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 (11) USING A 4.54 kg (10 lb) RAMMER AND A 457 mm (18 in.) DROP FOP FOR AASHTO T 180 (11)

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: Methods A, B, C, & D
- AASHTO T 180: Methods A, B, C, & D

This test method applies to soil mixtures having 40% or less retained on the 4.75 mm (No 4) sieve for methods A or B, or, 30% or less retained on the 19 mm (¾") with methods C or D. The retained material is defined as oversize (coarse) material. If no minimum percentage is specified, 5% will be used. Samples that contain oversize (coarse) material that meet percent retained criteria should be corrected by using the FOP for AASHTO T 224. 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 moist 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, made of metal and with the dimensions shown in Table 1 or Table 2. It shall include a detachable collar and a base plate to which the mold can be fastened. 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.

- 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 (3/8 in.) in diameter, spaced approximately 90 degrees apart and approximately 19 mm (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 the FOP for 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 20 kg (45 lb) and a sensitivity of 5 g (0.01 lb) for obtaining the sample, meeting the requirements of AASHTO M 231.

  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.

- Drying apparatus – A thermostatically controlled drying oven, capable of maintaining a temperature of 110 ±5°C (230 ±9°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.), conforming to AASHTO M 92.

- 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

	T 99	**T 180**
Mold Volume, m^3	Methods A, C: 0.000943 ± 0.000008	Methods A, C: 0.000943 ±0.000008
	Methods B, D: 0.002124 ± 0.000021	Methods B, D: 0.002124 ± 0.000021
Mold Diameter, mm	Methods A, C: 101.6± 0.41	Methods A, C: 101.6± 0.41
	Methods B, D: 152.4± 2.54	Methods B, D: 152.4± 2.54
Mold Height, mm	116.43± 0.13	116.43± 0.13
Detachable Collar Height, mm	50.80± 0.64	50.80± 0.64
Rammer Diameter, mm	50.80	50.80
Rammer Mass, kg	2.495	4.536
Rammer Drop, mm	305	457
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^3	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

	T 99	T 180
Mold Volume, ft^3	Methods A, C: 1/30 (0.0333) ± 0.0003	Methods A, C: 1/30 (0.0333) ± 0.0003
	Methods B, D: 1/13.33 (0.0750) ± 0.00075	Methods B, D: 1/13.33 (0.0750) ± 0.00075
Mold Diameter, in.	Methods A, C: 4.000±0.016	Methods A, C: 4.000±0.016
	Methods B, D: 6.000± 0.100	Methods B, D: 6.000± 0.100
Mold Height, in.	4.584± 0.005	4.584± 0.005
Detachable Collar Height, in.	2± 0.025	2± 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	18
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 B: 16 Method C: 12(1) Method D: 25(1)	
Energy, $lb\text{-}ft/ft^3$	12,375	56,250

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

Molds Out of Tolerance Due to Use—A mold that fails to meet manufacturing tolerances after continued service may remain in use provided those tolerances are not exceeded by more than 50 percent; and the volume of the mold, calibrated in accordance with T 19M/T 19, is used in the calculations.

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.

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

Note 2: 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. 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.

Procedure

1. Determine the mass of the clean, dry mold. Include the base plate, but exclude the extension collar. Record the mass to the nearest 0.005 kg (0.01 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. See Note 2. For many materials this condition can be identified by forming a cast by hand.

3. Form a specimen by compacting the prepared soil in the mold (with collar attached) in approximately equal layers. For each layer, spread the loose material uniformly in the mold. Lightly tamp the fluffy material with the manual rammer or other similar device. This establishes a firm surface on which to hold the rammer sleeve. 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. If material that has not been compacted remains adjacent to the walls of the mold and extends above the compacted surface, trim it down.

   Note 3: During compaction, the mold shall rest firmly on a dense, uniform, rigid, and stable foundation or base. This base shall remain stationary during the compaction process.

4. Remove the extension collar. Avoid shearing off the sample below the top of the mold. A rule of thumb is that 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. Determine the mass of the mold and wet soil in kg to the nearest 0.005 kg (0.01 lb) or better.

7. Determine the wet mass of the sample by subtracting the mass in Step 1 from the mass in Step 6.

8. Calculate the wet density as indicated below under "Calculations."

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

   Note 4: 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.

10. Determine the moisture content of the sample in accordance with the FOP for AASHTO T 255/T 265.

11. 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. See Note 2.

12. Add sufficient water to increase the moisture content of the remaining soil by approximately 1 to 2 percentage points and repeat steps 3 through 11.

13. Continue determinations until there is either a decrease or no change in the wet density. There will be a minimum of three points on the dry side of the curve and two points on the wet side.

Note 5: In cases of free-draining granular material, the development of points on the wet side of optimum may not be practical.

Calculations

When the mold meets the criteria of Table 1 or Table 2 calculating unit mass can be accomplished by multiplication using a Mold Factor, by division using a Mold volume; or by division using a measured volume (determined by performing T 19).

For molds not meeting the criteria of Table 1 or Table 2 but within 50%, a measured volume must be used.

Mold Factor

1a. Calculate the wet density, in kg/m^3 (lb/ft^3), by multiplying the wet mass from Step 7 by the appropriate factor chosen from the two below.

Methods A & C molds: 1060 (30)

Methods B & D molds: 471 (13.33)

Note 6: The moist mass is in kg (lb). The factors are the inverses of the mold volumes in m^3 (ft^3) shown in Table 1 or Table 2. If the moist mass is in grams, use 1.060 or 0.471 for factors when computing kg/m^3.

Example – Methods A or C mold:

Wet mass = 1.916 kg (4.22 lb)

(1.916)(1060) = 2031 kg/m^3 Wet Density* (4.22)(30) = 126.6 lb/ft^3 Wet Density*

Volume

1b. Calculate the wet density, in kg/m^3 (lb/ft^3), by dividing the wet mass from Step 7 by the appropriate volume from Table 1 or Table 2.

Example – Methods A or C mold:

Wet mass = 1.916 kg (4.22 lb)

$$\frac{1.1916\ kg}{0.000943\ m^3} = 2023 kg/m^3\ Wet\ Density^* \qquad \frac{4.22\ lb}{0.0333 ft^3} = 126.7 lb/ft^3\ Wet\ Density^*$$

* Differences in wet density are due to rounding in the respective calculations.

Measured Volume

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

Example – Methods A or C mold:

39

Wet mass = 1.916 kg (4.22 lb)

Measured volume of the mold = 0.000946m^3 (0.0334 ft^3)

$$\frac{1.1916\ kg}{0.000946\ m^3} = 2025 kg/m^3\ Wet\ Density^* \qquad \frac{4.22\ lb}{0.0334 ft^3} = 126.3 lb/ft^3\ Wet\ Density^*$$

2. Calculate the dry density as follows.

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

Where:

ρ_d = Dry density, kg/m^3 (lb/ft^3)
ρ_w = Wet density, kg/m^3 (lb/ft^3)
w = Moisture content, as a percentage

Example:

ρ_w = 2030 kg/m^3 (126.6 lb/ft^3) and w = 14.7%

$$\rho_d = \left(\frac{2030\ kg/m^3}{14.7+100}\right) \times 100 = 1770\ \ kg/m^3 \quad \rho_d = \left(\frac{126.6\ lb/ft^3}{14.7+100}\right) \times 100 = 110.4\ lb/ft^3$$

or

$$\rho_d = \left(\frac{2030\ kg/m^3}{\frac{14.7}{100}+1}\right) = 1770\ \ kg/m^3 \quad \rho_d = \left(\frac{126.6\ lb/ft^3}{\frac{14.7}{100}+1}\right) = 110.4\ lb/ft^3$$

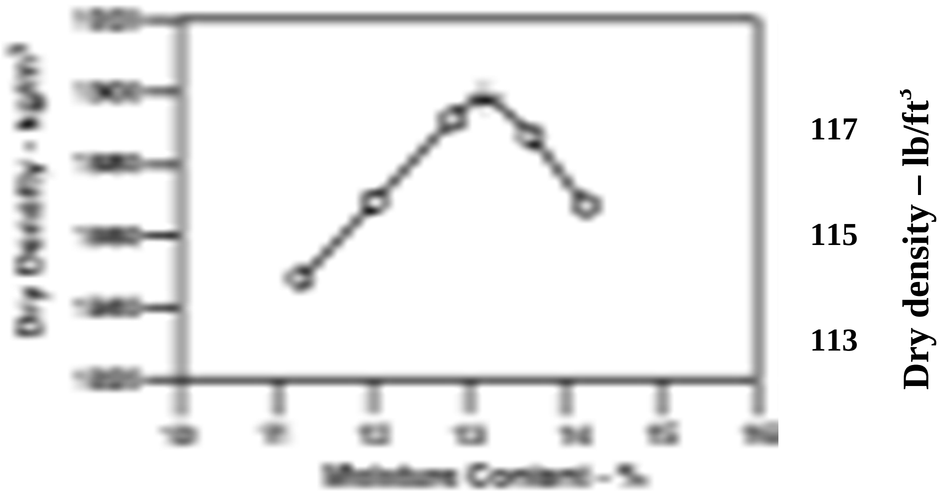
Moisture-Density Curve Development

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^3	**lb/ft^3**	
1846	114.3	11.3
1868	115.7	12.1
1887	116.9	12.8
1884	116.7	13.6
1871	115.9	14.2



In this case, the curve has its peak at:

Maximum dry density = 1890 kg/m^3 (117.0 lb/ft^3)
Optimum water content = 13.2%

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

Report

Results shall be reported on standard forms approved by the agency. Report maximum dry density to the closest 1 kg/m^3 (0.1 lb/ft^3) and optimum moisture content to the closest 0.1 percent.

PERFORMANCE EXAM CHECKLIST

MOISTURE-DENSITY RELATION OF SOILS
FOP FOR AASHTO T 99 and AASHTO 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
Procedure		
1. If damp, sample dried in air or drying apparatus, not exceeding 60°C (140°F)?	_____	_____
2. 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?	_____	_____
3. Sample passing the sieve has appropriate mass?	_____	_____
4. Sample determined to be 4 to 8 percent below expected optimum moisture content?	_____	_____
5. Layer of soil placed in mold with collar attached?	_____	_____
6. Mold placed on rigid and stable foundation?	_____	_____
7. Soil compacted with appropriate number of blows (25 or 56)?	_____	_____
8. Soil placed in appropriate number of approximately equal layers (3 or 5)?		
9. Collar removed without shearing off sample?	_____	_____
10. Approximately 6 mm (1/4 in.) of compacted material above the top of the base of the mold?	_____	_____
11. Soil trimmed to top of mold with the beveled side of the straightedge?	_____	_____
12. Mass of mold and contents determined to appropriate precision?	_____	_____
13. Wet density calculated from the wet mass?	_____	_____
14. Soil removed from mold using a sample extruder if needed?	_____	_____
15. Soil sliced vertically through center (non-granular material)?	_____	_____
16. Moisture sample removed ensuring all layers are represented?	_____	_____
17. Moist mass determined immediately to 0.1 g?	_____	_____

OVER

Procedure Element	Trial 1	Trial 2
18. Moisture sample mass of correct size?	_____	_____
19. Sample dried and water content determined according to T 255/T 265?	_____	_____
20. Remainder of material from mold broken up until it will pass through the sieve, as judged by eye, and added to remainder of original test sample?	_____	_____
21. Water added to increase moisture content of the remaining sample in 1 to 2 percent increments?	_____	_____
22. Steps 2 through 15 repeated for each increment of water added?	_____	_____
23. If soil is plastic (clay types):		
a. Samples mixed with water varying moisture content by 1 to 2 percent, bracketing the optimum moisture content?	_____	_____
b. Samples placed in covered containers and allowed to stand for at least 12 hours?	_____	_____
24. If material is degradable:		
Multiple samples mixed with water varying moisture content by 1 to 2 percent, bracketing the optimum moisture content?	_____	_____
25. Process continued until wet density either decreases or stabilizes?	_____	_____
26. Moisture content and dry density calculated for each sample?	_____	_____
27. Dry density plotted on vertical axis, moisture content plotted on horizontal axis, and points connected with a smooth curve?	_____	_____
28. Moisture content at peak of curve recorded as optimum water content and recorded to nearest 0.1 percent?	_____	_____
29. Dry density at optimum moisture content reported as maximum density to nearest 1 kg/m^3 (0.1 lb/ft^3)?	_____	_____

Comments: First attempt: Pass_____Fail_____ Second attempt: Pass_____Fail_____

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Examiner Signature _______________________________WAQTC #:_______________