T 99/ T 180

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

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Steel roller

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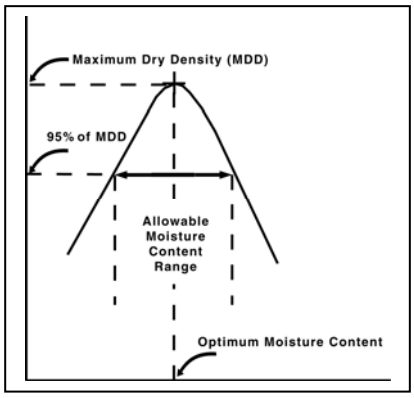
Adding water



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Significance

The density, or degree of compaction, of soil or soil-aggregate mixtures has a significant influence on the stability and durability of roadways. Low density subgrade, subbase, base or embankment will lead to excessive deflection under load and/or long term settlement in an amount higher than anticipated. Obtaining proper density depends on two major factors: compactive effort and moisture content.

Compactive effort relates to the type and weight of compaction equipment, along with the thickness of the “lift” being compacted and the number of times each lift is passed over by the compaction equipment. Equipment includes static and vibratory rollers, smooth and sheepsfoot steel rollers, and pneumatic tire rollers of varied weights yielding many different compactive efforts.

Density also depends upon moisture content. The moisture content corresponding to maximum dry density of the soil or soil-aggregate mixture under a given compactive effort is known as optimum water content. As the water content increases or decreases from this optimum value, the dry density decreases.

Agency specifications commonly require that a certain percentage of maximum dry density be obtained while the moisture content of the soil or soil-aggregate mixture is held within certain limits. For example, a specification might call for 95 percent of maximum dry density with a moisture content of the optimum value ±2 percent. For these reasons, it is critical to understand the various test methods and equipment used in determining the moisture-density relations of soil.

Scope

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

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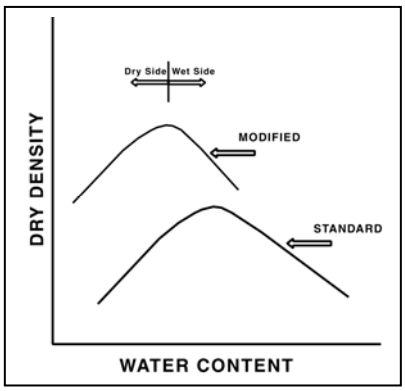
- AASHTO T 99 methods A, B, C & D
- AASHTO T 180 methods A, B, C & D

This test method applies to soil mixtures having 40% or less retained on the No. 4 sieve for methods A or B, or, 30 % or less on the 3/4 in. 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) that meet the 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 delivering a specified quantity of compactive energy. The moist masses of the compacted samples are divided by the volume of the mold 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.



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Molds and Rammer

Apparatus

- Mold – Cylindrical, made of metal and having 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 then 3/8 in.

diameter, spaced approximately 90 degrees apart and approximately 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

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- 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 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 10 in. long, having one beveled edge and at least one surface, used for final trimming, plane within 0.1 percent of its length.
- Sieve(s): No. 4 and/or 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.

No. 4 sieve - Straight edge

Table 1

Comparison of Apparatus, Sample, and Procedure - Metric

	T 99	T 180
Mold Volume, m^3	Methods A, C: 0.000943	Methods A, C: 0.000943
	Methods B, D: 0.002124	Methods B, D: 0.002124
Mold Diameter, mm	Methods A, C: 101.6	Methods A, C: 101.6
	Methods B, D: 152.4	Methods B, D: 152.4
Mold Height, mm	116.43	116.43
Detachable Collar Height, mm	51	51
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 B: 7 Method C: 5 (1) Method D: 11(1)	
Energy, kN-m/m^3	592	2,693

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Table 2

Comparison of Apparatus, Sample, and Procedure - English

	T 99	T 180
Mold Volume, ft^3	Methods A, C: 1/30	Methods A, C: 1/30
	Methods B, D: 1/13.33	Methods B, D: 1/13.33
Mold Diameter, in.	Methods A, C: 4.000	Methods A, C: 4.000
	Methods B, D: 6.000	Methods B, D: 6.000
Mold Height, in.	4.584	4.584
Detachable Collar Height, in.	2	2
Rammer Diameter, in.	2.000	2.000
Rammer Mass, lb	5.5	10
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-ft/ ft^3	12,375	56,250

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

Breaking up sample

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 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. Instances where the material is prone to degradation i.e. granular material a compaction sample with differing moisture content should be prepared for each point.

Mold \ Sieve	– No. 4	– 3/4 in.
4-inch	A	C
6-inch	B	D

Typical mold

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 6 percentage points below optimum moisture content. See note 2.
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 2 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.

Trimming

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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 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 edge of the straightedge.

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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."

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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 insuring 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 to be 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.

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Moisture sample

10. Determine the sample moisture according to the FOP for AASHTO T 255/T 265.

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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 the above procedure.
13. Continue determinations until there is either a decrease or no change in the wet density. A minimum of five determinations is usually necessary.

Calculations

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

   Method A & C molds: 30
   Method B & D molds: 13.33

Note 5: The moist mass is in kg (lb). The factors are the inverses of the mold volumes in ft^3 shown in Table 2.

1/(1/30) = 30
1/(1/13.33) = 13.33

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Example – Method A or C mold:

Wet mass = 4.22 lb

(4.22)(30) = 126.6 lb/ft^3 Wet Density

2. Calculate the dry density as follows.

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

where

ρ_d = Dry density, lb/ft^3

ρ_w = Wet density, lb/ft^3

w = Moisture content, as a percentage

Example:

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ρ_w = 126.6 lb/ft^3 and w = 14.7%

$$\rho_d = \left(\frac{126.6\,lb/\text{ft}^3}{14.7+100}\right) \times 100 = 110.4\ lb/\text{ft}^3 \qquad \text{or} \qquad \rho_d = \left(\frac{126.6\,lb/\text{ft}^3}{(14.7/100)+1}\right) = 110.4\ lb/\text{ft}^3$$

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, a moisture-density curve is developed. The peak of the curve has, as coordinates, the maximum dry density, or just "maximum density," and the "optimum moisture content" of the soil.

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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.

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Dry Density, lb/ft^3	Moisture Content, %
114.3	11.3
115.7	12.1
116.9	12.8
116.7	13.6
115.9	14.2

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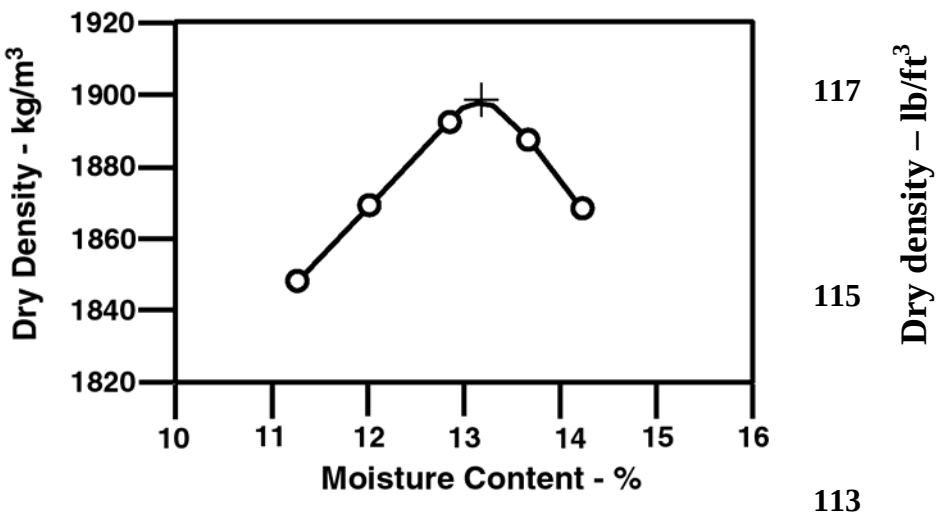

Ideally, there will be three points on the dry side of the curve and two points on the wet side. In this case, the curve has its peak at:

Maximum dry density = 117.0 lb/ft^3

Optimum water content = 13.2%

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

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Report

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

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Tips!

- Ideally, obtain dry 3 points and 2 wet points. This produces a reliable moisture-density curve.
- Moisture-density curves are based on dry, densities.
- If oversize material exists, corrections must be made

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REVIEW QUESTIONS

1. Describe how the plotted data is used to determine optimum moisture content and maximum dry density.

2. How many blows of the rammer are required per lift for the various procedures and methods?

3. Describe how the sample for moisture content is obtained.

4. What sample mass is required for Method A of the T 99 test?

   For Method C of the T 180 test?

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 140°F?	_____	_____
2. Sample pulverized and adequate amount sieved over the appropriate sieve No. 4 or ¾ in. to determine oversize (coarse particle) percentage?	_____	_____
3. Sample passing the sieve has appropriate mass?	_____	_____
4. Sample mixed with water to 4 to 6 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 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 edge of the straightedge?	_____	_____
12. Mass of mold and contents determined to appropriate precision?	_____	_____
13. Wet mass of specimen multiplied by appropriate factor to obtain wet density 30, 13.33?	_____	_____
14. Soil removed from mold using a sample extruder if needed?	_____	_____
15. Soil sliced vertically through center?	_____	_____
16. Moisture sample removed from one cut face insuring 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 to about passing sieve size 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 0.1 lb/ft^3?	_____	_____

Comments: First attempt: Pass ☐ Fail ☐ Second attempt: Pass ☐ Fail ☐

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Examiner Signature _____WAQTC #:_____