	_____	_____
12. Soil compacted with appropriate number of blows (25 or 56)?	_____	_____
13. Material adhering to the inside of the mold trimmed?	_____	_____
14. Layer of soil (approximately three fifths compacted depth) placed in mold with collar attached, loose material lightly tamped?	_____	_____
15. Soil compacted with appropriate number of blows (25 or 56)?	_____	_____
16. Material adhering to the inside of the mold trimmed?	_____	_____
17. Layer of soil (approximately four fifths compacted depth) placed in mold with collar attached, loose material lightly tamped?	_____	_____
18. Soil compacted with appropriate number of blows (25 or 56)?	_____	_____
19. Material adhering to the inside of the mold trimmed?	_____	_____

OVER

<b>Procedure Element</b>	<b>Trial 1</b>	<b>Trial 2</b>
20. Mold filled with soil such that compacted soil will be above the mold, loose material lightly tamped?	_____	_____
21. Soil compacted with appropriate number of blows (25 or 56)?	_____	_____
22. Collar removed without shearing off sample?	_____	_____
23. Approximately 6 mm (1/4 in.) of compacted material above the top of the mold (without the collar)?	_____	_____
24. Soil trimmed to top of mold with the beveled side of the straightedge?	_____	_____
25. Remove soil from exterior surface of mold and base plate?	_____	_____
26. Mass of mold and contents determined to appropriate precision?	_____	_____
27. Wet density calculated from the wet mass?	_____	_____
28. Soil removed from mold using a sample extruder if needed?	_____	_____
29. Soil sliced vertically through center (non-granular material)?	_____	_____
30. Moisture sample removed ensuring all layers are represented?	_____	_____
31. Moist mass determined immediately to 0.1 g?	_____	_____
32. Moisture sample mass of correct size?	_____	_____
33. Sample dried and water content determined according to the FOP for T 255/T 265?	_____	_____
34. One-point plotted on family of curves supplied?	_____	_____
a. One-point falls within 80 to 100 percent of optimum moisture content in order to be valid?	_____	_____
b. If one-point does not fall within 80 to 100 percent of optimum moisture content, another one-point determination with an adjusted water content is made?	_____	_____
c. Maximum dry density and corresponding optimum moisture content correctly estimated?	_____	_____
35. One-point plotted on a single reference curve?	_____	_____
a. Does one-point plot within 2 lb/ft <sup>3</sup> in order to be valid?	_____	_____
b. Does one-point fall within 80 to 100 percent of optimum moisture content in order to be valid?	_____	_____
c. Maximum dry density and corresponding optimum moisture content determined from single reference curve?	_____	_____

Comments:      First attempt:    Pass \_\_\_\_\_ Fail \_\_\_\_\_      Second attempt: Pass \_\_\_\_\_ Fail \_\_\_\_\_

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Examiner Signature \_\_\_\_\_ WAQTC #: \_\_\_\_\_

## **SPECIFIC GRAVITY AND ABSORPTION OF COARSE AGGREGATE FOP FOR AASHTO T 85**

### **Scope**

This procedure covers the determination of specific gravity and absorption of coarse aggregate in accordance with AASHTO T 85-22. Specific gravity may be expressed as bulk specific gravity ( $G_{sb}$ ), bulk specific gravity, saturated surface dry ( $G_{sb}$  SSD), or apparent specific gravity ( $G_{sa}$ ).  $G_{sb}$  and absorption are based on aggregate after soaking in water. This procedure is not intended to be used with lightweight aggregates.

### **Terminology**

Absorption – the increase in the mass of aggregate due to water being absorbed into the pores of the material, but not including water adhering to the outside surface of the particles, expressed as a percentage of the dry mass. The aggregate is considered “dry” when it has been maintained at a temperature of  $110 \pm 5^{\circ}\text{C}$  ( $230 \pm 9^{\circ}\text{F}$ ) for sufficient time to remove all uncombined water.

Saturated Surface Dry (SSD) – condition of an aggregate particle when the permeable voids are filled with water, but no water is present on exposed surfaces.

Specific Gravity – the ratio of the mass, in air, of a volume of a material to the mass of the same volume of gas-free distilled water at a stated temperature.

Apparent Specific Gravity ( $G_{sa}$ )– the ratio of the mass, in air, of a volume of the impermeable portion of aggregate to the mass of an equal volume of gas-free distilled water at a stated temperature.

Bulk Specific Gravity ( $G_{sb}$ )– the ratio of the mass, in air, of a volume of aggregate (including the permeable and impermeable voids in the particles, but not including the voids between particles) to the mass of an equal volume of gas-free distilled water at a stated temperature.

Bulk Specific Gravity (SSD) ( $G_{sb}$  SSD) – the ratio of the mass, in air, of a volume of aggregate, including the mass of water within the voids filled to the extent achieved by submerging in water for 15 to 19 hours (but not including the voids between particles), to the mass of an equal volume of gas-free distilled water at a stated temperature.

### **Apparatus**

- Balance or scale: with a capacity of 5 kg, sensitive to 0.1 g. Meeting the requirements of AASHTO M 231.
- Sample container: a wire basket of 3.35 mm (No. 6) or smaller mesh, with a capacity of 4 to 7 L (1 to 2 gal) to contain aggregate with a nominal maximum size of 37.5 mm (1 1/2 in.) or smaller; or a larger basket for larger aggregates, or both.
- Water tank: watertight and large enough to completely immerse aggregate and basket, equipped with an overflow valve to keep water level constant.

- Suspension apparatus: wire used to suspend apparatus shall be of the smallest practical diameter.
- Sieves: 4.75 mm (No. 4) or other sizes as needed, meeting the requirements of FOP for AASHTO T 27/T 11.
- Large absorbent cloth

**Sample Preparation**

1. Obtain the sample in accordance with the FOP for AASHTO R 90 (see Note 1).
2. Mix the sample thoroughly and reduce it to the approximate sample size required by Table 1 in accordance with the FOP for AASHTO R 76.
3. Reject all material passing the appropriate sieve by dry sieving.
4. Thoroughly wash sample to remove dust or other coatings from the surface.
5. Dry the sample to constant mass according to the FOP for AASHTO T 255/T 265 at a temperature of 110 ±5°C (230 ±9°F) and cool in air at room temperature for 1 to 3 hours.

*Note 1:* Where the absorption and specific gravity values are to be used in proportioning concrete mixtures in which the aggregates will be in their naturally moist condition, the requirement for initial drying to constant mass may be eliminated, and, if the surfaces of the particles in the sample have been kept continuously wet until test, the 15-to-19-hour soaking may also be eliminated.

6. Re-screen the sample over the appropriate sieve. Reject all material passing that sieve.
7. The sample shall meet or exceed the minimum mass given in Table 1.

*Note 2:* If this procedure is used only to determine the  $G_{sb}$  of oversized material for the FOP for AASHTO T 99 / T 180, the material can be rejected over the appropriate sieve. For T 99 / T 180 Methods A and B, use the 4.75 mm (No. 4) sieve; T 99 / T 180 Methods C and D use the 19 mm (3/4 in).

**Table 1**

Nominal Maximum Size* mm (in.)	Minimum Mass of Sample, g (lb)
12.5 (1/2) or less	2000 (4.4)
19.0 (3/4)	3000 (6.6)
25.0 (1)	4000 (8.8)
37.5 (1 1/2)	5000 (11)
50 (2)	8000 (18)
63 (2 1/2)	12,000 (26)
75 (3)	18,000 (40)

\* One sieve larger than the first sieve to retain more than 10 percent of the material using an agency specified set of sieves based on cumulative percent retained. Where large gaps in specification sieves exist, intermediate sieve(s) may be inserted to determine nominal maximum size.

## Procedure

1. Immerse the sample in water at room temperature for a period of 15 to 19 hours.

*Note 3:* When testing coarse aggregate of large nominal maximum size requiring large samples, it may be more convenient to perform the test on two or more subsamples, and then combine the values obtained.

2. Place the empty basket into the water bath and attach to the balance. Inspect the immersion tank to ensure the water level is at the overflow outlet height and basket is fully submerged. Tare the balance with the empty basket attached in the water bath.
3. Remove the sample from the water and roll it in a large absorbent cloth until all visible films of water are removed. Wipe the larger particles individually. If the sample dries past the SSD condition, immerse in water for 30 min, and then resume the process of surface-drying.

*Note 4:* A moving stream of air may be used to assist in the drying operation but take care to avoid evaporation of water from aggregate pores.

4. Determine the SSD mass of the sample, and record this and all subsequent masses to the nearest 0.1 g or 0.1 percent of the sample mass, whichever is greater. Designate this mass as "B."
5. Immediately place the SSD sample in the sample container and weigh it in water maintained at  $23.0 \pm 1.7^{\circ}\text{C}$  ( $73.4 \pm 3^{\circ}\text{F}$ ). Shake the container to release entrapped air before recording the weight. Re-inspect the immersion tank to ensure the water level is at the overflow outlet height and basket is fully submerged. Designate this submerged weight as "C."

*Note 5:* The container should be immersed to a depth sufficient to cover it and the sample during mass determination. Wire suspending the container should be of the smallest practical size to minimize any possible effects of a variable immersed length.

6. Remove the sample from the basket. Ensure all material has been removed. Place in a container of known mass.
7. Dry the sample to constant mass according to the FOP for AASHTO T 255 / T 265 at  $110 \pm 5^{\circ}\text{C}$  ( $230 \pm 9^{\circ}\text{F}$ ) and cool in air at room temperature for 1 to 3 hours.
8. Determine and record the dry mass. Designate this mass as "A."

### Calculations

Perform calculations and determine values using the appropriate formula below.

Bulk specific gravity ( $G_{sb}$ )

$$G_{sb} = \frac{A}{B - C}$$

Bulk specific gravity, SSD ( $G_{sb}$  SSD)

$$G_{sb}SSD = \frac{B}{B - C}$$

Apparent specific gravity ( $G_{sa}$ )

$$G_{sa} = \frac{A}{A - C}$$

Absorption

$$\text{Absorption} = \frac{B - A}{A} \times 100$$

Where:

- A = oven dry mass, g
- B = SSD mass, g
- C = weight in water, g

**Sample Calculations**

Sample	A	B	C	B - C	A - C	B - A
1	2030.9	2044.9	1304.3	740.6	726.6	14.0
2	1820.0	1832.5	1168.1	664.4	651.9	12.5
3	2035.2	2049.4	1303.9	745.5	731.3	14.2

Sample	G <sub>sb</sub>	G <sub>sb</sub> SSD	G <sub>sa</sub>	Absorption
1	2.742	2.761	2.795	0.7
2	2.739	2.758	2.792	0.7
3	2.730	2.749	2.783	0.7

These calculations demonstrate the relationship between G<sub>sb</sub>, G<sub>sb</sub> SSD, and G<sub>sa</sub>. G<sub>sb</sub> is always lowest since the volume includes voids permeable to water. G<sub>sb</sub> SSD is always intermediate. G<sub>sa</sub> is always highest since the volume does not include voids permeable to water. When running this test, check to make sure the values calculated make sense in relation to one another.

**Report**

- On forms approved by the agency
- Sample ID
- Specific gravity values to the nearest 0.001
- Absorption to the nearest 0.1 percent





## **IN-PLACE DENSITY AND MOISTURE CONTENT OF SOIL AND SOIL-AGGREGATE BY NUCLEAR METHODS (SHALLOW DEPTH) FOP FOR AASHTO T 310**

### **Scope**

This procedure covers the determination of density, moisture content, and relative compaction of soil, aggregate, and soil-aggregate mixes in accordance with AASHTO T 310-22. This procedure provides a rapid, nondestructive technique for determining the in-place wet density and moisture content of soil, aggregate, and soil-aggregate mixes. This field operating procedure is derived from AASHTO T 310. The nuclear moisture-density gauge is used in the direct transmission mode.

### **Apparatus**

- Nuclear density gauge with the factory matched standard reference block.
- Drive pin, guide/scrapper plate, and hammer for testing in direct transmission mode.
- Transport case for properly shipping and housing the gauge and tools.
- Instruction manual for the specific make and model of gauge.
- Radioactive materials information and calibration packet containing:
  - Daily Standard Count Log.
  - Factory and Laboratory Calibration Data Sheet.
  - Leak Test Certificate.
  - Shippers Declaration for Dangerous Goods.
  - Procedure Memo for Storing, Transporting and Handling Nuclear Testing Equipment.
  - Other radioactive materials documentation as required by local regulatory requirements.
- Sealable containers and utensils for moisture content determinations.

### **Radiation Safety**

This method does not purport to address all of the safety problems associated with its use. This test method involves potentially hazardous materials. The gauge utilizes radioactive materials that may be hazardous to the health of the user unless proper precautions are taken. Users of this gauge must become familiar with the applicable safety procedures and governmental regulations. All operators will be trained in radiation safety prior to operating nuclear density gauges. Some agencies require the use of personal monitoring devices such as a thermoluminescent dosimeter or film badge. Effective instructions together with routine safety procedures such as source leak tests, recording and evaluation of personal monitoring device data, etc., are a recommended part of the operation and storage of this gauge.

## Calibration

Calibrate the nuclear gauge as required by the agency. This calibration may be performed by the agency using manufacturer's recommended procedures or by other facilities approved by the agency. Verify or re-establish calibration curves, tables, or equivalent coefficients every 12 months.

## Standardization

1. Turn the gauge on and allow it to stabilize (approximately 10 to 20 minutes) prior to standardization. Leave the power on during the day's testing.
2. Standardize the nuclear gauge at the construction site at the start of each day's work and as often as deemed necessary by the operator or agency. Daily variations in standard count shall not exceed the daily variations established by the manufacturer of the gauge. If the daily variations are exceeded after repeating the standardization procedure, the gauge should be repaired and/or recalibrated.
3. Record the standard count for both density and moisture in the Daily Standard Count Log. The exact procedure for standard count is listed in the manufacturer's Operator's Manual.

*Note 1:* New standard counts may be necessary more than once a day. See agency requirements.

## Overview

There are two methods for determining in-place density of soil / soil aggregate mixtures. See agency requirements for method selection.

- Method A Single Direction
- Method B Two Direction

## Procedure

1. Select a test location(s) randomly and in accordance with agency requirements. Test sites should be relatively smooth and flat and meet the following conditions:
  - a. At least 10 m (30 ft) away from other sources of radioactivity
  - b. At least 3 m (10 ft) away from large objects
  - c. The test site should be at least 150 mm (6 in.) away from any vertical projection.
  - d. Correct for trench wall effect according to manufacturer's correction procedures if the test site is closer than 600 mm (24 in.) to vertical projection. See Note 2.

*Note 2:* To perform moisture and density tests in a trench or against a large solid object, it is necessary to perform a trench offset correction to adjust the gauge, or it may read a falsely high moisture content. Moisture present in the walls can thermalize neutrons which return to the gauge and are read as moisture by the detector in the gauge.

2. Remove all loose and disturbed material and remove additional material as necessary to expose the top of the material to be tested.
3. Prepare a flat area sufficient in size to accommodate the gauge. Plane the area to a smooth condition so as to obtain maximum contact between the gauge and the

material being tested. For Method B, the flat area must be sufficient to permit rotating the gauge 90 or 180 degrees about the source rod.

4. Fill in surface voids beneath the gauge with fines of the material being tested passing the 4.75 mm (No. 4) sieve or finer. Smooth the surface with the guide plate or other suitable tool. The depth of the filler should not exceed approximately 3 mm (1/8 in.).
5. Make a hole perpendicular to the prepared surface using the guide plate and drive pin. The hole shall be at least 50 mm (2 in.) deeper than the desired source rod depth and shall be aligned such that insertion of the source rod will not cause the gauge to tilt from the plane of the prepared area. Remove the drive pin by pulling straight up and twisting the extraction tool.
6. Place the gauge on the prepared surface so the source rod can enter the hole without disturbing loose material.
7. Lower the source rod into the hole to the desired test depth using the handle and trigger mechanism.
8. Seat the gauge firmly by partially rotating it back and forth about the source rod. Ensure the gauge is seated flush against the surface by pressing down on the gauge corners and making sure that the gauge does not rock.
9. Pull gently on the gauge to bring the side of the source rod nearest to the scaler / detector firmly against the side of the hole.
10. Perform one of the following methods, per agency requirements:
  - a. Method A Single Direction: Take a test consisting of the average of two, one-minute readings, and record both density and moisture data. The two wet density readings should be within  $32 \text{ kg/m}^3$  ( $2.0 \text{ lb/ft}^3$ ) of each other. The average of the two wet densities and moisture contents will be used to compute dry density.
  - b. Method B Two Direction: Take a one-minute reading and record both density and moisture data. Rotate the gauge 90 or 180 degrees, pivoting it around the source rod. Reseat the gauge by pulling gently on the gauge to bring the side of the source rod nearest to the scaler/detector firmly against the side of the hole and take a one-minute reading. (In trench locations, rotate the gauge 180 degrees for the second test.) Some agencies require multiple one-minute readings in both directions. Analyze the density and moisture data. A valid test consists of wet density readings in both gauge positions that are within  $50 \text{ kg/m}^3$  ( $3.0 \text{ lb/ft}^3$ ). If the tests do not agree within this limit, move to a new location. The average of the wet density and moisture contents will be used to compute dry density.
11. If required by the agency, obtain a representative sample of the material, 4 kg (9 lb) minimum, from directly beneath the gauge full depth of material tested. This sample will be used to verify moisture content and / or identify the correct density standard. Immediately seal the material to prevent loss of moisture.

The material tested by direct transmission can be approximated by a cylinder of soil approximately 300 mm (12 in.) in diameter directly beneath the centerline of the

radioactive source and detector. The height of the cylinder will be approximately the depth of measurement. When organic material or large aggregate is removed during this operation, disregard the test information, and move to a new test site.

12. To verify the moisture content from the nuclear gauge, determine the moisture content with a representative portion of the material using the FOP for AASHTO T 255/T 265 or other agency approved methods. If the moisture content from the nuclear gauge is within  $\pm 1$  percent, the nuclear gauge readings can be accepted. Moisture content verification is gauge and material specific. Retain the remainder of the sample at its original moisture content for a one-point compaction test under the FOP for AASHTO T 272, or for gradation, if required.

*Note 2:* Example: A gauge reading of 16.8 percent moisture and an oven dry of 17.7 percent are within the  $\pm 1$  percent requirement. Moisture correlation curves will be developed according to agency guidelines. These curves should be reviewed and possibly redeveloped every 90 days.

13. Determine the dry density by one of the following.
  - a. From nuclear gauge readings, compute by subtracting the mass (weight) of the water ( $\text{kg/m}^3$  or  $\text{lb/ft}^3$ ) from the wet density ( $\text{kg/m}^3$  or  $\text{lb/ft}^3$ ) or compute using the percent moisture by dividing wet density from the nuclear gauge by 1 plus the moisture content expressed as a decimal.
  - b. When verification is required and the nuclear gauge readings cannot be accepted, the moisture content is determined by the FOP for AASHTO T 255/T 265 or other agency approved methods. Compute dry density by dividing wet density from the nuclear gauge by 1 plus the moisture content expressed as a decimal.

## Percent Compaction

- Percent compaction is determined by comparing the in-place dry density as determined by this procedure to the appropriate agency density standard. For soil or soil-aggregate mixes, these are moisture-density curves developed using the FOP for AASHTO T 99/T 180. When using maximum dry densities from the FOP for AASHTO T 99/T 180 or FOP for AASHTO T 272, it may be necessary to use the Annex in the FOP for T 99/T 180 to determine corrected maximum dry density and optimum moisture content.

For coarse granular materials, the density standard may be density-gradation curves developed using a vibratory method such as AKDOT&PF's ATM 212, ITD's T 74, WAQTC TM 15, or WFLHD's Humphres.

See appropriate agency policies for use of density standards.

## Calculation

Calculate the dry density as follows:

$$\rho_d = \left( \frac{\rho_w}{w + 100} \right) \times 100 \quad \text{or} \quad \rho_d = \frac{\rho_w}{\frac{w}{100} + 1}$$

Where:

$\rho_d$  = Dry density, kg/m<sup>3</sup> (lb/ft<sup>3</sup>)

$\rho_w$  = Wet density, kg/m<sup>3</sup> (lb/ft<sup>3</sup>)

w = Moisture content from the FOP's for AASHTO T 255 / T 265, as a percentage

Calculate percent compaction as follows:

$$\% \text{ Compaction} = \frac{\rho_d}{\text{Agency density standard}} \times 100$$

Where:

$\rho_d$  = Dry density, kg/m<sup>3</sup> (lb/ft<sup>3</sup>)

Agency density standard = Corrected maximum dry density  
from the FOP from T 99/T 180 Annex

## Example:

Wet density readings from gauge: 1948 kg/m<sup>3</sup> (121.6 lb/ft<sup>3</sup>)

1977 kg/m<sup>3</sup> (123.4 lb/ft<sup>3</sup>)

Avg: 1963 kg/m<sup>3</sup> (122.5 lb/ft<sup>3</sup>)

**Moisture readings from gauge: 14.2% and 15.4% = Avg 14.8%**

Moisture content from the FOP's for AASHTO T 255/ T 265: 15.9%

*Moisture content is greater than 1 percent different so the gauge moisture cannot be used.*

**Calculate the dry density as follows:**

$$\rho_d = \left( \frac{1963 \text{ kg/m}^3 \text{ or } 122.5 \text{ lb/ft}^3}{15.9 + 100} \right) \times 100 \text{ or } \rho_d = \frac{1963 \text{ kg/m}^3 \text{ or } 122.5 \text{ lb/ft}^3}{\frac{15.9}{100} + 1}$$
$$= 1694 \text{ kg/m}^3 \text{ or } 105.7 \text{ lb/ft}^3$$

Given:

$$\rho_w = 1963 \text{ kg/m}^3 \text{ or } 122.5 \text{ lb/ft}^3$$

$$w = 15.9\%$$

**Calculate percent compaction as follows:**

$$\% \text{ Compaction} = \frac{105.7 \text{ lb/ft}^3}{111.3 \text{ lb/ft}^3} \times 100 = 95\%$$

Given:

$$\text{Agency density standard} = 111.3 \text{ lb/ft}^3$$

## Report

- On forms approved by the agency
- Sample ID
- Location of test, elevation of surface, and thickness of layer tested
- Visual description of material tested
- Make, model and serial number of the nuclear moisture-density gauge
- Wet density to the nearest 0.1 lb/ft<sup>3</sup>
- Moisture content as a percent, by mass, of dry soil mass to the nearest 0.1 percent
- Dry density to the nearest 0.1 lb/ft<sup>3</sup>
- Density standard to the nearest 0.1 lb/ft<sup>3</sup>
- Percent compaction the nearest 1 percent
- Name and signature of operator

**PERFORMANCE EXAM CHECKLIST**

**IN-PLACE DENSITY AND MOISTURE CONTENT OF SOIL AND SOIL-AGGREGATE BY NUCLEAR METHODS (SHALLOW DEPTH)  
FOP FOR AASHTO T 310**

Participant Name \_\_\_\_\_ Exam Date \_\_\_\_\_

Record the symbols “P” for passing or “F” for failing on each step of the checklist.

<b>Procedure Element</b>	<b>Trial 1</b>	<b>Trial 2</b>
1. Gauge turned on 10 to 20 minutes before use?	_____	_____
2. Calibration verified?	_____	_____
3. Standard count taken and recorded in accordance with manufacturer’s instructions?	_____	_____
4. Test location selected appropriately 10 m (30 ft.) from other radioactive sources, 3 m (10 ft.) from large objects, 150 mm (6 in.) away from vertical projections?	_____	_____
5. Loose, disturbed material removed?	_____	_____
6. Flat, smooth area prepared?	_____	_____
7. Surface voids filled with native fines (-No. 4) to 3 mm (1/8 in.) maximum thickness?	_____	_____
8. Hole driven 50 mm (2 in.) deeper than source rod depth?	_____	_____
9. Gauge placed and source rod lowered without disturbing loose material?	_____	_____
10. Method A:		
a. Gauge firmly seated, and gently pulled back so that the source rod is against the side of the hole toward the scaler / detectors?	_____	_____
b. Two, one-minute reading taken; wet density within 32 kg/m <sup>3</sup> (2.0 lb/ft <sup>3</sup> )?	_____	_____
c. Density and moisture data averaged?	_____	_____
11. Method B:		
a. Gauge firmly seated, and gently pulled back so that the source rod is against the side of the hole toward the scaler / detectors?	_____	_____
b. A minimum of a one-minute reading taken; density and moisture data recorded?	_____	_____
c. Gauge turned 90° or 180° (180° in trench)?	_____	_____

**OVER**

Procedure Element	Trial 1	Trial 2
d. Gauge firmly seated, and gently pulled back so that the source rod is against the side of the hole toward the scaler / detectors?	_____	_____
e. A minimum of a one-minute reading taken; density and moisture data recorded?	_____	_____
f. Wet densities within 50 kg/m <sup>3</sup> (3.0 lb/ft <sup>3</sup> )?	_____	_____
g. Density and moisture data averaged?	_____	_____
12. Representative sample (4 kg or 9 lb) obtained from test location?	_____	_____
13. Sample sealed immediately to prevent moisture loss?	_____	_____
14. Moisture content correctly determined using other means than the nuclear density gauge reading?	_____	_____
15. Dry Density calculated using proper moisture content?	_____	_____
16. Percent compaction calculated correctly?	_____	_____

Comments: First attempt: Pass \_\_\_\_\_ Fail \_\_\_\_\_ Second attempt: Pass \_\_\_\_\_ Fail \_\_\_\_\_

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Examiner Signature \_\_\_\_\_ WAQTC #: \_\_\_\_\_



## **THEORETICAL MAXIMUM SPECIFIC GRAVITY ( $G_{mm}$ ) AND DENSITY OF ASPHALT MIXTURES FOP FOR AASHTO T 209**

### **Scope**

This procedure covers the determination of the maximum specific gravity ( $G_{mm}$ ) of uncompacted asphalt mixtures in accordance with AASHTO T 209-23. Two methods using different containers – bowl and pycnometer / volumetric flask– are covered.

Specimens prepared in the laboratory shall be cured according to agency standards.

### **Apparatus**

- Balance or scale: 10,000 g capacity, readable to 0.1 g, meeting AASHTO M 231, Class G2
- Container: A glass, metal, or plastic bowl, pycnometer or volumetric flask between 2000 and 10,000 mL as required by the minimum sample size requirements in Table 1 sample and capable of withstanding full vacuum applied
- Pycnometer / volumetric flask cover: A glass plate or a metal or plastic cover with a vented opening
- Vacuum lid: A transparent lid with a suitable vacuum connection, with a vacuum opening to be covered with a fine wire mesh
- Vacuum pump or water aspirator: Capable of evacuating air from the container to a residual pressure of 3.4 kPa (25 mm Hg)
- Vacuum measurement device: Residual pressure manometer or vacuum gauge, capable of measuring residual pressure down to 3.4 kPa (25 mmHg) or less and readable to at least 0.2 kPa (2 mmHg)
- Suspension apparatus: Suitable apparatus and holder to permit determining the mass of the sample while suspended below the balance. The wire suspending the holder shall be the smallest practical size to minimize any possible effects of a variable immersed length for Bowl Method.
- Water bath: A constant-temperature water bath (optional for Pycnometer or Volumetric Flask Method)
- Thermometers: Thermometric devices accurate to 0.25°C (0.5°F) and with a temperature range of at least 20 to 45°C (68 to 113°F).
- Bleeder valve to adjust vacuum
- Automatic vacuum control unit (optional)
- Timer
- Towel

**Standardization**

Use a container that has been standardized according to the Annex. The container shall be standardized periodically in conformance with procedures established by the agency.

**Test Sample Preparation**

1. Obtain samples in accordance with the FOP for AASHTO R 97 and reduce according to the FOP for AASHTO R 47.
2. Test sample size shall conform to the requirements of Table 1. Samples larger than the capacity of the container may be tested in two or more increments. Results will be combined by calculating the weighted average ( $G_{mm(avg)}$ ). If the increments have a specific gravity difference greater than 0.013, the test must be re-run.
3. Plant-produced samples may be short-term conditioned according to AASHTO R 30 as specified by the agency.

*Note 1:* Short-term conditioning at the specified temperature is especially important when absorptive aggregates are used. This short-term conditioning will ensure the computation of realistic values for the amount of asphalt absorbed by the aggregate and void properties of the mix. Plant-produced asphalt mixtures should be evaluated to make sure short-term conditioning has taken place during production and delivery.

**Table 1  
Test Sample Size for  $G_{mm}$**

<b>Nominal Maximum* Aggregate Size mm (in.)</b>	<b>Minimum Mass g</b>
37.5 or greater (1½)	4000
19 to 25 (¾ to 1)	2500
12.5 or smaller (½)	1500

\*Nominal maximum size: One sieve larger than the first sieve to retain more than 10 percent of the material using an agency specified set of sieves based on cumulative percent retained.

**Procedure – General**

Two procedures – bowl and pycnometer / volumetric flask – are covered. The first 11 steps are the same for both.

1. Separate the particles of the sample, taking care not to fracture the mineral particles, so that the particles of the fine aggregate portion are not larger than 6.3 mm (¼ in.). If the mixture is not sufficiently soft to be separated manually, place it in a large flat pan and warm in an oven only until it is pliable enough for separation.
2. Cool the sample to room temperature.
3. Determine and record the mass of the dry container to the nearest 0.1 g.
4. Place the sample in the container.
5. Determine and record the mass of the dry container and sample to the nearest 0.1 g.

6. Determine and record the mass of the sample by subtracting the mass determined in Step 3 from the mass determined in Step 5. Designate this mass as “A.”
  7. Add sufficient water at approximately 25° C (77° F) to cover the sample by about 25 mm (1 in.).
- Note 1:* The release of entrapped air may be facilitated by the addition of a wetting agent. Check with the agency to see if this is permitted and, if it is, for a recommended agent.
8. Place the lid on the container and attach the vacuum line. To ensure a proper seal between the container and the lid, wet the O-ring or use a petroleum gel.
  9. Remove entrapped air by subjecting the sample to a partial vacuum of  $4.0 \pm 0.6$  kPa ( $30 \pm 5$  mmHg) residual pressure for  $15 \pm 1$  minutes.
  10. Agitate the container and sample, either continuously by mechanical device or manually by vigorous shaking at 2-minute intervals. This agitation facilitates the removal of air.
  11. Release the vacuum. Increase the pressure to atmospheric pressure in 10 to 15 seconds if the vacuum release is not automated. Turn off the vacuum pump and remove the lid. When performing the pycnometer / volumetric flask method, complete steps 12B through 16B within  $10 \pm 1$  minute.

#### **Procedure – Bowl**

- 12A. Fill the water bath to overflow level with water at  $25 \pm 1^\circ\text{C}$  ( $77 \pm 2^\circ\text{F}$ ) and allow the water to stabilize.
- 13A. Zero or tare the balance with the immersion apparatus attached, ensuring that the device is not touching the sides or the bottom of the water bath. Immerse the suspension apparatus sufficiently to cover both it and the bowl.
- 14A. Suspend and immerse the bowl and sample in water at  $25 \pm 1^\circ\text{C}$  ( $77 \pm 2^\circ\text{F}$ ) for  $10 \pm 1$  minute.
- 15A. Determine and record the submerged weight of the bowl and sample to the nearest 0.1 g. Designate as “C.”

#### **Procedure – Pycnometer or Volumetric Flask**

- 12B. Immediately fill the pycnometer / volumetric flask with water without reintroducing air.
- 13B. Stabilize the temperature of the pycnometer / volumetric flask and sample so that the final temperature is within  $25 \pm 1^\circ\text{C}$  ( $77 \pm 2^\circ\text{F}$ ).
- 14B. Finish filling the pycnometer / volumetric flask with water that is  $25 \pm 1^\circ\text{C}$  ( $77 \pm 2^\circ\text{F}$ ), place the cover or a glass plate on the pycnometer / volumetric flask, and eliminate all air.

*Note 2:* When using a metal pycnometer and cover, place the cover on the pycnometer and push down slowly, forcing excess water out of the hole in the center of the cover. Use care when filling the pycnometer to avoid reintroducing air into the water.

- 15B. Towel dry the outside of the pycnometer / volumetric flask and cover.

16B. Determine and record the mass of the pycnometer / volumetric flask, cover, de-aired water, and sample to the nearest 0.1 g. within 10 ±1 minute of completion of Step 11. Designate this mass as “E.”

**Procedure – Mixtures Containing Uncoated Porous Aggregate**

If the pores of the aggregates are not thoroughly sealed by an asphalt binder film, they may become saturated with water during the vacuuming procedure, resulting in an error in  $G_{mm}$  and theoretical maximum density. To determine if this has occurred, complete the general procedure and then:

1. Carefully drain water from sample through a towel held over the top of the container to prevent loss of material.
2. Spread sample in a flat shallow pan and place before an electric fan to remove surface moisture.
3. Determine the mass of the sample when the surface moisture appears to be gone.
4. Continue drying and determine the mass of the sample at 15-minute intervals until less than a 0.5 g loss is found between determinations.
5. Record the mass as the saturated surface dry mass to the nearest 0.1 g. Designate this mass as “ $A_{SSD}$ .”
6. Calculate, as indicated below,  $G_{mm}$  using “A” and “ $A_{SSD}$ ,” and compare the two values.

**Calculation**

Calculate the  $G_{mm}$  to three decimal places as follows:

**Bowl Procedure**

$$G_{mm} = \frac{A}{A + B - C} \quad \text{or} \quad G_{mm} = \frac{A}{A_{SSD} + B - C}$$

(for mixes containing uncoated aggregate materials)

Where:

- A = mass of dry sample in air, g
- $A_{SSD}$  = mass of saturated surface dry sample in air, g
- B = standardized submerged weight of the bowl, g (see Annex)
- C = submerged weight of sample and bowl, g

**Example:**

$$G_{mm} = \frac{1432.7 \text{ g}}{1432.7 \text{ g} + 286.3 \text{ g} - 1134.9 \text{ g}} = 2.453 \quad \text{or}$$

$$G_{mm} = \frac{1432.7 \text{ g}}{1434.2 \text{ g} + 286.3 \text{ g} - 1134.9 \text{ g}} = 2.447$$

Given:

A = 1432.7 g

A<sub>SSD</sub> = 1434.2 g

B = 286.3 g

C = 1134.9 g

**Pycnometer / Volumetric Flask Procedure**

$$G_{mm} = \frac{A}{A + D - E} \quad \text{or} \quad G_{mm} = \frac{A}{A_{SSD} + D - E}$$

(for mixtures containing uncoated materials)

Where:

A = mass of dry sample in air, g

A<sub>SSD</sub> = mass of saturated surface-dry sample in air, g

D = standardized mass of pycnometer / volumetric flask filled with water at 25°C (77°F), g, (See Annex)

E = mass of pycnometer / volumetric flask filled with water and the test sample at test temperature, g

**Example (two increments of a large sample):**

$$G_{mm_1} = \frac{2200.3 \text{ g}}{2200.3 \text{ g} + 7502.5 \text{ g} - 8812.0 \text{ g}} = 2.470$$

$$G_{mm_2} = \frac{1960.2 \text{ g}}{1960.2 \text{ g} + 7525.5 \text{ g} - 8690.8 \text{ g}} = 2.466$$

Given:

Increment 1	Increment 2
A <sub>1</sub> = 2200.3 g	A <sub>2</sub> = 1960.2 g
D <sub>1</sub> = 7502.5 g	D <sub>2</sub> = 7525.5 g
E <sub>1</sub> = 8812.0 g	E <sub>2</sub> = 8690.8 g

$$\text{Variation} = 2.470 - 2.466 = 0.004, \text{ which is } < 0.013$$

Allowable variation is: 0.013. The values may be used.

**Weighted average**

For large samples tested a portion at a time, calculate the  $G_{mm(avg)}$  by multiplying the dry mass of each increment by its  $G_{mm}$ , add the results together ( $\Sigma$ ) and divide by the sum ( $\Sigma$ ) of the dry masses.

$$G_{mm(avg)} = \frac{\Sigma(A_x \times G_{mm_x})}{\Sigma A_x}$$

or

$$G_{mm(avg)} = \frac{(A_1 \times G_{mm_1}) + (A_2 \times G_{mm_2})}{A_1 + A_2} \text{ etc.}$$

Where:

- A<sub>x</sub> = mass of dry sample increment in air, g
- G<sub>mmx</sub> = theoretical maximum specific gravity of the increment

**Example:**

$$G_{mm(avg)} = \frac{(2200.3 \text{ g} \times 2.470) + (1960.2 \text{ g} \times 2.466)}{2200.3 \text{ g} + 1960.2 \text{ g}} = \frac{10,268.6}{4160.5 \text{ g}} = 2.468$$

**Theoretical Maximum Density**

To calculate the theoretical maximum density at 25°C (77°F) use one of the following formulas. The density of water at 25°C (77°F) is 997.1 kg/ m<sup>3</sup> in Metric units or 62.245 lb/ft<sup>3</sup> in English units.

$$\text{Theoretical maximum density kg/m}^3 = G_{mm} \times 997.1 \text{ kg/ m}^3$$

$$2.468 \times 997.1 \text{ kg/ m}^3 = 2461 \text{ kg/ m}^3$$

or

$$\text{Theoretical maximum density lb/ft}^3 = G_{mm} \times 62.245 \text{ lb/ft}^3$$

$$2.468 \times 62.245 \text{ lb/ft}^3 = 153.6 \text{ lb/ft}^3$$

**Report**

- On forms approved by the agency
- Sample ID
- $G_{mm}$  to the nearest 0.001
- Theoretical maximum density to the nearest 1 kg/m<sup>3</sup> (0.1 lb/ft<sup>3</sup>)





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**ANNEX – STANDARDIZATION OF BOWL AND PYCNOMETER OR VOLUMETRIC FLASK**

(Mandatory Information)

**Bowl – Standardization**

1. Fill the water bath to overflow level with  $25 \pm 1^{\circ}\text{C}$  ( $77 \pm 2^{\circ}\text{F}$ ) water and allow the water to stabilize.
2. Zero or tare the balance with the immersion apparatus attached, ensuring that the device is not touching the sides or the bottom of the water bath. Immerse the suspension apparatus sufficiently to cover both it and the bowl.
3. Suspend and completely immerse the bowl for  $10 \pm 1$  minute.
4. Determine and record the submerged weight of the bowl to the nearest 0.1 g.
5. Refill the water bath to overflow level.
6. Perform Steps 2 through 5 two more times for a total of three determinations.
7. If the range of the three determinations is less than or equal to 0.3 g., average the determinations. Designate as “B.”
8. If the range of the three determinations is greater than 0.3 g., take corrective action and perform the standardization procedure again.

**Bowl – Check**

1. Fill the water bath to overflow level  $25 \pm 1^{\circ}\text{C}$  ( $77 \pm 2^{\circ}\text{F}$ ) water and allow the water to stabilize.
2. Zero or tare the balance with the immersion apparatus attached, ensuring that the device is not touching the sides or the bottom of the water bath. Immerse the suspension apparatus sufficiently to cover both it and the bowl.
3. Suspend and completely immerse the bowl for  $10 \pm 1$  minute.
4. Determine and record the submerged weight of the bowl to the nearest 0.1 g.
5. If this determination is within 0.3 g of the standardized value, use the standardized value for “B.”
6. If it is not within 0.3 g, take corrective action and perform the standardization procedure again.
7. For labs that check the bowl standardization frequently (such as daily), calculate the moving average and range of the last three mass determinations. Designate the average of the last three masses as “B.”
8. If the moving range exceeds 0.3 g at any time, take corrective action and perform the standardization procedure again.

**Pycnometer or Volumetric Flask – Standardization**

1. Fill the pycnometer / volumetric flask with water at approximately 25°C (77°F).
2. Place the metal or plastic cover, or a glass plate on the pycnometer / volumetric flask and eliminate all air. (See Note 2.)
3. Stabilize the pycnometer / volumetric flask at  $25 \pm 1^\circ\text{C}$  ( $77 \pm 2^\circ\text{F}$ ) for  $10 \pm 1$  min.
4. Towel dry the outside of the pycnometer / volumetric flask and cover.
5. Determine and record the mass of the pycnometer / volumetric flask, water, and cover or plate to the nearest 0.1 g.
6. Perform Steps 2 through 5 two more times for a total of three determinations.
7. If the range of the three determinations is less than or equal to 0.3 g, average the three determinations. Designate as “D.”
8. If the range of the determinations is greater than 0.3 g., take corrective action and perform the “Pycnometer or Volumetric Flask – Standardization” again.

**Pycnometer or Volumetric Flask – Check**

1. Fill the pycnometer / volumetric flask with water at approximately 25°C (77°F).
2. Place the metal or plastic cover or a glass plate on the pycnometer / volumetric flask and eliminate all air. (See Note 2.)
3. Stabilize the pycnometer / volumetric flask at  $25 \pm 1^\circ\text{C}$  ( $77 \pm 2^\circ\text{F}$ ) for  $10 \pm 1$  min.
4. Towel dry the outside of the pycnometer / volumetric flask and cover.
5. Determine and record the mass of the pycnometer / volumetric flask, water, and cover or plate.
6. If this determination is within 0.3 g of the standardized value, use the standardized value for “D.”
7. If it is not within 0.3 g, perform the standardization procedure again.

## **BULK SPECIFIC GRAVITY ( $G_{mb}$ ) OF COMPACTED ASPHALT MIXTURES USING SATURATED SURFACE-DRY SPECIMENS FOP FOR AASHTO T 166**

### **Scope**

This procedure covers the determination of bulk specific gravity ( $G_{mb}$ ) of compacted asphalt mixtures using three methods – A, B, and C – in accordance with AASHTO T 166-22. This FOP is for use on specimens not having open or interconnecting voids or absorbing more than 2.00 percent water by volume, or both. When specimens have open or interconnecting voids or absorbing more than 2.00 percent water by volume, or both, AASHTO T 275 or AASHTO T 331 should be performed.

### **Overview**

- Method A: Suspension
- Method B: Volumeter
- Method C: Rapid test for A or B

### **Test Specimens**

Test specimens may be either laboratory-molded or sampled from asphalt mixture pavement. For specimens it is recommended that the diameter be equal to four times the maximum size of the aggregate and the thickness be at least one- and one-half times the maximum size.

### **Terminology**

*Constant Mass:* The state at which a mass does not change more than a given percent, after additional drying for a defined time interval, at a required temperature.

### **Apparatus – Method A (Suspension)**

- Balance or scale: 5 kg capacity, readable to 0.1 g, and fitted with a suitable suspension apparatus and holder to permit weighing the specimen while suspended in water, conforming to AASHTO M 231.
- Suspension apparatus: Wire of the smallest practical size and constructed to permit the container to be fully immersed.
- Water bath: For immersing the specimen in water while suspended under the balance or scale and equipped with an overflow outlet for maintaining a constant water level.
- Towel: Damp cloth towel used for surface drying specimens.
- Oven: Capable of maintaining a temperature of  $52 \pm 3^{\circ}\text{C}$  ( $126 \pm 5^{\circ}\text{F}$ ) for drying the specimens to a constant mass.

- Pan: Pan or other suitable container of known mass, large enough to hold a sample for drying in oven.
- Thermometer: Having a range of 15 to 45°C (59 to 113°F) and, graduated in 0.1°C (0.2°F) subdivisions.
- Vacuum device: refer to the FOP for AASHTO R 79 (optional)

### Procedure – Method A (Suspension)

Recently molded laboratory samples that have not been exposed to moisture do not need drying.

1. Dry the specimen to constant mass, if required.
  - a. Oven method
    - i. Initially dry overnight at  $52 \pm 3^{\circ}\text{C}$  ( $125 \pm 5^{\circ}\text{F}$ ).
    - ii. Determine and record the mass of the specimen. Designate this mass as  $M_p$ .
    - iii. Return the specimen to the oven for at least 2 hours.
    - iv. Determine and record the mass of the specimen. Designate this mass as  $M_n$ .
    - v. Determine percent change by subtracting the new mass determination,  $M_n$ , from the previous mass determination,  $M_p$ , dividing by the previous mass determination  $M_p$ , and multiplying by 100.
    - vi. Continue drying until there is no more than 0.05 percent change in specimen mass after 2-hour drying intervals (constant mass).
    - vii. Constant mass has been achieved; sample is defined as dry.
  - b. Vacuum dry method according to the FOP for AASHTO R 79.
2. Cool the specimen in air to  $25 \pm 5^{\circ}\text{C}$  ( $77 \pm 9^{\circ}\text{F}$ ), and determine and record the dry mass to the nearest 0.1 g. Designate this mass as A.
3. Fill the water bath to the overflow level with water at  $25 \pm 1^{\circ}\text{C}$  ( $77 \pm 2^{\circ}\text{F}$ ) and allow the water to stabilize.
4. Zero or tare the balance with the suspension apparatus attached, ensuring that the suspension apparatus is completely submerged and not touching the sides or the bottom of the water bath.
5. Immerse the specimen shaking to remove the air bubbles. Place the specimen on its side in the suspension apparatus. Leave it immersed for  $4 \pm 1$  minutes.
6. Determine and record the submerged weight to the nearest 0.1 g. Designate this submerged weight as C.
7. Remove the sample from the water and quickly surface dry with a damp cloth towel within 5 sec.

*Note 1:* To expedite the procedure, steps 1 and 2 may be performed last. To further expedite the process, see Method C.

8. Zero or tare the balance.
9. Immediately determine and record the mass of the saturated surface-dry (SSD) specimen to nearest 0.1 g. Designate this mass as B. Any water that seeps from the specimen during the mass determination is considered part of the saturated specimen. Do not exceed 15 sec. performing Steps 7 through 9.

**Calculations – Method A (Suspension)**

**Constant Mass:**

Calculate constant mass using the following formula:

$$\%Change = \frac{M_p - M_n}{M_p} \times 100$$

Where:

$M_p$  = previous mass measurement, g

$M_n$  = new mass measurement, g

**Bulk specific gravity ( $G_{mb}$ ) and percent water absorbed:**

$$G_{mb} = \frac{A}{B - C}$$

$$Percent\ Water\ Absorbed\ (by\ volume) = \frac{B - A}{B - C} \times 100$$

Where:

- $G_{mb}$  = Bulk specific gravity
- A = Mass of dry specimen in air, g
- B = Mass of SSD specimen in air, g
- C = Weight of specimen in water at  $25 \pm 1^\circ C$  ( $77 \pm 2^\circ F$ ), g

**Example:**

$$G_{mb} = \frac{4833.6 \text{ g}}{4842.4 \text{ g} - 2881.3 \text{ g}} = 2.465$$

$$\% \text{ Water Absorbed (by volume)} = \frac{4842.4 \text{ g} - 4833.6 \text{ g}}{4842.4 \text{ g} - 2881.3 \text{ g}} \times 100 = 0.45\%$$

Given:

A	=	4833.6 g
B	=	4842.4 g
C	=	2881.3 g

**Apparatus – Method B (Volumeter)**

- Balance or scale: 5 kg capacity, readable to 0.1 g and conforming to AASHTO M 231.
- Water bath: For immersing the specimen in water, capable of maintaining a uniform temperature at  $25 \pm 1^\circ\text{C}$  ( $77 \pm 2^\circ\text{F}$ ).
- Thermometer: Range of  $15$  to  $45^\circ\text{C}$  ( $59$  to  $113^\circ\text{F}$ ) and graduated in  $0.1^\circ\text{C}$  ( $0.2^\circ\text{F}$ ) subdivisions.
- Volumeter: Calibrated to 1200 mL or appropriate capacity for test sample and having a tapered lid with a capillary bore.
- Oven: Capable of maintaining a temperature of  $52 \pm 3^\circ\text{C}$  ( $126 \pm 5^\circ\text{F}$ ). for drying the specimens to a constant mass.
- Pan: Pan or other suitable container of known mass, large enough to hold a sample for drying in oven.
- Towel: Damp cloth towel used for surface drying specimens.
- Vacuum device: refer to the FOP for AASHTO R 79 (optional)

**Procedure – Method B (Volumeter)**

Method B is not acceptable for use with specimens that have more than 6 percent air voids.

Recently molded laboratory samples that have not been exposed to moisture do not need drying.

1. Dry the specimen to constant mass, if required.
  - a. Oven method:
    - i. Initially dry overnight at  $52 \pm 3^{\circ}\text{C}$  ( $125 \pm 5^{\circ}\text{F}$ ).
    - ii. Determine and record the mass of the specimen. Designate this mass as  $M_p$ .
    - iii. Return the specimen to the oven for at least 2 hours.
    - iv. Determine and record the mass of the specimen. Designate this mass as  $M_n$ .
    - v. Determine percent change by subtracting the new mass determination,  $M_n$ , from the previous mass determination,  $M_p$ , dividing by the previous mass determination,  $M_p$ , and multiplying by 100.
    - vi. Continue drying until there is no more than 0.05 percent change in specimen mass after 2-hour drying intervals (constant mass).
    - vii. Constant mass has been achieved; sample is defined as dry.
  - b. Vacuum dry method according to the FOP for AASHTO R 79.
2. Cool the specimen in air to  $25 \pm 5^{\circ}\text{C}$  ( $77 \pm 9^{\circ}\text{F}$ ), and determine and record the dry mass to the nearest 0.1 g. Designate this mass as A.
3. Immerse the specimen in the temperature-controlled water bath at  $25 \pm 1^{\circ}\text{C}$  ( $77 \pm 2^{\circ}\text{F}$ ) for at least 10 minutes.
4. At the end of the ten-minute period, fill the volumeter with distilled water at  $25 \pm 1^{\circ}\text{C}$  ( $77 \pm 2^{\circ}\text{F}$ ) making sure some water escapes through the capillary bore of the tapered lid.
5. Wipe the volumeter dry. Determine the mass of the volumeter and water to the nearest 0.1 g. Designate this mass as D.
6. Remove the specimen from the water bath and quickly surface dry with a damp cloth towel within 5 sec.
7. Immediately determine and record the mass of the SSD specimen to the nearest 0.1 g. Designate this mass as B. Any water that seeps from the specimen during the mass determination is considered part of the saturated specimen.
8. Place the specimen in the volumeter and let stand 60 sec.
9. Bring the temperature of the water to  $25 \pm 1^{\circ}\text{C}$  ( $77 \pm 2^{\circ}\text{F}$ ) and cover the volumeter, making sure some water escapes through the capillary bore of the tapered lid.
10. Wipe the volumeter dry.

*Note 1:* To expedite the procedure, steps 1 and 2 may be performed last. To further expedite the process, see Method C.

11. Determine and record the mass of the volumeter, water, and specimen to the nearest 0.1 g. Designate this mass as E.

### Calculations – Method B (Volumeter)

#### Constant Mass:

Calculate constant mass using the following formula:

$$\%Change = \frac{M_p - M_n}{M_p} \times 100$$

Where:

$M_p$  = previous mass measurement, g

$M_n$  = new mass measurement, g

#### Bulk specific gravity ( $G_{mb}$ ) and percent water absorbed:

$$G_{mb} = \frac{A}{B + D - E}$$

$$\text{Percent Water Absorbed (by volume)} = \frac{B - A}{B + D - E} \times 100$$

Where:

$G_{mb}$  = Bulk specific gravity

A = Mass of dry specimen in air, g

B = Mass of SSD specimen in air, g

D = Mass of volumeter filled with water at  $25 \pm 1^\circ\text{C}$  ( $77 \pm 2^\circ\text{F}$ ), g

E = Mass of volumeter filled with specimen and water, g



**Example:**

$$G_{mb} = \frac{4833.6 \text{ g}}{4842.4 \text{ g} + 2924.4 \text{ g} - 5806.0 \text{ g}} = 2.465$$

$$\% \text{ Water Absorbed (by volume)} = \frac{4842.4 \text{ g} - 4833.6 \text{ g}}{4842.4 \text{ g} + 2924.4 \text{ g} - 5806.0 \text{ g}} \times 100 = 0.45\%$$

Given:

A	=	4833.6 g
B	=	4842.4 g
D	=	2924.4 g
E	=	5806.0 g

**Apparatus – Method C (Rapid Test for Method A or B)**

- Oven: Capable of maintaining a temperature of  $110 \pm 5^\circ\text{C}$  ( $230 \pm 9^\circ\text{F}$ ) for drying the specimens to a constant mass.

See Methods A or B.

*Note 2:* This procedure can be used for specimens that are not required to be saved and contain substantial amounts of moisture. Cores can be tested the same day as obtained by this method.

**Procedure – Method C (Rapid Test for Method A or B)**

1. Start on Step 3 of Method A or B, and complete that procedure, then determine dry mass, A, as follows.
2. Determine and record mass of a large, flat-bottom container.
3. Place the specimen in the container.
4. Place in an oven at  $110 \pm 5 \text{ C}$  ( $230 \pm 9 \text{ F}$ ).
5. Dry until the specimen can be easily separated into fine aggregate particles that are not larger than 6.3 mm ( $\frac{1}{4}$  in.).
6. Determine and record the mass of the specimen. Designate this mass as  $M_p$ .
7. Return the specimen to the oven for at least 2 hours.
8. Determine and record the mass of the specimen. Designate this mass as  $M_n$ .

9. Determine percent change by subtracting the new mass determination,  $M_n$ , from the previous mass determination,  $M_p$ , dividing by the previous mass determination,  $M_p$ , and multiplying by 100.
10. Continue drying until there is no more than 0.05 percent change in specimen mass after 2-hour drying intervals (constant mass).
11. Constant mass has been achieved; sample is defined as dry.
12. Cool in air to  $25 \pm 5^\circ\text{C}$  ( $77 \pm 9^\circ\text{F}$ ).
13. Determine and record the mass of the container and dry specimen to the nearest 0.1 g.
14. Determine and record the mass of the dry specimen to the nearest 0.1 g by subtracting the mass of the container from the mass determined in Step 13. Designate this mass as A.

### **Calculations – Method C (Rapid Test for Method A or B)**

Complete the calculations as outlined in Methods A or B, as appropriate.

### **Report**

- On forms approved by the agency
- Sample ID
- $G_{mb}$  to the nearest 0.001
- Absorption to the nearest 0.01 percent
- Method performed.

## **IN-PLACE DENSITY OF ASPHALT MIXTURES BY NUCLEAR METHODS FOP FOR AASHTO T 355**

### **Scope**

This test method describes a procedure for determining the density of asphalt mixtures by means of a nuclear gauge using the backscatter method in accordance with AASHTO T 355-22. Correlation with densities determined under the FOP for AASHTO T 166 is required by some agencies.

### **Apparatus**

- Nuclear density gauge with the factory-matched standard reference block.
- Transport case for properly shipping and housing the gauge and tools.
- Instruction manual for the specific make and model of gauge.
- Radioactive materials information and calibration packet containing:
  - Daily standard count log
  - Factory and laboratory calibration data sheet
  - Leak test certificate
  - Shippers' declaration for dangerous goods
  - Procedure memo for storing, transporting, and handling nuclear testing equipment
  - Other radioactive materials documentation as required by local regulatory requirements

### **Material**

- Filler material: Fine-graded sand from the source used to produce the asphalt pavement or other agency approved materials.

### **Radiation Safety**

This method does not purport to address all of the safety problems associated with its use. This test method involves potentially hazardous materials. The gauge utilizes radioactive materials that may be hazardous to the health of the user unless proper precautions are taken. Users of this gauge must become familiar with the applicable safety procedures and governmental regulations. All operators will be trained in radiation safety before operating nuclear density gauges. Some agencies require the use of personal monitoring devices such as a thermoluminescent dosimeter or film badge. Effective instructions, together with routine safety procedures such as source leak tests, recording and evaluation of personal monitoring device data, etc., are a recommended part of the operation and storage of this gauge.

## Calibration

Calibrate the nuclear gauge as required by the agency. This calibration may be performed by the agency using the manufacturer's recommended procedures or by other facilities approved by the agency. Verify or re-establish calibration curves, tables, or equivalent coefficients every 12 months.

## Standardization

1. Turn the gauge on and allow it to stabilize (approximately 10 to 20 minutes) before standardization. Leave the power on during the day's testing.
2. Standardize the nuclear gauge at the construction site at the start of each day's work and as often as deemed necessary by the operator or agency. Daily variations in standard count shall not exceed the daily variations established by the manufacturer of the gauge. If the daily variations are exceeded after repeating the standardization procedure, the gauge should be repaired, recalibrated, or both.
3. Record the standard count for both density and moisture in the daily standard count log. The exact procedure for standard count is listed in the manufacturer's Operator's Manual.

*Note 1:* New standard counts may be necessary more than once a day. See agency requirements.

## Test Site Location

1. Select a test location(s) randomly and in accordance with agency requirements. Test sites should be relatively smooth and flat and meet the following conditions:
  - a. At least 10 m (30 ft.) away from other sources of radioactivity.
  - b. At least 3 m (10 ft.) away from large objects.
  - c. If the gauge will be closer than 600 mm (24 in.) to any vertical mass, or less than 300 mm (12 in.) from a vertical pavement edge, use the gauge manufacturer's correction procedure.

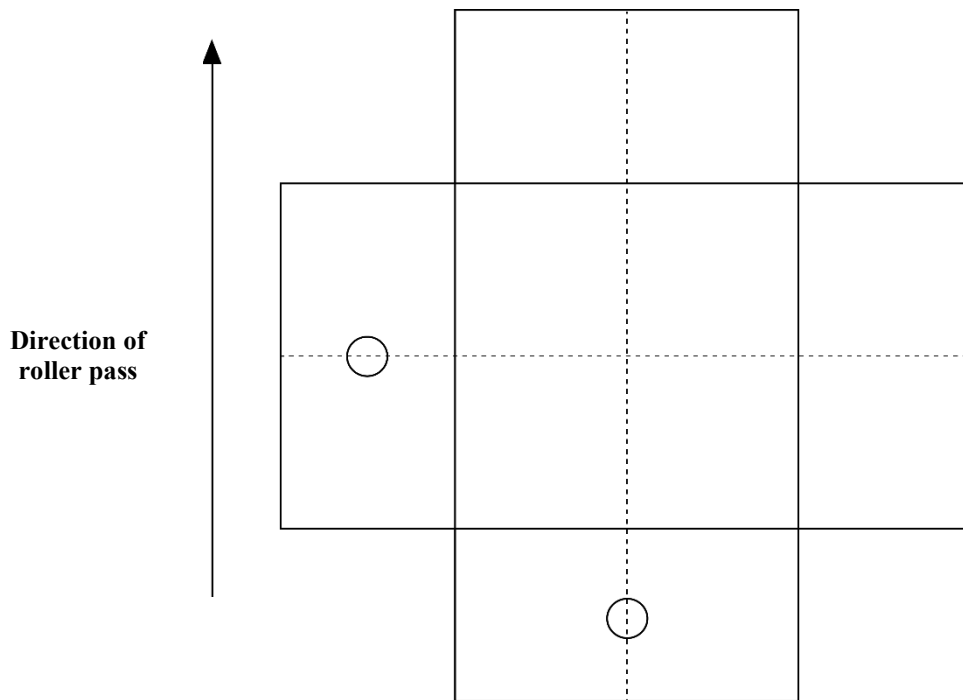
## Procedure

1. Maintain maximum contact between the base of the gauge and the surface of the material under test.
2. Use filler material to fill surface voids.
3. Spread a small amount of filler material over the test site surface and distribute it evenly. Strike off the surface with a straightedge (such as a lathe or flat-bar steel) to remove excess material.
4. If using thin-layer mode, enter the anticipated overlay thickness into the gauge.

*Note 2:* If core correlation is required, entered thickness, anticipated thickness, and nominal core thickness may be required to match.

**Method A – Average of two one-minute tests**

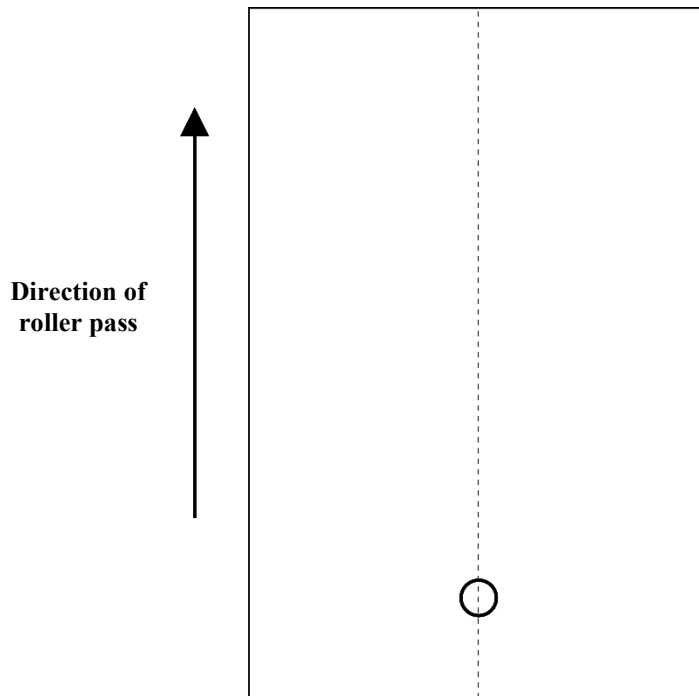
1. Place the gauge on the test site, perpendicular to the roller passes.
2. Using a crayon (not spray paint), mark the outline or footprint of the gauge.
3. Extend the source rod to the backscatter position.
4. Take a one-minute test and record the wet density reading.
5. Rotate the gauge 90 degrees centered over the original footprint. Mark the outline or footprint of the gauge.
6. Take another one-minute test and record the wet density reading.
7. If the difference between the two one-minute tests is greater than  $40 \text{ kg/m}^3$  ( $2.5 \text{ lb/ft}^3$ ), retest in both directions. If the difference of the retests is still greater than  $40 \text{ kg/m}^3$  ( $2.5 \text{ lb/ft}^3$ ) test at 180 and 270 degrees.
8. The density reported for each test site shall be the average of the two individual one-minute wet density readings.



**Method A**  
**Footprint of the gauge test site**

**Method B – One four-minute test**

1. Place the gauge on the test site, parallel to the roller passes.
2. Using a crayon (not spray paint), mark the outline or footprint of the gauge.
3. Extend the source rod to the backscatter position.
4. Take one 4-minute test and record the wet density reading.



**Method B**  
**Footprint of the gauge test site**

### Calculation of Results

Percent (%) compaction is determined by comparing the in-place wet density as determined by this method to the appropriate agency density standard. See appropriate agency policy for use of density standards.

$$\% \text{ Compaction} = \frac{\text{Corrected Reading}}{\text{Maximum Density}} \times 100$$

#### Method A Example:

Reading #1: 141.5 lb/ft<sup>3</sup>

Reading #2: 140.1 lb/ft<sup>3</sup> Are the two readings within the tolerance? (YES)

Reading average: 140.8 lb/ft<sup>3</sup>

Core correction: +2.1 lb/ft<sup>3</sup>

Corrected reading: 142.9 lb/ft<sup>3</sup>

#### Method B Example:

Reading: 140.8 lb/ft<sup>3</sup>

Core correction: +2.1 lb/ft<sup>3</sup>

Corrected reading 142.9 lb/ft<sup>3</sup>

#### Example percent (%) compaction:

From the FOP for AASHTO T 209:

$$G_{mm} = 2.466$$

$$\text{Theoretical Maximum Density} = 2.466 \times 62.245 \text{ lb/ft}^3 = 153.5 \text{ lb/ft}^3$$

$$\% \text{ Compaction} = \frac{142.9 \text{ lb/ft}^3}{153.5 \text{ lb/ft}^3} \times 100 = 93.1\%$$

## Report

- On forms approved by the agency
- Test ID
- Location of test and thickness of layer tested
- Mixture type
- Make, model and serial number of the nuclear moisture-density gauge
- Calculated wet density of each measurement and any adjustment data
- Density standard
- Compaction to the nearest 0.1 percent
- Name and signature of operator



## APPENDIX – CORRELATION WITH CORES

(Nonmandatory Information)

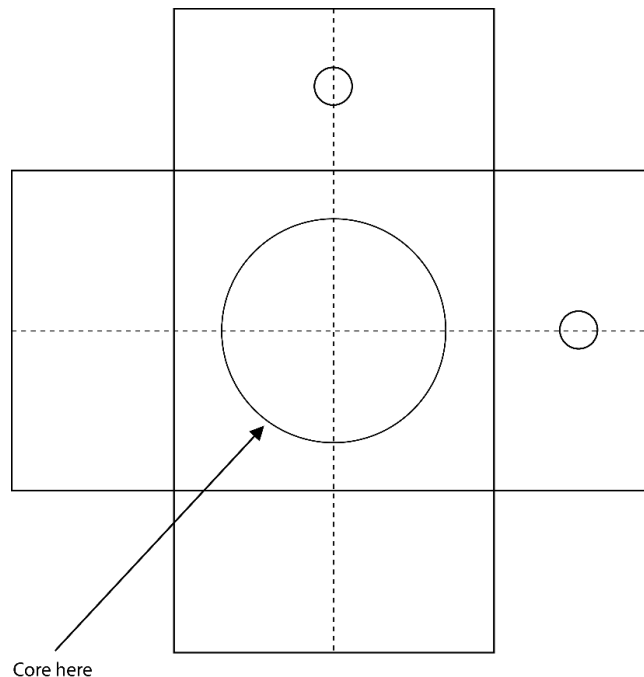
The bulk specific gravity ( $G_{mb}$ ) of the core is a physical measurement of the in-place asphalt mixture and can be compared with the nuclear density gauge readings. Comparing the core value to the corresponding gauge values, a correlation can be established.

The correlation can then be used to adjust the gauge readings to the in-place density of the cores. The core correlation is gauge specific and must be determined without traffic allowed on the pavement between nuclear density gauge readings and obtaining the core. When using multiple nuclear density gauges each gauge should be correlated to the core locations before removal of the core.

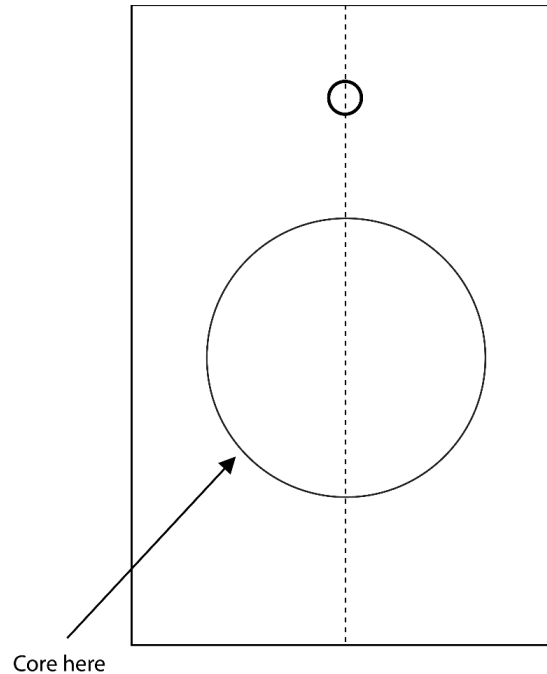
When density correlation with the FOP for AASHTO T 166 is required, correlation of the nuclear gauge with pavement cores shall be made on the first day's paving (within 24 hours) or from a test strip constructed before the start of paving. Cores must be taken before traffic is allowed on the pavement.

### Correlation with Cores

1. Determine the number of cores required for correlation from the agency's specifications. Cores shall be located on the first day's paving or on the test strip. Locate the test sites in accordance with the agency's specifications. Follow the "Procedure" section above to establish test sites and obtain densities using the nuclear gauge.
2. Obtain a pavement core from each of the test sites according to AASHTO R 67. The core should be taken from the center of the nuclear gauge footprint.



**Method A – Footprint of the gauge test site. Core location in the center of the footprint.**



**Method B - Footprint of the gauge test site.**

3. Determine the density of the cores by the FOP for AASHTO T 166, Bulk Specific Gravity of Compacted Asphalt Mixtures Using Saturated Surface Dry Specimens.
4. Calculate a correlation factor for the nuclear gauge reading as follows:
  - a. Calculate the difference between the core density and the average nuclear gauge density at each test site to the nearest  $1 \text{ kg/m}^3$  ( $0.1 \text{ lb/ft}^3$ ). Calculate the average difference and standard deviation of the differences for the entire data set to the nearest  $1 \text{ kg/m}^3$  ( $0.1 \text{ lb/ft}^3$ ).
  - b. If the standard deviation of the differences is equal to or less than  $40 \text{ kg/m}^3$  ( $2.5 \text{ lb/ft}^3$ ), the correlation factor applied to the average nuclear gauge density shall be the average difference calculated above in 4.a.
  - c. If the standard deviation of the differences is greater than  $40 \text{ kg/m}^3$  ( $2.5 \text{ lb/ft}^3$ ), the test site with the greatest variation from the average difference shall be eliminated from the data set and the data set properties and correlation factor recalculated following 4.a and 4.b.
  - d. If the standard deviation of the modified data set still exceeds the maximum specified in 4.b, additional test sites will be eliminated from the data set and the data set properties and correlation factor recalculated following 4.a and 4.b. If the data set consists of less than five test sites, additional test sites shall be established.

**Note A1:** The exact method used in calculating the nuclear gauge correlation factor shall be defined by agency policy.

**Note A2:** The above correlation procedure must be repeated if there is a new job mix formula. Adjustments to the job mix formula beyond tolerances established in the contract documents will constitute a new

job mix formula. A correlation factor established using this procedure is only valid for the particular gauge used in the correlation procedure. If another gauge is brought onto the project, it shall be correlated using the same procedure. Multiple gauges may be correlated from the same series of cores if done at the same time.

**Note A3:** For the purpose of this procedure, a job mix formula is defined as the percent and grade of paving asphalt used with a specified gradation of aggregate from a designated aggregate source. A new job mix formula may be required whenever compaction of the wearing surface exceeds the agency's specified maximum density or minimum air voids.

## Calculations

### Correlation Factor

$$\sqrt{\frac{\sum x^2}{n - 1}}$$

Where:

$\sum$  = Sum

x = Difference from the average Difference

n-1 = number of data sets minus 1

### Example

Core #	Core results from T 166:	Average Gauge reading	Difference:	x	x <sup>2</sup>
1	144.9 lb/ft <sup>3</sup>	142.1 lb/ft <sup>3</sup>	2.8 lb/ft <sup>3</sup>	-0.7	0.49
2	142.8 lb/ft <sup>3</sup>	140.9 lb/ft <sup>3</sup>	1.9 lb/ft <sup>3</sup>	0.2	0.04
3	143.1 lb/ft <sup>3</sup>	140.7 lb/ft <sup>3</sup>	2.4 lb/ft <sup>3</sup>	-0.3	0.09
4	140.7 lb/ft <sup>3</sup>	138.9 lb/ft <sup>3</sup>	1.8 lb/ft <sup>3</sup>	0.3	0.09
5	145.1 lb/ft <sup>3</sup>	143.6 lb/ft <sup>3</sup>	1.5 lb/ft <sup>3</sup>	0.6	0.36
6	144.2 lb/ft <sup>3</sup>	142.4 lb/ft <sup>3</sup>	1.8 lb/ft <sup>3</sup>	0.3	0.09
7	143.8 lb/ft <sup>3</sup>	141.3 lb/ft <sup>3</sup>	2.5 lb/ft <sup>3</sup>	-0.4	0.16
8	142.8 lb/ft <sup>3</sup>	139.8 lb/ft <sup>3</sup>	3.0 lb/ft <sup>3</sup>	0.9	0.81
9	144.8 lb/ft <sup>3</sup>	143.3 lb/ft <sup>3</sup>	1.5 lb/ft <sup>3</sup>	-0.6	0.36
10	143.0 lb/ft <sup>3</sup>	141.0 lb/ft <sup>3</sup>	2.0 lb/ft <sup>3</sup>	-0.1	<u>0.01</u>
Average Difference:			+2.1 lb/ft <sup>3</sup>	$\Sigma x^2 = 2.5$	

**Number of data sets**

$$n - 1 = 10 - 1 = 9$$

**Standard deviation**

$$\text{standard deviation} = \sqrt{\frac{2.5}{9}} = 0.53$$

Given:

$$\text{Sum of } x^2 = 2.5$$

$$\text{Number of data sets} = 9$$

The standard deviation of 0.53 is less than 2.5 therefore no cores are eliminated. The average difference from all ten cores is used.

**PERFORMANCE EXAM CHECKLIST**

**IN-PLACE DENSITY OF ASPHALT MIXTURES BY NUCLEAR METHODS  
FOP FOR AASHTO T 355**

Participant Name \_\_\_\_\_ Exam Date \_\_\_\_\_

Record the symbols "P" for passing or "F" for failing on each step of the checklist.

Procedure Element	Trial 1	Trial 2
1. Gauge turned on approximately 10 to 20 minutes before use?	_____	_____
2. Gauge calibrated, and standard count recorded?	_____	_____
3. Test location selected appropriately [600 mm (24 in.) from vertical projections or 10 m (30 ft.) from any other radioactive sources]?	_____	_____
4. Filler spread evenly over test site?	_____	_____
5. Excess filler material removed by striking off the surface?	_____	_____
6. Gauge placed on pavement surface and footprint of gauge marked?	_____	_____
7. Source rod extended to backscatter position?	_____	_____
8. Method A:		
a. One-minute count taken; gauge rotated 90°, reseated, and another one-minute count taken?	_____	_____
b. Densities averaged?	_____	_____
c. If difference of the wet densities is greater than 40 kg/m <sup>3</sup> (2.5 lb/ft <sup>3</sup> ), retest conducted in both directions?	_____	_____
9. Method B:		
a. One four-minute count taken?	_____	_____
10. Core correlation applied if required?	_____	_____
11. Percent compaction calculated correctly?	_____	_____

Comments: First attempt: Pass\_\_\_\_Fail\_\_\_\_ Second attempt: Pass\_\_\_\_Fail\_\_\_\_

\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

Examiner Signature \_\_\_\_\_ WAQTC #: \_\_\_\_\_

