

**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 99-15: Methods A, B, C, and D
- AASHTO T 180-15: 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 (¾ in.) 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. 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 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 the “Calibration of Measure” section of AASHTO T 19 for Unit Mass of Aggregate.
- 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 (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 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.), 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**

	<b>T 99</b>	<b>T 180</b>
Mold Volume, m <sup>3</sup>	Methods A, C: 0.000943 ± 0.000001	Methods A, C: 0.000943 ±0.000001
	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	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 <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: 0.0750 ±0.0009	Methods B, D: 0.0750 ±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	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 <sub>(1)</sub>	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.

**Note 1:** Both T 99 and 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

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.

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

**Note 3:** 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 (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 to the nearest 1 g (0.005 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**

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

Example – Methods A or C mold:

Wet mass = 1.916 kg (4.22 lb)

Measured volume of the mold = 0.000946 m<sup>3</sup> (0.0334 ft<sup>3</sup>)

$$Wet\ Density = \frac{1.916\ kg}{0.000946\ m^3} = 2025\ kg/m^3$$

$$Wet\ Density = \frac{4.22\ lb}{0.0334\ ft^3} = 126.3\ lb/ft^3$$

2. Calculate the dry density as follows.

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

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, as a percentage

**Example:**

$\rho_w = 2030\ kg/m^3$  (126.6 lb/ft<sup>3</sup>)

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

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

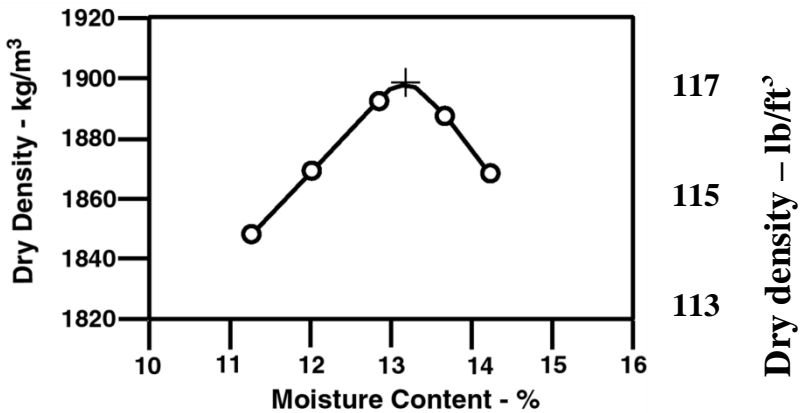
### Moisture-Density Curve Development

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 <sup>3</sup>	lb/ft <sup>3</sup>	
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<sup>3</sup> (117.0 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 closest  $1 \text{ kg/m}^3$  ( $0.1 \text{ lb/ft}^3$ )
- Optimum moisture content to the closest 0.1 percent



## ANNEX

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

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.

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.

$$P_f = \frac{100M_{DF}}{M_{DF} + M_{DC}} \quad \frac{100 \times 15.4 \text{ lb}}{15.4 \text{ lbs} + 5.7 \text{ lb}} = 73\% \quad \frac{100 \times 7.034 \text{ kg}}{7.03 \text{ kg} + 2.602 \text{ kg}} = 73\%$$

And

$$P_c = \frac{100M_{DC}}{M_{DF} + M_{DC}} \quad \frac{100 \times 5.7 \text{ lb}}{15.4 \text{ lbs} + 5.7 \text{ lb}} = 27\% \quad \frac{100 \times 2.602 \text{ kg}}{7.03 \text{ kg} + 2.602 \text{ kg}} = 27\%$$

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 fine particles  
 $M_{DC}$  = mass of 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 of the total sample (combined fine and oversized particles) as follows:

$$D_d = \frac{100\%}{\frac{P_f}{D_f} + \frac{P_c}{k}}$$

Where:

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

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

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

$P_f$  = percent of 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

Sample Calculations:

- Metric:

Maximum laboratory dry density ( $D_f$ ):	1890 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>

$$D_a = \frac{100\%}{\frac{P_f}{D_f} + \frac{P_c}{k}}$$

$$D_a = \frac{100\%}{\frac{73\%}{1890 \text{ kg/m}^3} + \frac{27\%}{2697 \text{ kg/m}^3}}$$

$$D_a = \frac{100\%}{0.03862 \text{ kg/m}^3 + 0.01001 \text{ kg/m}^3}$$

$$D_a = 2056.3 \text{ kg/m}^3 \text{ report } 2056 \text{ kg/m}^3$$

English:

Maximum laboratory dry density ( $D_f$ ): 117.0 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>

$$D_a = \frac{100\%}{\frac{P_f}{D_f} + \frac{P_c}{k}}$$

$$D_a = \frac{100\%}{\frac{73\%}{117.0 \text{ lb/ft}^3} + \frac{27\%}{168.3 \text{ lb/ft}^3}}$$

$$D_a = \frac{100\%}{0.6239 \text{ lb/ft}^3 + 0.1604 \text{ lb/ft}^3}$$

$$D_a = \frac{100\%}{0.7843 \text{ lb/ft}^3}$$

$$D_a = 127.50 \text{ lb/ft}^3 \text{ report } 127.5 \text{ lb/ft}^3$$

## Report

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

EMBANKMENT AND BASE  
IN-PLACE DENSITY

WAQTC

FOP AASHTO T 99 / T 180 (15)