ATM 201 Sticks & Roots Content of Aggregate and Soil

1. Scope

This is the procedure for determining the percent of sticks & roots by wet mass of the total aggregate or soil sample.

2. Significance

Use this test to quantify the organic content of soils for particles that are too large to test in accordance with ATM 203, Organic Content of Soils by Ignition.

3. Apparatus

- Balance or scale: Capacity sufficient for the field sample mass, readable to 0.1 percent or 0.1 g and meeting the requirements of AASHTO M 231.
- 2.00 mm (No. 10) sieve conforming to AASHTO M 92 (ASTM E11).
- Miscellaneous equipment including pans, gloves, etc.

4. Sampling and Sample Preparation

Obtain the sample in accordance with WAQTC FOP for AASHTO T 2 (ASTM D75). Perform the test on the complete as-received sample before drying.

5. Procedure

1. Determine the mass of the as-received sample to 0.1 percent or 0.1 g. Record this as the Total Sample Mass.
2. Separate the sample on a 2.00 mm (No. 10) sieve to ease identification of sticks & roots.
3. Separate the sticks & roots from the plus 2.00 mm (No. 10) material and place in a separate pan.
4. Determine the mass of the sticks & roots to 0.1 percent or 0.1 g. Record this as the Sticks & Roots Mass.

6. Calculations

Calculate the percentage of sticks & roots by:

$$\text{Sticks \& Roots, percent} = \left(\frac{\text{Sticks \& Roots Wet Mass}}{\text{Total Wet Sample Mass}} \right) \text{x } 100$$

7. Report

- Results on forms approved by the Department
- Stick and Root Content to nearest 1 percent

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ATM 202 Moisture Content of Aggregate and Soils

The following are guidelines for using WAQTC FOP for AASHTO T 255/T 265 by the State of Alaska DOT&PF.

1. Use controlled methods of drying for most samples. It is assumed that constant mass has been reached for soils and aggregates when dried overnight at 230º F (110º C) ± 9º. Drying for 8-16 hours is sufficient in most cases. Shorter drying times require reweighing of samples until constant mass is achieved.

2. Uncontrolled methods of drying may be used when time is of the essence. These methods require reweighing of samples until constant mass is achieved.

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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 ± 5°C (230 ± 9°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

Nominal Maximum Size*		Minimum Sample Mass	
mm	(in.)	g	(lb)
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

Maximum Particle Size		Minimum Sample Mass
mm	(in.)	g
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 aggregate: the lid is optional unless drying with a microwave then a ventilated lid is required.
   b. For soils: the container includes the mass of the close-fitting lid.
2. Place the wet sample in the container.
3. Determine and record the total mass of the wet sample and container with lid, when used.
   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. Subtract the container mass determined in Step 1 from the mass of the container and sample determined in Step 3 and record the wet mass of the sample (M_W).
5. Remove the lid, if used, and place the sample in one of the following drying apparatuses:
   a. For aggregate –
      i. Controlled heat source (oven): at 110 ±5°C (230 ±9°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 ±5°C (230 ±9°F).

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

6. Dry until sample appears moisture free.
7. Determine mass of sample and container and lid, when used.
8. Subtract the container mass determined in Step 1 from the mass of the container and sample determined in Step 7 and record the mass of the sample.
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 with lid, if used.
11. Subtract the container mass determined in Step 1 from the mass of the container and sample determined in Step 10 and record the mass of the sample.
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 and container with lid, when used, to cool. Determine and record the total mass.

16. Subtract the mass of the container determined in Step 1 from the mass of the container and sample determined in Step 15 and record the dry mass of the sample (M_D).

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

Aggregate		
Heat Source	**Specific Instructions**	**Drying intervals to achieve constant mass (minutes)**
Controlled: Forced draft (preferred), ventilated, or convection oven	110 ±5°C (230 ±9°F)	30
Uncontrolled:		
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
Soil		
Heat Source	**Specific Instructions**	**Drying interval to achieve constant mass**
Controlled: 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:

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

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 g - 1232.1 g =	1405.1 g
Mass of container and sample after second drying cycle:		2634.1 g
Mass, M_n, of sample:	2634.1 g - 1232.1 g =	1402.0 g

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

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 g - 1232.1 g = 1400.9 g

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

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

Moisture Content Aggregate and Soils:

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_W	=	wet mass
M_D	=	dry mass

Example:

Mass of container:		1232.1 g
Mass of container and wet sample:		2764.7 g
Mass, M_W, of wet sample:	2764.7 g - 1232.1 g =	1532.6 g
Mass of container and dry sample (COOLED):		2633.5 g
Mass, M_D, of dry sample:	2633.5 g - 1232.1 g =	1401.4 g

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

Report

- On forms approved by the agency
- Sample ID
- M_W, wet mass
- M_D, dry mass
- w, moisture content to the nearest 0.1 percent

ATM 203 Organic Content of Soils

1. Scope

This method describes the procedure for determining organic content of soils by loss on ignition as adopted from ASTM D2974.

This standard involves hazardous materials, operations and equipment. This standard does not purport to address all of the safety problems associated with its use. It is the responsibility of the agency to establish appropriate safety and health practices and to train the user of this standard prior to use. It is the responsibility of the user to consult the appropriate agency authority for and to practice and maintain the appropriate safety and health practices.

2. Apparatus

- Sieves conforming to AASHTO M 92 (ASTM E11)
- Pulverizing apparatus suitable for breaking up aggregations of soil particles without reducing the size of individual grains
- Balance or scale: Class G1, sensitive to 0.01 g with a capacity sufficient for the principle sample mass, and meeting the requirements of AASHTO M 231
- For this test, this would require a scale with a capacity of at least 150 g and readable to 0.01 g
- Muffle Furnace, thermostatically controlled, capable of maintaining a temperature of 445 ± 10°C (830 ±15°F). The combustion chamber will be capable of accommodating the designated container(s) and sample(s). The furnace shall be equipped with a pyrometer recorder that will indicate chamber temperature while in use.
- Crucible, with covers, having a minimum volume of 100 ml and capable of withstanding repeated exposure to temperatures of 500ºC (950°F)
- Non-asbestos, heat-resistant, gauntlet-type gloves capable of withstanding temperatures of 500ºC (950°F)
- Desiccator of sufficient size containing an effective desiccant
- Miscellaneous equipment including tongs, spatulas, wire brushes, etc.

3. Sampling and Sample Preparation

1. Obtain the sample in accordance with WAQTC FOP for AASHTO T 2 (ASTM D75).
2. Dry the sample to constant mass in accordance with the soil procedure of WAQTC FOP for AASHTO T 255/T 265.
3. If the material contains lumps of organics or aggregations of soil, they shall be broken up by such means that will not reduce the size of the aggregate particles. Sieve the dry sample through the 4.75 (No. 4) sieve.

   Note 1: Sticks and roots shall not be broken up, but shall be removed by hand and reported as Sticks and Roots (see ATM 201).

4. Reduce the sample to a mass of approximately 50 g in accordance with WAQTC FOP for AASHTO T 248.

4. Procedure

1. Determine the mass of a crucible to the nearest 0.01 g and record as Tare.
2. Place the sample into the crucible, determine the mass to the nearest 0.01 g and record as Mass Before Ignition + Tare.

   Note 2: Sample masses for lightweight materials such as peat may be less than 50 g but should be of sufficient amount to fill the crucible to at least 3/4 depth. A cover may initially be required over the crucible during the initial phase of ignition to decrease the possibility of the sample being "blown out" from container.
3. Place the crucible into a pre-heated muffle furnace at a temperature of 445ºC (835°F) for a minimum of six hours until the sample is completely ashed (no change of mass occurs after at least 1 hr. of additional heating. If a cover has been used, it shall be removed after approximately 2 hours of combustion.
4. Remove the test sample from the muffle furnace and cool it to room temperature in a desiccator.
5. Determine the mass to the nearest 0.01 grams and record as Mass After Ignition + Tare.

5. Calculations

Calculate the percent organic content by the following formula:

$$\text{Organic Content} = \left(\frac{A - B}{A - C}\right) \times 100$$

Where:
A = Mass Before Ignition + Tare,
B = Mass After Ignition + Tare,
C = Tare.

6. Report

- Results on forms approved by the Department
- Organic Content to nearest 0.1 percent

ATM 204 Determining the Liquid Limit of Soils

Use WAQTC FOP Module T 89-1 for AASHTO T 89.

DETERMINING THE LIQUID LIMIT OF SOILS
FOP FOR AASHTO T 89

Scope

This procedure covers the determination of the liquid limit of a soil in accordance with AASHTO T 89-22. It is used in conjunction with the FOP for AASHTO T 90, Determining the Plastic Limit and Plasticity Index of Soils. The three values are used for soil classification and other purposes.

Apparatus

- Dish: preferably unglazed porcelain or similar mixing dish, about 115 mm (4.5 in.) in diameter.
- Spatula: having a blade 75 to 100 mm (3 to 4 in.) long and about 20 mm (3/4 in.) wide.
- Liquid Limit Device: manually or mechanically operated, consisting of a brass cup, carriage, and base plate and conforming to the critical dimensions shown in AASHTO T 89 Figure 1.
- Grooving Tool: used to cut the soil in the liquid limit device cup and conforming to the critical dimensions shown in AASHTO T 89 Figure 1.

Grooving tool

Alternate Flat Grooving Tool

Figure 1

- Gauge: either part of the grooving tool or a separate metal bar, 10.0 ±0.2 mm (0.394 ±0.008 in.) thick and approximately 50 mm (2 in.) long.
- Containers: corrosion resistant, suitable for repeated heating and cooling, having close fitting lids to prevent the loss of moisture. One container is needed for each moisture content determination.
- Balance: conforming to AASHTO M 231, class G1, sensitive to 0.01 g with a minimum capacity of 100 g.
- Oven: thermostatically controlled, capable of maintaining temperatures of 110 ±5°C (230 ±9°F).
- Graduated cylinders for measuring distilled or demineralized water.
- Sieve: 0.425 mm (No. 40) sieve meeting the requirements of the FOP for AASHTO T 27/T 11.

Adjustment of Liquid Limit Device

The liquid limit device shall be inspected to determine that the device is in good working order; that the pin connecting the cup is not worn to permit side play; that the screws connecting the cup to the hanger are tight; that the points of contact on the cup and base are not excessively worn; that the lip of the cup is not excessively worn; and that a groove has not been worn in the cup. The grooving tool shall be inspected to determine that the critical dimensions are correct.

Note 1: Wear is considered excessive when the point of contact on the cup or base exceeds approximately 13 mm (0.5 in.) in diameter, or when any point on the rim of the cup is worn to approximately 1/2 the original thickness. A slight groove in the center of the cup is not objectionable. If the groove becomes pronounced, the cup shall be replaced. A base that is excessively worn may be refinished as long as it is maintained within the tolerances specified.

Adjust the height of drop of the cup so that the point on the cup that comes in contact with the base rises to a height of 10.0 ±0.2 mm (0.394 ±0.008 in.).

Note 2: Check the height of the drop, before each new sample, by turning the crank at two revolutions per second while holding the gauge in position against the cup. If a ringing or clicking sound is heard without the cup rising from the gauge, the adjustment is correct. If no ringing is heard or if the cup rises from gauge, readjust the height of the drop. If the cup rocks on the gauge during this checking operation, the cam follower pivot is excessively worn and should be replaced.

Sample

Samples must be prepared per the AASHTO R 58 or R 74. Obtain a sample with a mass of about 100 g taken from the portion of the material passing the 0.425 mm (No. 40) sieve.

The mass required depends upon the method chosen. Method A (multi-point method) requires approximately 100 g. Method B (single point method) requires approximately 50 g.

Procedure – Method A (Multi-Point)

1. Determine mass of empty dry container(s) and lid(s) to the nearest 0.01 g.
2. Place the sample in the dish and thoroughly mix with 15 to 20 mL of distilled or demineralized water by alternately and repeatedly stirring, kneading, and chopping with a spatula. Further additions of water shall be in increments of 1 to 3 mL. Each increment shall be thoroughly mixed with the soil before another increment is added. Once testing has begun, no additional dry soil should be added to the moistened soil. The cup of the Liquid Limit device shall not be used for mixing soil and water. If too much water is added, the sample shall either be discarded or mixed and kneaded until natural evaporation lowers the moisture content.

Note 3: Some soils are slow to absorb water. It is possible to add water so fast that a false LL value is obtained. This can be avoided by allowing more mixing and/or time. Also, tap water may be used for routine testing if comparative tests indicate no differences in results between using tap water and distilled or demineralized water.

3. Add sufficient water to form a uniform mass of a stiff consistency.
4. Place enough material in the cup so that, when squeezed and spread with the spatula, the soil will rest in the cup above the spot where the cup rests on the base and will be 10 mm thick at the point of maximum thickness. Use as few strokes of the spatula as possible, taking care to prevent the entrapment of air bubbles in the sample.
5. Divide the soil in the cup with a firm stroke of the grooving tool. Avoid tearing of the sides of the groove or slipping of the soil cake on the cup. Up to six strokes are permitted with a stroke from front to back or from back to front counting as 1 stroke. The depth of the groove should be increased with each stroke, and only the last stroke should scrape the bottom of the cup.
6. Lift and drop the cup by turning the crank at a rate of approximately two revolutions per second until the two halves of the soil pat come together along a distance of about 13 mm (0.5 in.). Do not hold the base while the crank is turned. Record the number of shocks required to close the groove this distance.

Note 4: Some soils tend to slide on the cup instead of flowing. If this occurs, water should be added, the sample remixed, and the procedure repeated. If the soil continues to slide on the cup, the test is not applicable, and a note should be made that the liquid limit could not be determined.

7. Use the spatula to obtain a moisture content sample by slicing through the soil pat perpendicularly to the groove. Remove the sample extending edge to edge and including the portion of the groove that flowed together. Place it into a suitable container and cover for subsequent moisture determination.

8. Determine the moisture percentage of the moisture content sample in accordance with the FOP for AASHTO T 255/T 265 (Soil).
9. Place the soil remaining in the cup back in the mixing dish and add 1 to 3 mL of water or use previously prepared portions to which sufficient water has been added to result in a more fluid condition.
10. Repeat Steps 4 through 9, a minimum of two times. The object is to have a determination in all three shock ranges 25-35, 20-30, and 15-25 and span a range of at least 10 shocks.
11. Determine the moisture content of the moisture content sample in accordance with the FOP for AASHTO T 255/T 265 (Soil). (Remove lids and keep with containers while drying.)

Flow Curve – Method A

Prepare a flow curve on a semi-logarithmic graph with moisture content on the arithmetic vertical axis and the number of shocks on the logarithmic horizontal axis. The flow curve is a straight line drawn as closely as possible through three or more plotted points.

Liquid Limit – Method A

Determine the liquid limit. The moisture content at the intersection of the flow curve and the 25 shock line is the liquid limit.

Procedure – Method B (Single-Point)

1. Determine mass of empty dry container(s) and lid(s) to the nearest 0.01 g.
2. Place the sample in the dish and thoroughly mix with 8 to 10 mL of distilled or demineralized water, and follow the mixing procedure in Method A, Step 1.
3. Follow the procedure in Method A except that the soil pat should be prepared with water to produce a consistency that will close the two halves of the soil pat at least 13 mm (0.5 in.) within 22 to 28 shocks of the cup.

Note 5: Groove closures occurring between 15 and 40 blows may be accepted if variations of ±5 percent of the true liquid limit are tolerable.

4. Return the soil remaining in the cup to the mixing dish and, without adding any additional water, repeat Step 2. If the closure again occurs within the acceptable range and is within 2 shocks of the first, obtain a moisture content specimen as described in Method A.
5. Determine the moisture content of the moisture content sample in accordance with the FOP for AASHTO T 255/T 265 (Soil).
6. Determine the moisture content of the moisture content sample in accordance with the FOP for AASHTO T 255/T 265 (Soil). (Remove lids and keep with containers while drying.)

Liquid Limit – Method B

Calculate the liquid limit as follows:

$$LL = (W_N)(N/25)^{0.121}$$

Where:
LL = liquid limit
w_N = moisture content of sample at N blows
N = number of blows

Example:

w_N = 16.0% and N = 23

$$LL = 16.0\% \times \left(\frac{23}{25}\right)^{0.121} = 15.8\%,\ report\ 16\%$$

Or using Table 1 (when number of shocks to closure of gap is 22-28):

$$LL = 16.0\% \times 0.990 = 15.8\%,\ report\ 16\%$$

Table 1

N	$(N/25)^{0.121}$
22	0.985
23	0.990
24	0.995
25	1.000
26	1.005
27	1.009
28	1.014

Use Method A for referee testing to settle a dispute.

Report

- Results on forms approved by the agency.
- LL rounded to the nearest 1 percent.

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ATM 205 Determining the Plastic Limit and Plasticity Index of Soils

Use WAQTC FOP Module T 90 for AASHTO T 90.

DETERMINING THE PLASTIC LIMIT AND PLASTICITY INDEX OF SOILS FOP FOR AASHTO T 90

Scope

This procedure covers the determination of the plastic limit and plasticity index of soil in accordance with AASHTO T 90-22. It is used in conjunction with the FOP for AASHTO T 89, Determining the Liquid Limit of Soils. The three values are used for soil classification and other purposes. Two procedures, hand rolling and an alternate rolling method, are covered. The hand rolling method is to be used as the referee method.

Apparatus

- Dish: preferably unglazed porcelain or similar mixing dish, about 115 mm (4.5 in.) in diameter.
- Spatula: having a blade 75 to 100 mm (3 to 4 in.) long and about 20 mm (3/4 in.) wide.
- Rolling Surface:
  - A ground glass plate or piece of smooth, unglazed paper.
  - Plastic Limit Rolling Device: (Optional) A device made of acrylic conforming to the dimensions shown in AASHTO T 90 Figure 1.
  - Paper for Rolling Device: Unglazed paper that does not add foreign matter to the soil during the rolling process. Paper is attached to both the top and bottom plates of the rolling device by either spray-on adhesive or self-adhesive backing. Remove all adhesive from the rolling device after each test to prevent buildup.
- Containers: corrosion resistant, suitable for repeated heating and cooling, having close fitting lids to prevent the loss of moisture before initial mass determination and while sample is cooling before final mass determination. One container is needed for each moisture content determination.
- Balance: conforming to AASHTO M 231, class G1, sensitive to 0.01 g with a minimum capacity of 100 g.
- Oven: thermostatically controlled, capable of maintaining temperatures of 110 ±5°C (230 ±9°F).
- Sieve: 0.425 mm (No. 40) sieve meeting the requirements of the FOP for AASHTO T 27/T 11.

Sample

The plastic limit procedure is often run in conjunction with the liquid limit procedure. If this is the case, the plastic limit sample should be obtained from the soil prepared for the liquid limit test, FOP for AASHTO T 89, at any point in the process at which the soil is plastic enough to be easily shaped into a ball without sticking to the fingers excessively when squeezed. Obtain approximately 10 g of soil to run the plastic limit test.

If only the plastic limit is to be determined, the sample must be prepared according to AASHTO R 58 or R 74. Obtain about 20 g of material passing the 0.425 mm (No. 40) sieve. Mix the soil with distilled or demineralized water until the mass becomes plastic enough to be easily shaped into a ball. Use approximately 10 g of the soil ball to run the plastic limit test.

Note 1: Tap water may be used for routine testing if comparative tests indicate no differences in results between using tap water and distilled or demineralized water.

Procedure

1. Determine and record the mass of the container and lid.
2. Obtain a 1.5 to 2 g mass test sample from the initial 10 g.

3. Squeeze and form the test sample into an ellipsoidal-shape mass.
4. Use one of the following methods to roll the mass.
    - Hand Rolling Method—Roll the mass between the fingers or palm and the rolling surface with just sufficient pressure to roll the mass into a thread of uniform diameter along its length. The sample must be rolled into the 3 mm (1/8 in.) thread in no longer than 2 minutes.
    - Alternate Rolling Method, Plastic Limit Device Method—Place the soil mass on the bottom plate. Place the top plate in contact with the soil mass. Roll the mass between the plates with sufficient pressure to form the mass into a thread of uniform diameter along its length so that top plate contacts the side rails within 2 minutes. During this rolling process, do not allow the soil thread to contact the side rails. Rolling multiple threads at once is allowed.
5. Break the thread into six or eight pieces when the diameter of the thread reaches 3 mm (1/8 in.).
6. Squeeze the pieces together between the thumbs and fingers of both hands into an ellipsoidal-shape mass and reroll.

    Continue this process of alternately rolling to a thread 3 mm (1/8 in.) in diameter, cutting into pieces, gathering together, kneading and rerolling until the thread crumbles under the pressure required for rolling and the soil can no longer be rolled into a thread 3 mm in diameter.

    Crumbling may occur when the thread has a diameter greater than 3 mm (1/8 in.). This shall be considered a satisfactory end point, provided the soil has been previously rolled into a thread 3 mm (1/8 in.) in diameter. At no time, shall the tester attempt to produce failure at exactly 3 mm (1/8 in.) diameter. It is permissible, however, to reduce the total amount of deformation for feebly plastic soils by making the initial diameter of the ellipsoidal-shaped mass nearer to the required 3 mm (1/8 in.) final diameter.

Note 2: The crumbling will manifest itself differently with various types of soil. Some soils fall apart in many pieces; others form an outside tubular layer that splits at both ends; splitting progresses toward the middle, and the thread falls apart in small platy particles. Heavy clay requires much pressure to deform the thread, particularly as it approaches the plastic limit, and the thread breaks into a series of barrel-shaped segments each 6 to 9 mm (1/4 to 3/8 in.) long.

7. Gather the portions of the crumbled soil together, place in the moisture content container and cover.
8. Repeat steps one through seven until 10 g of sample have been tested and placed in the covered container.
9. Determine the moisture content of the sample in accordance with the FOP for AASHTO T 255/T 265 (Soil) and record the results. (Remove lids and keep with containers during drying.)

Plastic Limit

The moisture content, as determined in Step 9 above, is the Plastic Limit.

Note 3: It is advisable to run several trials on the same material to ensure a proper determination of the Plastic Limit of the soil.

Plasticity Index

The Plasticity Index (PI) of the soil is equal to the difference between the Liquid Limit (LL) and the Plastic Limit (PL). If either the liquid limit or plastic limit cannot be determined, report the plasticity index as NP (non-plastic). If the plastic limit is equal to, or greater than the liquid limit, report the plasticity index as NP.

$$PI = LL - PL$$

Examples:

No. 1	No. 2
LL = 34 and PL = 17	LL = 16 and PL = 10
PI = 34 – 17 = 17	PI = 16 – 10 = 6

Example Calculation

Container	Container Mass, g	Container and Wet Soil Mass, g	Wet Soil Mass, g	Container and Dry Soil Mass, g	Dry Soil Mass, g
1	14.44	25.21	10.77	23.62	9.18
2	14.18	24.84	10.66	23.90	9.72

Water Mass, g	Moisture Content	Plastic Limit
1.59	17.3%	17
0.94	9.7%	10

Report

- Results on forms approved by the agency
- PL and PI rounded to the nearest 1 percent and reported as a whole number.

ATM 206 pH of Topsoil

1. Scope

This method describes the procedure for determining the pH of topsoil.

2. Apparatus

- A soil test kit capable of determining the pH of soils. These are available from commercial greenhouses. Verify reagent expiration dates and replace as needed.
- pH Meter—Calibrate according to manufacturer's recommendations.
- 2.00 mm (No. 10) sieve conforming to ASTM E11.

3. Sampling and Sample Preparation

1. Obtain the sample in accordance with WAQTC FOP for AASHTO T 2 (ASTM D75).
2. Prepare the soil sample in accordance with AASHTO R 58 and the manufacturer's instructions for the soils kit.

4. Procedure

1. Separate sample on a 2.00 mm (No. 10) sieve. Discard the plus 2.00 mm (No. 10) material unless required for other testing.
2. Determine the pH of the minus 2.00 mm (No. 10) material in accordance with the manufacturer's instructions.

5. Report

- PH value to the nearest 0.5.

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ATM 207 Moisture Density Relations of Soil

The following are DOT&PF guidelines for using WAQTC FOP for AASHTO T 99/T 180.

1. ASTM D4253 or ATM 212 are more appropriate to determine standard density values for compaction control of non-plastic or manufactured aggregate materials.

2. Moisture content shall be determined using the mass requirements listed in table 2 of WAQTC FOP for AASHTO T 255/T 265.

3. Under Table 1 and 2 insert:

   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 Annex B of this method, is used in the calculations.

4. For Procedure step #5, to attain a true representation based on the volume of the mold, use a No. 4, No. 8, or No. 10 sieve to generate fine material suitable for filling any voids remaining after trimming.

5. In order to properly draw the moisture-density curve, it may be helpful to plot a Zero Air Voids (ZAV) curve. The ZAV curve must be to the right of the wet side of the curve. To plot the curve, you will need to establish the specific gravity of the soil. Specific gravity of the soil can be estimated, assumed to be 2.700, or it can be determined in accordance with AASHTO T 100.

6. The points for plotting the ZAV shall be calculated by selecting dry unit masses and calculating a corresponding moisture content value as follows:

$$W_s = \frac{(\gamma_w)G_s - \gamma_d}{(\gamma_d)(G_s)} \times 100$$

   Where:
   W_s = Water content for complete saturation, %
   γ_w = Unit Mass of water 9.789 kN/m^3 (62.4 lbf/ft^3)
   γ_d = Dry unit mass of soil, kN/m^3 (lbf/ft^3)
   G_s = Specific Gravity of soil or G_{avg} as described below

7. When the material includes plus 4.75 mm (No. 4) materials, the plus 4.75 mm (No. 4) specific gravity may be estimated, assumed to be 2.700 or it can be tested in accordance with WAQTC FOP for AASHTO T 85. If a weighted average is used, it shall be calculated as follows:

$$G_{avg} = \frac{1}{\frac{R_1}{100G_1} + \frac{P_1}{100G_2}}$$

   Where:
   G_{avg} = Weighted average specific gravity of soils
   R_1 = Percent of soil particles retained on the 4.75 mm (No. 4) sieve
   P_1 = Percent of soil particles passing the 4.75 mm (No. 4) sieve
   G_1 = Apparent specific gravity of soil particles retained on the 4.75 mm (No. 4) sieve
   G_2 = Specific gravity of soil particles passing the 4.75 mm (No. 4) sieve

8. The use of an extruder is optional when the sample being tested is granular.

9. Calculate wet density by Measured Volume as shown in Calculations 1.

Annex A

1. The maximum allowable oversized (+19 mm [3/4 in]) material is 40 percent. The maximum dry density to be used with material containing 30 to 40 percent oversized is the oversized correction calculated at 30 percent.

2. Along with density, the moisture content can be corrected. The moisture content can be determined by the FOP for AASHTO T 255 / T 265, other agency approved methods, or the nuclear density gauge moisture content reading from the FOP for AASHTO T 310. If the nuclear gauge moisture reading is used, or when the moisture content is determined on the entire sample (both fine and oversized particles), the use of the "Optimum Moisture Correction Equation" is not needed. Combined moisture contents with material having an appreciable amount of silt or clay should be performed using FOP for AASHTO T 255 / T 265 (Soil). Moisture contents used from FOP for AASHTO T 310 must meet the criteria for that method.

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 (¾ 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 (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 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 ±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.), 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

	T 99	T 180
Mold Volume, m^3	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 B: 7 Method C: 5 (1) Method D: 11(1)	
Energy, $kN\text{-}m/m^3$	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: 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

	T 99	T 180
	Methods C, D: 3/4 minus	Methods C, D: 3/4 minus
Test Sample Size, lb	Method A: 7 Method C: 12(1)	Method B: 16 Method D: 25(1)
Energy, lb-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.

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

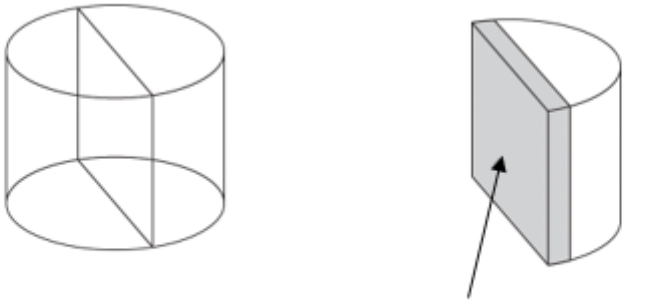
During compaction, rest the mold firmly on a dense, uniform, rigid, and stable foundation, or base. This base shall remain stationary during the compaction process.

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 (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 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 (ρ_w), in kg/m^3 (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:

ρ_w = wet density, kg/m^3 (lb/ft^3)
M_w = wet mass
V_m = volume of the mold, Annex B

Dry Density

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

Where:

ρ_d = dry density, kg/m^3 (lb/ft^3)
w = moisture content, as a percentage

Example for 4-inch mold, Methods A or C

Wet mass, M_w = 1.928 kg (4.25 lb)

Moisture content, w = 11.3%

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

Wet Density

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

Dry Density

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

Or

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

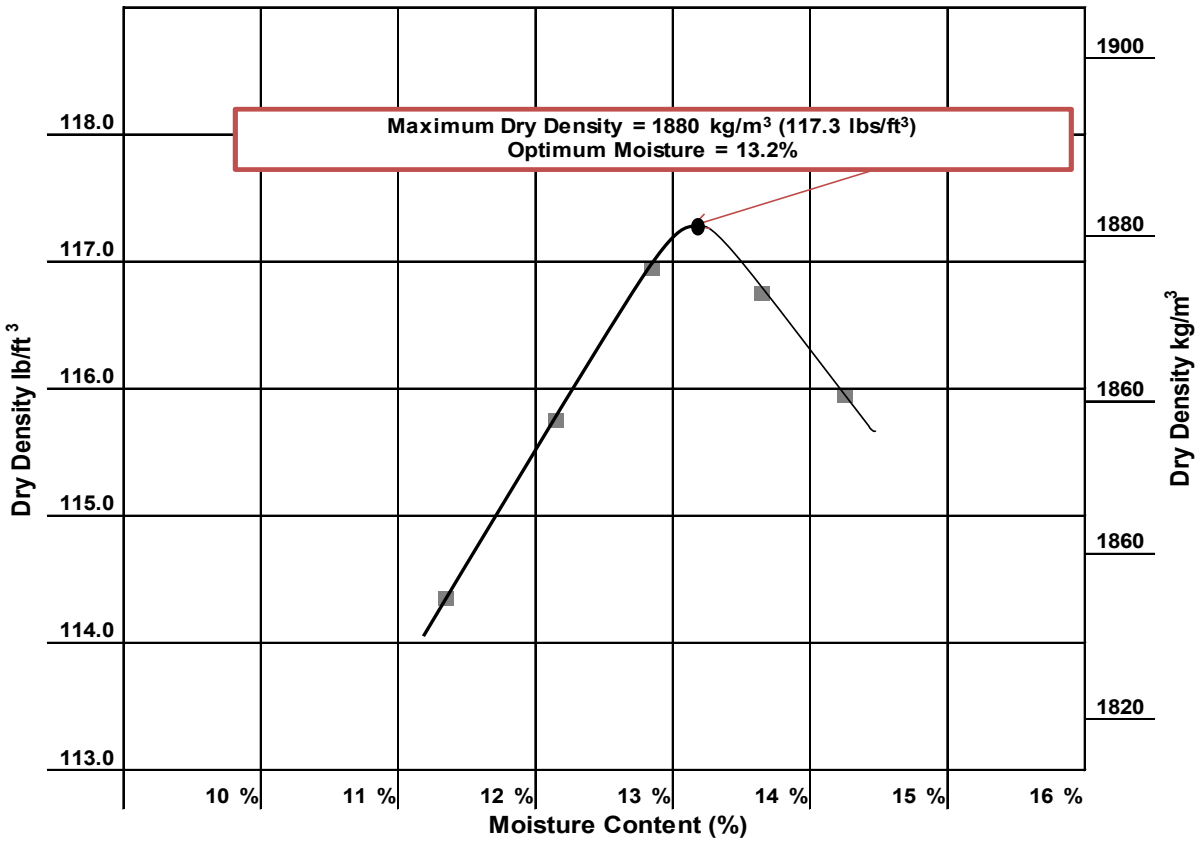
Moisture-Density Curve Development

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	%
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^3 (117.3 lb/ft^3)
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^3 (0.1 lb/ft^3)
- 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 60ºC (140ºF).
   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.

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

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.

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

And

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

Or for $\mathbf{P_c}$:

$$P_c = 100 - P_f$$

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:

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

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 (ρ_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:

ρ_d = corrected total dry density (com d fine and oversized particles) kg/m^3 (lb/ft ^{3})
ρ_f = dry density of the fine particles kg/m^3 (lb/ft^3), 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^3).
k = English: 62.4 * Bulk Specific Gravity (G_{sb}) (oven dry basis) of coarse particles (lb/ft^3)

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 (ρ_f):	1880 kg/m^3
Percent coarse particles (P_c):	27%
Percent fine particles (P_f):	73%
Mass per volume coarse particles (k):	(2.697) (1000) = 2697 kg/m^3

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

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

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

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

English:

Maximum laboratory dry density (ρ_f): 117.3 lb/ft^3
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^3

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

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

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

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

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

Report

- On forms approved by the agency
- Sample ID
- Corrected maximum dry density to the nearest 1 kg/m^3 (0.1 lb/ft^3)
- 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
ρ_{water} = density of water at the measured temperature

Example

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

ρ_{water} at 23°C (73.4°F) = 997.54 kg/m^3 (62.274 lb/ft^3)

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

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

°C	(°F)	kg/m^3	(lb/ft^3)	°C	(°F)	kg/m^3	(lb/ft^3)
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 m^3 (0.0001 ft^3)

ATM 211 Density of Soil In-Place by the Sand-Cone Method

1. Scope

This method is a Field Operating Procedure adapted from AASHTO T 191. It is intended for use in determining the in-place density of soils. The apparatus described herein is restricted to tests in soils containing maximum particle size not larger than 1½ in.

2. Referenced Documents

- WAQTC Standards:
  - FOP for AASHTO T 99/ T 180, Moisture-Density Relations of Soils
  - FOP for AASHTO T 255/ T 265, Total Evaporable Moisture Content of Aggregate by Drying and Laboratory Determination of Moisture Content of Soils
- AASHTO Standards:
  - AASHTO T 19, Bulk Density ("Unit Weight") and Voids of Aggregate
  - AASHTO T 191, Density of Soil In-Place by the Sand-Cone Method

3. Significance and Use

This method has been created to have an alternate when circumstances make having a nuclear gauge for density testing difficult, if not impossible.

4. Apparatus

- Sand-cone apparatus with base plate conforming to AASHTO T 191
- Sturdy cylindrical container of known volume (V), dimensionally approximate to the largest test hole that will be dug and calibrated according to AASHTO T 19M/T 19.
- Any clean, dry, free-flowing, uncemented sand composed mostly of particles retained on the No. 200 and passing the 2.00-mm (No. 10) sieves. Determine the bulk density from multiple determinations using the same representative sample for each determination. Any sand having a variation in bulk density less than 1 percent is acceptable.
- Balances conforming to the requirements of M 231, one with capacity of at least 16 kg readable to 1g and the other with a capacity of at least 5 kg readable to 0.1g.
- Stove or oven or other suitable equipment for drying moisture content samples
- Containers, clean, dry and capable of being sealed
- Suitable drying containers
- Small pick, chisels, screw drivers and/or spoons for digging test hole

5. Bulk Density of Sand and Cone Correction (C)

1. Fill the apparatus by:
   a. Place the empty sand-cone apparatus upright on a firm level surface and fill with sand.

      Note 1: Appreciable time intervals between the bulk density determination of the sand and its use in the field may result in change in the bulk density caused by a change in the moisture content or effective gradation.

b. Determine and record the initial mass of the sand-cone apparatus filled with sand (m_i).

2. Determining the bulk density of sand (ρ_b) to be used in the field test.

   a. Determine the mass of the empty calibration container (m_t).

   b. Position the calibration container on a clean, level, plane surface. Invert the apparatus and seat the funnel over the calibration container.

   c. Open the valve fully and keep open until the sand stops flowing .

   d. Close the valve sharply, and remove the sand-cone apparatus from the calibration container.

   e. Strike off the sand even with the top of the calibration container being careful to not disturb the sand in the container. Determine the mass of the calibration container and sand (m_f).

   f. Determine and record the bulk density of the sand (ρ_b) by dividing the mass of the sand needed to fill the calibration container (m_f - m_t), by it's volume (V) as determined according to T 19M/T 19.

$$\rho_b = \frac{m_f - m_t}{V}$$

3. Determine the volume of sand required to fill the funnel and base plate (C).

   a. Fill the sand-cone apparatus, determine and record the mass in accordance with step 1.

   b. Place the base plate on a clean, level, plane surface. Close the valve and invert the sand-cone apparatus filled with sand and seat the funnel in the recess of the base plate.

   c. Open the valve fully; allow the sand to flow until the sand stops flowing.

   d. Close the valve sharply, remove the sand-cone apparatus and determine the final mass of the sand-cone apparatus and the remaining sand (m_f).

   e. Determine the volume of the cone and base plate (C) by dividing the mass of sand required to fill the cone and base plate ($m_i - m_f$) by the density of the sand (ρ_b). (Note 2).

$$C = \frac{m_i - m_f}{\rho_b}$$

Note 2: For each lot of sand there will be a unique bulk density. If the lot consists of several bags, verify that each bag is within 1% of the lot density. Each sand-cone and matched base plate will also have a unique volume. If more than one sand cone apparatus is available, the sand-cone and base plate should be marked and the associated volume recorded.

6. Procedure

1. Determine the density of the soil in place as follows:

   a. Fill the sand-cone apparatus with sand. Record the initial mass of the sand and sand-cone apparatus (m_i).

   b. Fill in surface voids with fines of the material being tested passing the 4.75 mm (No. 4) sieve or finer. Smooth the surface with the base plate or other suitable tool. The depth of the filler should not exceed approximately 3 mm (1/8 in.).

   c. Place the base plate on the prepared surface and seat. Remove the material from the test hole by digging the soil out, being careful to avoid disturbing the soil that will bound the hole. Soils that are

granular require extreme care. Remove all loosened soil and place in a container, being careful to avoid losing any material. Care must be taken to avoid moisture loss during excavation. The test hole volume must conform to those given in Table 1.

Table 1

Maximum Particle Size		Minimum Test Hole, Volume	
mm	Alternate	cm^3	ft^3
4.75	No. 4	710	0.0250
12.5	½"	1415	0.0500
25.0	1"	2125	0.0750
37.5	1 ½"	2830	0.1000

d. Close the valve and invert the sand-cone apparatus filled with sand and seat the funnel in the recess of the base plate.

e. Open the valve fully; allow the sand to flow until the sand stops flowing.

f. Close the valve sharply, remove the sand-cone apparatus and determine the final mass of the sand-cone apparatus and the remaining sand (m_f).

g. Determine the final mass of the apparatus with the remaining sand (m_f) and record.

h. Determine the mass of the moist material that was removed from the test hole.

i. Mix the material thoroughly and determine the moisture content in accordance with WAQTC FOP for AASHTO T 255/ T 265.

7. Calculation

1. Calculate the volume of the test hole (V_h) to the nearest 0.0001 ft^3:

$$V_h = \frac{m_i - m_f}{\rho_b} - C$$

Where:

V_h = volume of the test hole,
m_i = initial mass of the apparatus and sand,
m_f = final mass of the apparatus and sand,
C = Cone Correction, and
ρ_b= bulk density of the sand.

2. Determine the dry mass of the material removed from the test hole to the nearest 1 g by either drying the entire sample or calculate as follows:

$$M_d = \frac{M_w}{\left(1 + \left(\frac{w}{100}\right)\right)}$$

Where:

M_d = dry mass of the material removed from the test hole,
M_w = moist mass of the material removed from the test hole, and
w = moisture content of the material removed from the test hole as determined by WAQTC FOP for AASHTO T 255/ T 265.

3. Calculate the in-place dry density of the material removed from the test hole as follows:

$$\rho_d = \frac{M_d}{V_h}$$

Where:

ρ_d = in-place dry density of the material removed from the test hole,
M_d = dry mass of the material removed from the test hole, and
V_h = volume of the test hole (from Calculations Step 1)

4. Calculate the in-place dry density to the nearest 0.1 lb/ft^3.
5. Calculate the percentage compaction by dividing the in-place dry density by the standard density determined in accordance with WAQTC FOP for AASHTO T 99/ T 180, ATM 212, or ATM 309, and report to the nearest 0.1 percent.

8. Report

Results shall be reported on standard forms approved by the Department. Report the following information:

- Date and location of test.
- Calibration bulk density of the sand
- Identification of the standard density used
- Volume of the test hole, 0.0001 ft^3
- In-place dry density, 0.1 lb/ft^3
- Percent compaction, 0.1%

ATM 212 Determining the Standard Density of Coarse Granular Materials Using the Vibratory Compactor

1. Scope

This method determines the maximum density values of granular materials for a standard compaction energy. The method accounts for variations in the maximum attainable density of a given material due to fluctuations in gradation.

With the specific gravity and the compacted density of the plus 4.75 mm (no. 4) and the minus 4.75 mm (No. 4) fractions, a chart and/or curve of standard density values versus percent passing the No. 4 sieve can be plotted.

This test method is conducted using the minus 75 mm (3 in) portion of the sample. It applies to free-draining cohesionless materials with the minus 4.75 mm (No. 4) portion of the sample having 10 percent or less passing the 75 µm (No. 200) sieve.

Note 1: The Vibratory Compaction Test was developed for sandy gravels whose fine fraction is non-plastic and highly permeable or free draining. When the fine fraction is primarily a soil with some plasticity and low permeability or not free draining, WAQTC FOP for AASHTO T 99/T 180 will be used. With borderline materials, both tests shall be applied, and the one yielding the highest unit weight value will be used.

2. Apparatus

- A vibratory spring-loaded compactor essentially conforming to specifications that can be obtained from the State Materials Engineer or the Vibratory Table specified in ASTM D4253.
- Standard Mold and base with a piston to fit inside the mold that has a maximum 1.5 mm (1/16 in) clearance between piston and mold.
- A 0.014 m^3 (1/2 ft^3) mold with a piston to fit inside mold that has a maximum 1.5 mm (1/16 in) clearance between piston and mold.

  Note 2: The molds and pistons will be constructed of metal of such dimensions as to remain rigid and inflexible under test conditions.
- Spacer blocks of varying heights compatible with the compactor and pistons.
- Measuring device, accurate and readable to 0.1 mm (0.01 in) with a minimum 150 mm (6 in) length.
- A 75 mm (3 in) and a 4.75 mm (No. 4) sieve conforming to AASHTO M 92 (ASTM E11) requirements.
- Balance or scale: Capacity sufficient for the sample mass, readable to 0.1 percent or 0.1 g and meeting the requirements of AASHTO M 231.

  Note 3: The compaction tests require a scale with a capacity of at least 40 kg (90 lb),readable to 5 g (0.01 lb) or better.

  Note 4: The moisture content tests require a scale with a capacity of at least 1000 g and readable to 0.1 g or better.
- A 2.5 kg (5.5 lb) metal rammer conforming to the requirements of WAQTC FOP for AASHTO T 99/T 180.
- Tamping rod of straight steel, 16 mm (5/8 in) in diameter and approximately 600 mm (24 in) long having at least one end rounded to a hemispherical tip.
- Graduated cylinder, 1000 ml capacity, readable to 5 ml.
- A stopwatch or timer accurate to 1 second.
- Miscellaneous tools including pans, spoon, trowel, mechanical mixer (optional), etc.

3. Mold Calibration

The following calibration of test apparatus should be performed before initial use and at intervals not exceeding 1000 tests, or annually, whichever occurs first. Additionally, the ATM apparatus or Vibrating Table should be calibrated after any event (including repairs) which might affect its operation.

Molds – Determine the volume of each mold by the water-filling method described below. Enter data and perform calculations on the included worksheet.

1. Measure inside height of cylindrical mold to nearest 0.001 inch at three locations around mold circumference approximately 120 degrees apart and record as (**h_1**, **h_2**, **h_3**).
2. Average the three inside height readings, divide by 12 to convert from inches to feet, and record as (**h**), Average Inside Mold Height (ft). Equation: **h** = (**h_1** + **h_2** + **h_3**) / (**3** x **12**)
3. Measure thickness of steel top plate, that confines soil in mold, to nearest 0.001 inch at three locations around plate circumference approximately 120 degrees apart and record as (**t_1**, **t_2**, **t_3**).
4. Average the three plate thickness readings and record as (**t**), Average Plate Height.
5. Determine mass of mold, glass cover plate, and any grease or silicone lubricant used on mold rim to make a watertight seal with the glass plate to nearest 0.001 lb Record as (**b**), Mass of Mold + Glass.
6. Fill mold with room temperature water and record water temperature to nearest 0.1^0F under (**d**), Water Temperature.
7. Look up the water density for this temperature in the included "Table 1: Water Density variation with Temperature" and record this density under (**e**), Water Density.
8. Determine mass of mold, water and glass cover plate to nearest 0.001 lb and record as (**a**), Mass of Mold + Glass + Water.
9. Determine Water Mass, (**c**) required to fill mold completely, by subtracting mass of mold and plate (**b**) from mass of mold, plate, and water (**a**). Equation: **c** = **a** - **b**
10. Calculate Mold Volume (**f**). Density = Mass / Volume. Solving for Volume gives: Volume = Mass / Density. The Volume of water contained = Mold Volume. Equation: **f** = **c** / **e**
11. Calculate Mold Cross-Sectional Area (**g**). Volume of a cylinder = Area of base x Height, (or Mold Cross-Sectional Area x Height). Solving for Mold Cross-Sectional Area gives:

    Mold Cross-Sectional Area = Volume / Height. Equation: **g** = **f** / **h**

CALIBRATION DATA & CALCULATIONS	Formulae	Data and Calculations			
			h_1 (in)	h_2 (in)	h_3 (in)
h. Mold Inside Height Readings (in)					
Average Height (ft)	$(h_1+h_2+h_3)/36$				
a. Mass of Mold + Glass + Water (lb)					
b. Mass of Mold + Glass (lb)					
c. Water Mass (lb)	c = a - b				
d. Water Temperature (^{0}C)					
e. Water Density (lbm/ft^3 at temp d)					
f. Water Volume = Mold Volume (ft^3)	f = c/e				
g. Mold Cross-Sectional Area (ft^2)	g = f/h				
			t_1 (in)	t_2 (in)	t_3 (in)
t. Top Plate Thickness Readings (in)					
Average Thickness (ft)	$(t_1+t_2+t_3)/36$				

Table 1: Water Density variation with Temperature								
Temp	**Water Density, ρ**		**Temp**	**Water Density, ρ**		**Temp**	**Water Density, ρ**	
^{0}C	g/cm^3	lbm/ft^3	^{0}C	g/cm^3	lbm/ft^3	^{0}C	g/cm^3	lbm/ft^3
15.0	**0.9991016**	62.37187	**20.0**	**0.9982063**	62.31598	**25.0**	**0.9970480**	62.24367
15.1	0.9990864	62.37092	20.1	0.9981856	62.31469	25.1	0.9970223	62.24206
15.2	0.9990712	62.36997	20.2	0.9981649	62.31339	25.2	0.9969965	62.24045
15.3	0.9990558	62.36901	20.3	0.9981440	62.31209	25.3	0.9969707	62.23884
15.4	0.9990403	62.36804	20.4	0.9981230	62.31078	25.4	0.9969447	62.23722
15.5	0.9990247	62.36707	20.5	0.9981019	62.30946	25.5	0.9969186	62.23559
15.6	0.9990090	62.36609	20.6	0.9980807	62.30814	25.6	0.9968925	62.23396
15.7	0.9989932	62.36510	20.7	0.9980594	62.30681	25.7	0.9968663	62.23233
15.8	0.9989772	62.36411	20.8	0.9980380	62.30547	25.8	0.9968399	62.23068
15.9	0.9989612	62.36311	20.9	0.9980164	62.30412	25.9	0.9968135	62.22903
16.0	**0.9989450**	62.36209	**21.0**	**0.9979948**	62.30278	**26.0**	**0.9967870**	62.22738
16.1	0.9989287	62.36108	21.1	0.9979731	62.30142	26.1	0.9967604	62.22571
16.2	0.9989123	62.36005	21.2	0.9979513	62.30006	26.2	0.9967337	62.22405
16.3	0.9988957	62.35902	21.3	0.9979294	62.29869	26.3	0.9967069	62.22237
16.4	0.9988791	62.35798	21.4	0.9979073	62.29731	26.4	0.9966800	62.22070
16.5	0.9988623	62.35693	21.5	0.9978852	62.29593	26.5	0.9966530	62.21901
16.6	0.9988455	62.35588	21.6	0.9978630	62.29455	26.6	0.9966259	62.21732
16.7	0.9988285	62.35482	21.7	0.9978406	62.29315	26.7	0.9965987	62.21562
16.8	0.9988114	62.35375	21.8	0.9978182	62.29175	26.8	0.9965714	62.21392
16.9	0.9987942	62.35268	21.9	0.9977957	62.29035	26.9	0.9965441	62.21221
17.0	**0.9987769**	62.35160	**22.0**	**0.9977730**	62.28893	**27.0**	**0.9965166**	62.21049
17.1	0.9987595	62.35051	22.1	0.9977503	62.28751	27.1	0.9964891	62.20878
17.2	0.9987419	62.34942	22.2	0.9977275	62.28609	27.2	0.9964615	62.20706
17.3	0.9987243	62.34832	22.3	0.9977045	62.28465	27.3	0.9964337	62.20532
17.4	0.9987065	62.34721	22.4	0.9976815	62.28322	27.4	0.9964059	62.20358
17.5	0.9986886	62.34609	22.5	0.9976584	62.28178	27.5	0.9963780	62.20184
17.6	0.9986706	62.34496	22.6	0.9976351	62.28032	27.6	0.9963500	62.20009
17.7	0.9986525	62.34383	22.7	0.9976118	62.27887	27.7	0.9963219	62.19834
17.8	0.9986343	62.34270	22.8	0.9975883	62.27740	27.8	0.9962938	62.19659
17.9	0.9986160	62.34156	22.9	0.9975648	62.27593	27.9	0.9962655	62.19482
18.0	**0.9985976**	62.34041	**23.0**	**0.9975412**	62.27446	**28.0**	**0.9962371**	62.19305
18.1	0.9985790	62.33925	22.1	0.9975174	62.27297	28.1	0.9962087	62.19127
18.2	0.9985604	62.33809	23.2	0.9974936	62.27149	28.2	0.9961801	62.18949
18.3	0.9985416	62.33691	23.3	0.9974697	62.26999	28.3	0.9961515	62.18770
18.4	0.9985228	62.33574	23.4	0.9974456	62.26849	28.4	0.9961228	62.18591
18.5	0.9985038	62.33455	23.5	0.9974215	62.26699	28.5	0.9960940	62.18411
18.6	0.9984847	62.33336	23.6	0.9973973	62.26548	28.6	0.9960651	62.18231
18.7	0.9984655	62.33216	23.7	0.9973730	62.26396	28.7	0.9960361	62.18050
18.8	0.9984462	62.33096	23.8	0.9973485	62.26243	28.8	0.9960070	62.17868
18.9	0.9984268	62.32974	23.9	0.9973240	62.26090	28.9	0.9959778	62.17686
19.0	**0.9984073**	62.32853	**24.0**	**0.9972994**	62.25936	**29.0**	**0.9959486**	62.17504
19.1	0.9983877	62.32730	24.1	0.9972747	62.25782	29.1	0.9959192	62.17320
19.2	0.9983680	62.32607	24.2	0.9972499	62.25627	29.2	0.9958898	62.17137
19.3	0.9983481	62.32483	24.3	0.9972250	62.25472	29.3	0.9958603	62.16952
19.4	0.9983282	62.32359	24.4	0.9972000	62.25316	29.4	0.9958306	62.16767
19.5	0.9983081	62.32233	24.5	0.9971749	62.25159	29.5	0.9958009	62.16582
19.6	0.9982880	62.32108	24.6	0.9971497	62.25002	29.6	0.9957712	62.16396
19.7	0.9982677	62.31981	24.7	0.9971244	62.24844	29.7	0.9957413	62.16209
19.8	0.9982474	62.31855	24.8	0.9970990	62.24685	29.8	0.9957113	62.16022
19.9	0.9982269	62.31727	24.9	0.9970735	62.24526	29.9	0.9956813	62.15835

4. Sample Preparation

1. Sample the material in accordance with WAQTC FOP for AASHTO T 2 (ASTM D75). Initially prepare the field sample by splitting out representative portions in accordance with WAQTC FOP for AASHTO T 248, Method A, to provide sufficient material for the following tests:

    a. Retain an as-received compaction sample of approximately 20 kg (45 lb) to be used if verification of the end result "Maximum Dry Density vs. the Percent Passing 4.75 mm (No. 4) Sieve" curve is needed. (See Section 11, Supplementary Requirement.)

    b. Sieve Analysis in accordance with WAQTC FOP for AASHTO T 27/T 11.

    c. Coarse Aggregate Apparent Specific Gravity in accordance with WAQTC FOP for AASHTO T 85.

    d. Fine Aggregate Apparent Specific Gravity in accordance with AASHTO T 84 or AASHTO T100.

    e. Compaction sample to provide sufficient material for the compaction specimens detailed below.

5. Dry the compaction sample to constant mass in accordance with the aggregate section of WAQTC FOP for AASHTO T 255/ T 265.

6. Scalp the plus 75 mm (3 in) material from the compaction sample (e.) and discard, if not needed for any other tests. Separate the remainder of the compaction sample into coarse [minus 75 mm (3 in) to 4.75 mm (No. 4)] and fine [minus 4.75 mm (No. 4)] aggregate fractions.

7. The quantity of material necessary to complete tests on both fractions is:

    a. Fine aggregate, minimum of 3 portions approximately 6 kg (13 lb) each.

    b. Coarse aggregate:

        1) For material containing 5 percent or less of 19.0 mm (3/4 in) material, a portion of the minus 19.0 mm (3/4 in) aggregate of approximately 6 kg (13 lb).

        2) For material containing more than 5 percent plus 19.0 mm (3/4 in) aggregate a portion of 18 to 20 kg (40 to 45 lb).

5. Procedure

1. Compaction Test of the Fine Fraction:

    a. Assemble the Standard Mold and determine its mass, along with the Piston, to the nearest 5 g (0.01 lb). Record this as the Mass of Mold Assembly.

    b. Using one of the fine aggregate portions, add an amount of water estimated to produce a saturated sample when compacted and mix thoroughly.

        1) When the material is at its saturation point, free water (a drop or two) will show at the base of the mold at about the 227 kg (500 lb) load of the first compression run. The ideal saturation point would be a bead of water around the base of the mold at the end of the 10-minute compaction run. Most materials will yield the highest density at that moisture content. Some materials may continue to gain density at higher moisture contents; however, this is due to the washing out of fines, which will alter the character of the sample. Therefore, if severe washing-out or pumping of fines occurs (as evidenced by dirty water flooding off of the base or pumped on top of the piston), the sample is beyond the saturation point, will be discarded and a lower moisture content tried for the saturation point.

        2) Moisture contents beyond the saturation point need not be tested.

c. Set the piston aside and place the sample in the mold in three approximately equal layers. Consolidate each lift by 25 strokes of the tamping rod followed by 25 blows of the manual rammer. If severe displacement of the material occurs, adjust the blow strength by limiting the height of each blow to produce the maximum compaction and minimum displacement. The surface of the top lift should be finished as level as possible.

d. Place the piston on top of the sample and mount the mold on the jack platform in the compactor. Spacers between the load spring and piston must be used to adjust the elevation of the mold so the hammers strike the mold in the center of the lift area. Elevate the mold until the loading head seats on top of the piston. Apply an initial seating load of approximately 45 kg (100 lbs) on the sample.

e. Start the vibratory hammers and, by elevating the jack, begin the loading application rate procedure.

The load application rate to 2000 lbs. is applied as follows:

Load	Elapsed Time
0 to 225 kg (500 lb)	**1 minute**
225 kg to 450 kg (1000 lb)	**1-1/2 minutes**
450 kg to 900 kg (2000 lb)	**2 minutes**

f. Upon reaching the 900 kg (2000 lb) load at the end of the 2-minute cycle, stop the hammers, release the load on the jack, and return to zero pressure.

g. Repeat Steps (e) and (f) four additional times. After the last run remove the mold from the compactor.

h. Measure the height of the compacted sample, to the top of the piston, to the nearest 0.1 mm (0.01 in) by measuring from the top of the mold to the surface of the sample at a minimum of 4 different places evenly spaced around the circumference of the mold. Record and average these measurements. Subtract this average from the overall height of the mold and record as the Height of Sample.

i. Determine the mass of the specimen in the mold to the nearest 5 g (0.01 lb). Record this as Mass of Mold Assembly + Aggregate.

j. Remove the specimen from the mold and determine the moisture content in accordance with WAQTC FOP for AASHTO T 255, recording the data on the Vibratory Compaction Worksheet.

k. Repeat Steps (b) thru (j) at lower or higher moisture content increments of approximately 1 percent intervals to determine the maximum density value for the material. Three tests are usually sufficient.

2. Compaction Test of the Coarse Fraction:

a. For minus 19 mm (3/4 in) aggregates:

1) Determine the mass of the coarse aggregate to the nearest 5 g (0.01 lb). Record this mass as Net Mass of Coarse Aggregate.

2) Add 2.5 percent moisture to the sample, mix thoroughly and place in the Standard CBR mold in approximately three equal lifts. Compact each lift with 25 blows of the tamping rod (omit hammering). Avoid the loss of any material during this operation, or the net mass of coarse aggregate must be determined again, after determining the height of the sample and drying the material to constant mass.

3) Follow the procedures outlined in Steps 5.1.d. through 5.1.h.

b. For plus 19 mm (3/4 in) aggregates:

1) Determine the mass of the coarse aggregate to the nearest 5 g (0.01 lb) or better. Record this mass the Net Mass of Coarse Aggregate.

2) Divide the sample into three representative and approximately equal portions.

3) Place one of the portions into the 0.014 m^3 (1/2 ft^3) mold. Level the surface by hand and consolidate the layer with 25 strokes of the tamping rod, using the rounded end. Distribute the strokes evenly over the entire cross section of the material rodding full depth, if possible, without hitting the bottom too hard.

4) Repeat this procedure for the other lifts, penetrating, if possible, into the lower layer. Avoid the loss of any material during this operation, or the net mass of coarse aggregate must be re-determined after determining the height of the sample. Position the piston on the sample, mount the mold in the compactor and follow the procedure described in Steps 5.1.d. through 5.1.h.

6. Calculations

Calculate the dry density of each of the fine and coarse aggregate fractions following steps 1-17 below. The maximum dry density for the fine aggregate fraction is the highest density at or below the saturation point.

1. Enter mold inside height (**a**) from current mold calibration form.
2. Enter mold cross-sectional area (**b**) from current mold calibration form.
3. Enter thickness of steel top plate (**c**), that confines aggregate in mold, from current mold calibration form.
4. Determine mass of empty mold and top plate (**d**) to nearest 0.001 lb.
5. Determine mass of mold + aggregate + top plate (**e**) to nearest 0.001 lb.
6. Subtract mass of empty mold and top plate (**d**) from aggregate filled mold assembly (**e**) to get mass of aggregate (**f**). Equation: $\mathbf{f} = \mathbf{e} - \mathbf{d}$
7. After compaction take four height measurements from top of mold to top of plate, approximately 90 degrees apart, record as ($\mathbf{d_1}$, $\mathbf{d_2}$, $\mathbf{d_3}$, $\mathbf{d_4}$), then average the four values and convert to feet (**g**). Equation: $\mathbf{g} = (\mathbf{d_1} + \mathbf{d_2} + \mathbf{d_3} + \mathbf{d_4}) / (4 \times 12)$
8. Subtract distance from top of mold to top plate (**g**) + thickness of top plate (**c**) from mold height (**a**) to get height of aggregate (**h**). Equation: $\mathbf{h} = \mathbf{a} - \mathbf{c} - \mathbf{g}$
9. Calculate aggregate volume (**i**) by multiplying mold cross-sectional area (**b**) by the aggregate height (**h**). Equation: $\mathbf{i} = (\mathbf{b})(\mathbf{h})$
10. Calculate Wet Density of Compacted Aggregate (**j**) by dividing aggregate mass (**f**) by aggregate volume (**i**). Equation: $\mathbf{j} = \mathbf{f}/\mathbf{i}$
11. Determine the tare mass (**k**) of pan to be used for a wet aggregate moisture test.
12. Remove the wet aggregate from the mold and immediately record mass of tare and representative moisture sample (**l**).
13. Dry moisture sample to constant mass and record mass of dry aggregate and tare (**m**).
14. Calculate Dry Aggregate mass (**n**). Equation: $\mathbf{n} = \mathbf{m} - \mathbf{k}$
15. Calculate Water mass (**o**). Equation: $\mathbf{o} = \mathbf{l} - \mathbf{m}$
16. Calculate decimal fraction of water in aggregate (**p**). Equation: $\mathbf{p} = \mathbf{o}/\mathbf{n}$
17. Calculate Dry Density of Compacted Aggregate (**q**). Equation: $\mathbf{q} = \mathbf{j}/(1 + \mathbf{p})$
18. Determine the apparent specific gravity of the fine aggregate in accordance with AASHTO T 84.

19. Determine the apparent specific gravity of the coarse aggregate in accordance with WAQTC FOP for AASHTO T 85.

20. Plotting the "Maximum Dry Density vs. the Percent Passing 4.75 mm (No. 4) Sieve" curve is based on complex theoretical formulae. Programs for solution of these formulae, which produce curve data points and charts, have been developed for spreadsheets. These programs are available from the Statewide/ Regional laboratories.

TEST DATA & CALCULATIONS:	Formulae	Data			
a. Mold Inside Height (ft)					
b. Mold Cross-Sectional Area (ft^2)					
c. Top Plate Thickness (ft)					
d. Mass Empty Mold + Top Plate (lb)					
e. Mass Mold + Aggregate + Top Plate (lb)					
f. Mass of Compacted Aggregate (lb)	f = e - d				
		d_1 (in)	d_2 (in)	d_3 (in)	d_4 (in)
Distance, top of mold to plate (in)					
g. Average Distance (ft)	g = $(d_1+d_2+d_3+d_4)/48$				
h. Height of Compacted Aggregate (ft)	h = a - c - g				
i. Volume of Compacted Aggregate (ft^3)	i = (b)(h)				
j. Compacted Aggregate Wet Density (lb/ft^3)	j = f/i				
Moisture Content of Aggregate:					
k. Tare mass (g)					
l. Wet Aggregate + Tare (g)					
m. Dry Aggregate + Tare (g)					
n. Dry Aggregate mass (g)	n = m - k				
o. Water mass (g)	o = l - m				
p. Decimal Fraction of Water in Aggregate	p = o/n				
q. Compacted Aggregate Dry Density (lb/ft^3)	q = j/(1+p)				

7. Report

- Results on forms approved by the Department
- Standard Conformance tests for the material
- Maximum dry density in chart form to the nearest 1 kg/m^3 (0.1 lb/ft^3) vs. the Percent Passing 4.75 mm (No. 4) in whole percentages from 0 to 100 percent.
- The data may be displayed graphically in addition to the chart.

8. Supplementary Requirement

The following supplementary requirement shall apply only when specified, or when required by the Regional Quality Assurance or Materials Engineer.

1. Using the sample obtained in Step 4.1.a., adjust its moisture content to optimum as determined by the following:

$$MCt = \frac{(MCf \times Pf) + (MCc \times Pc)}{100}$$

Where:

MCt = total moisture content of combined fine and coarse fractions, expressed as a % moisture

MCf = moisture content of the fine fraction corresponding to the maximum dry density determined in Step 6.1.d., expressed as a % moisture

Pf = percent fine fraction determined from original gradation, in Step 4.1.b.

MCc = moisture content of the coarse fraction when Step 5.2 was performed, expressed as a % moisture (if moisture was not used, two (2) percent can be assumed)

Pc = percent coarse fraction determined from original gradation, in Step 4.1.b.

2. Compact the sample per Step 5.2.b.
3. Determine maximum dry density of the sample per Step 6.17
4. Plot the sample point on the graph containing the "Maximum Dry Density vs. the Percent Passing 4.75 mm (No. 4) sieve" curve generated in Step 6.20.
5. If the sample point falls more than 4 pcf below (or above) the point on the curve corresponding to its respective FA percentage then produce 2-4 additional CA/FA blends spaced evenly through the range of gradation. Compact these points per Step 5.2.b. Plot this series of dry densities at their respective FA percentages and draw a best-fit curve through the points to establish the compaction curve.

ATM 213 In-Place Density and Moisture Content of Soil and Soil-Aggregate by Nuclear Methods (Shallow Depth)

Following are guidelines for the use of WAQTC FOP for AASHTO T 310 by the State of Alaska DOT&PF.

1. The procedure designated as Method A will be used.
2. Report percent compaction to the nearest whole percent.
3. The visual description of the material will be the material classification, i.e. Borrow, D-1, etc.
4. A representative sample of material is required from beneath the gauge for purposes of: verification of moisture content for nuclear gauge according to ATM 213; correcting the Standard Density determined by ATM 207, Annex A, when greater than 5% coarse particles are present; and determining the minus No. 4 for ATM 212.

   A sample of material will not be required when any one of the following conditions applies:

   a. The Standard Density is determined by ATM 212 or ATM 215, and the test meets the minimum density requirement using the maximum density from the peak of the curve.

   b. The Project Engineer may waive this requirement when testing top layer of surface or base course and the Standard Density is determined using ATM 207. In this case, the percent coarse (oversized) for calculating the corrected density is established from proctor gradation of the material being tested.

   c. A sample is not required for moisture content when the nuclear gauge moisture has been determined to be within 1% of the oven dry moisture and is verified at least every 90 days.
5. The offset factor (k) shall be used to correct the moisture content reading from the gauge.

   THE OFFSET FACTOR IS GAUGE-SPECIFIC AND MATERIAL-SPECIFIC and must be established for each gauge and material type tested.

   a. Determine the offset factor (k) by:

      i. Average minimum five gauge derived moisture contents.

      ii. Average minimum five moisture contents determined by ATM 202, taken from the locations used to determine the gauge derived moistures.

      iii. Calculate the offset factor (k) using the following formula.

$$k = \left(\frac{\%M_{\text{Lab}} - \%M_{Gauge}}{100 + \%M_{Gauge}} \right) \times 1000$$

   b. Follow the gauge Manufacturer's instructions to enable the offset function to correct the moisture reading.

   c. Be sure to disengage the offset function upon completion of test.

      Note: This procedure is set up for Troxler gauges.
6. When allowed by the Project Engineer, a standard density value may be developed using a one-point proctor compacted in accordance with ATM 207, or ATM 309.

7. When the Standard Density is determined using ATM 309, use the average of the tests performed according to ATM 213, taken at three separate random test locations, as the acceptance test value.

8. For “Procedure step 9, Replace “Pull gently on the gauge” with “Pull gently on the base of the gauge”

9. Delete “Procedure” Step 10.a and replace with:

   Method A Single Direction: Take a test consisting of the average of two one minute readings, or one four minute reading, and record both density and moisture data. When performing two one minute readings, the two wet density readings should be within 32 kg/m^3 (2.0 lb/ft^3) of each other. The average of the two wet densities and moisture contents will be used to compute dry density. When performing one four minute reading the gauge will average four one minute readings.

10. Delete section “Percent Compaction” and replace with:

    ## “Percent Compaction”

    “Percent compaction is determined by comparing the in-place dry density as determined by this procedure to the maximum dry density of the appropriate Standard Density curve.

    “For plastic or cohesive soil or soil-aggregate mixes, develop the Standard Density curve using the FOP for AASHTO T 99/T 180. When using curves developed by the FOP for AASHTO T 99 / T 180, it may be necessary to use Annex A from FOP for AASHTO T 99/T 180 and FOP for AASHTO T 272 to determine the corrected maximum dry density and optimum moisture.

    “For non-plastic coarse granular materials, develop the Standard Density curve using ATM 212 to determine maximum dry density and optimum moisture. Maximum dry density values may also be determined by ATM 309 or ASTM D4253.”

11. Density measured using a low activity nuclear densometer used per ASTM D8167 Standard Test Method for In-Place Bulk Density of Soil and Soil Aggregate by a Low Activity Nuclear Method (Shallow Depth) is an approved alternate to this method.

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/scraper 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 kg/m^3 (2.0 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 kg/m^3 (3.0 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 ±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 ±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 (kg/m^3 or lb/ft^3) from the wet density (kg/m^3 or 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:

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

Where:

ρ_d = Dry density, kg/m^3 (lb/ft^3)
ρ_w = Wet density, kg/m^3 (lb/ft^3)
w = Moisture content from the FOP's for AASHTO T 255 / T 265, as a percentage

Calculate percent compaction as follows:

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

Where:

ρ_d = Dry density, kg/m^3 (lb/ft^3)
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^3 (121.6 lb/ft^3)
1977 kg/m^3 (123.4 lb/ft^3)
Avg: 1963 kg/m^3 (122.5 lb/ft^3)

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:

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

$$= 1694\ kg/m^3\ or\ 105.7\ lb/ft^3$$

Given:

ρ_w = 1963 kg/m^3 or 122.5 lb/ft^3
w = 15.9%

Calculate percent compaction as follows:

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

Given:

Agency density standard = 111.3 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^3
- 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^3
- Density standard to the nearest 0.1 lb/ft^3
- Percent compaction the nearest 1 percent
- Name and signature of operator

ATM 215 One-Point Method for Determining Maximum Dry Density and Optimum Moisture

Following are guidelines for the use of WAQTC FOP for AASHTO T 272 by the State of Alaska DOT&PF.

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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 soil moisture-density relations group (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 develop the soil moisture-density relations. For example, when moisture-density relationships as determined by T 99 – Method C are used to form the soil moisture-density relations group 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 soil moisture-density relations group 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 soil moisture density relations group. 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.

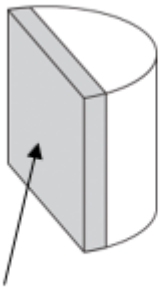
   b. Lightly tamp the loose material with the manual rammer or other similar device, this establishes a firm surface.

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 (ρ_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

Wet Density

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

Where:

ρ_w = wet density, kg/m^3 (lb/ft^3)
M_w = wet mass
V_m = volume of the mold, (FOP for AASHTO T 99/T 180)

Dry Density

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

Where:

ρ_d = dry density, kg/m^3 (lb/ft^3)
w = moisture content, as a percentage

Example for 4-inch mold, Methods A or C

Wet mass, M_w = 2.0055 kg (4.42 lb)
Moisture content, w = 13.5%
Measured volume of the mold, V_m = 0.0009469 m^3 (0.0334 ft^3)

Wet Density

$$\rho_w = \frac{2.0055\ kg}{0.0009469\ m^3} = 2118\ kg/m^3 \quad \rho_w = \frac{4.42\ lb}{0.0334\ ft^3} = 132.2\ lb/ft^3$$

Where:

ρ_w = Wet density, kg/m^3 (lb/ft^3)

Dry Density

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

or

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

ρ_d = Dry density, kg/m^3 (lb/ft^3)

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

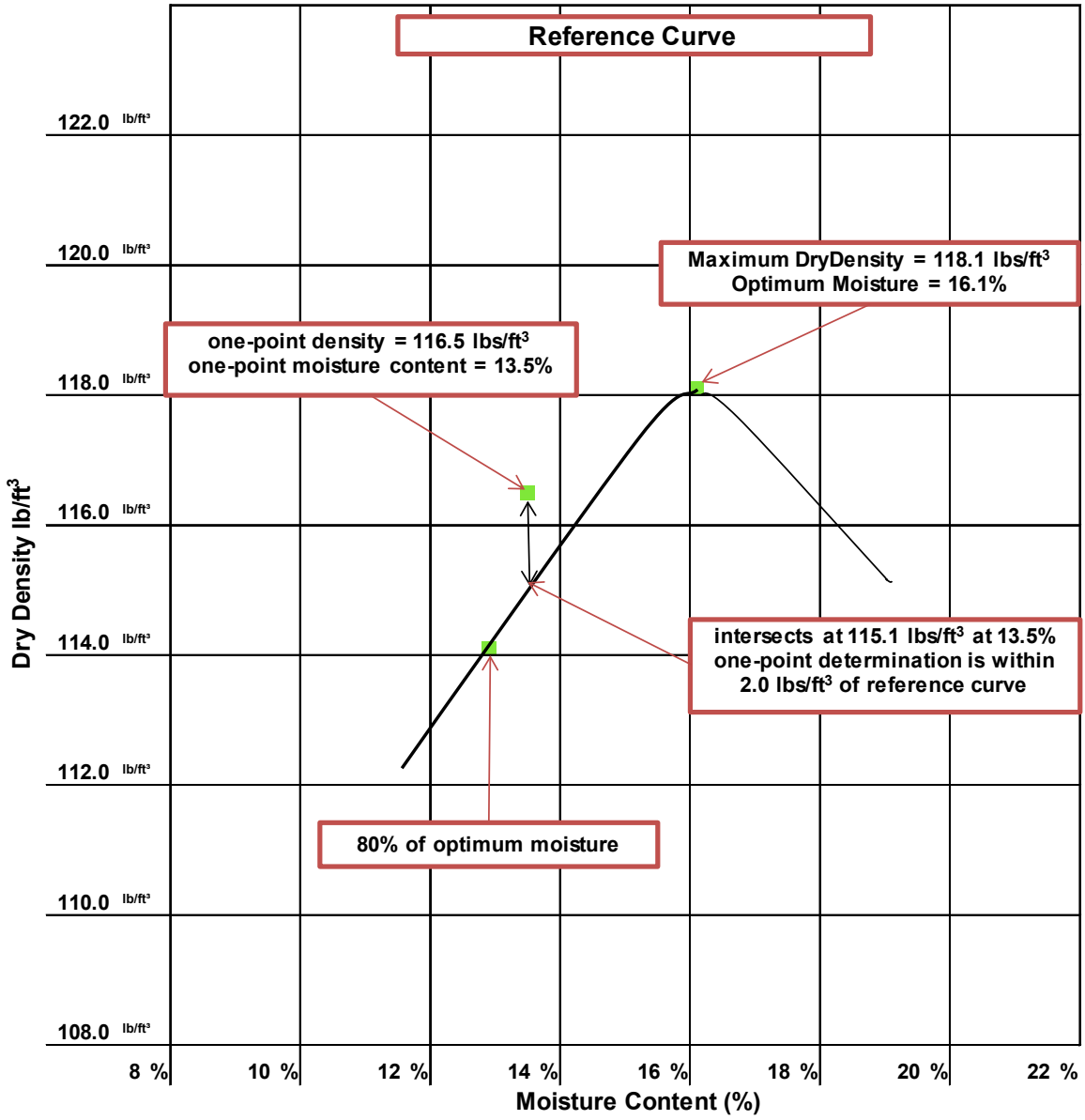
1. The moisture content must be within 80 to 100 percent of optimum moisture of the reference curve. Compact another specimen, using the same material, at an adjusted moisture content if the one-point does not fall in the 80 to 100 percent of optimum moisture range.

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 ±2.0 lbs/ft^3, 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 ±2.0 lbs/ft^3 of the reference curve at 80 to 100 percent optimum moisture.



Example

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

Maximum Dry Density and Optimum Moisture Content Determination Using Soil Moisture-Density Relations

1. Plot the one-point, dry density on the vertical axis and moisture content on the horizontal axis, on the reference soil moisture-density relations graph.

2. If the moisture-density one-point falls on one of the curves in the soil moisture-density relations, use the maximum dry density and optimum moisture content defined by that curve.

3. If the moisture-density one-point falls within the soil moisture-density relations 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 soil moisture-density relations. Use the maximum dry density and optimum moisture content as defined by the new curve.

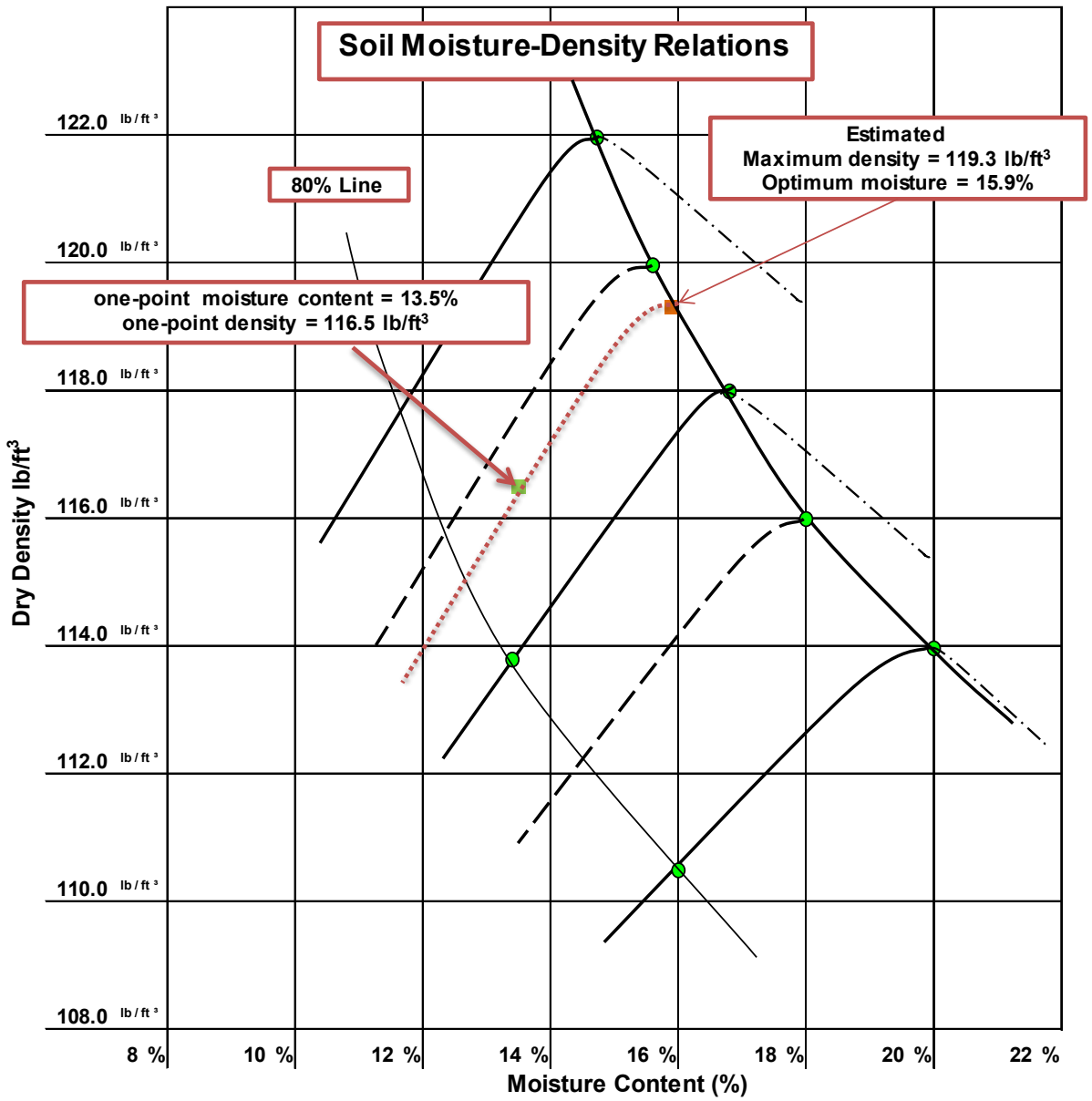
    a. The one-point must fall either between or on the highest or lowest curves. If it does not, then a full curve must be developed.

    b. If the one-point plotted within or on the soil moisture-density relations group 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 soil moisture-density relations.

Note 2: New curves drawn through plotted single point determinations shall not become a permanent part of the soil moisture-density relations 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^3 at 13.5 percent moisture. The point was plotted on the reference curve graph. The point was plotted on the appropriate group 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^3 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 kg/m^3 (0.1 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 Soil Moisture-Density Relations used

ATM 216 Developing MOISTURE-DENSITY RELATIONS FOP FOR AASHTO R 75

Following are guidelines for the use of WAQTC FOP for AASHTO R 75 by the State of Alaska DOT&PF.

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DEVELOPING MOISTURE-DENSITY RELATIONS FOP FOR AASHTO R 75

Scope

This procedure provides a method to develop soils moisture density relations in accordance with AASHTO R 75-24 using multiple moisture-density curves developed using the same method, A, B, C, or D, from the FOP for AASHTO T 99/T 180.

All curves used in a group 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

soil moisture-density relations — a group of soil moisture-density relations (commonly known as a family of 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 group 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 per group.
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 soil moisture-density relations.
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.

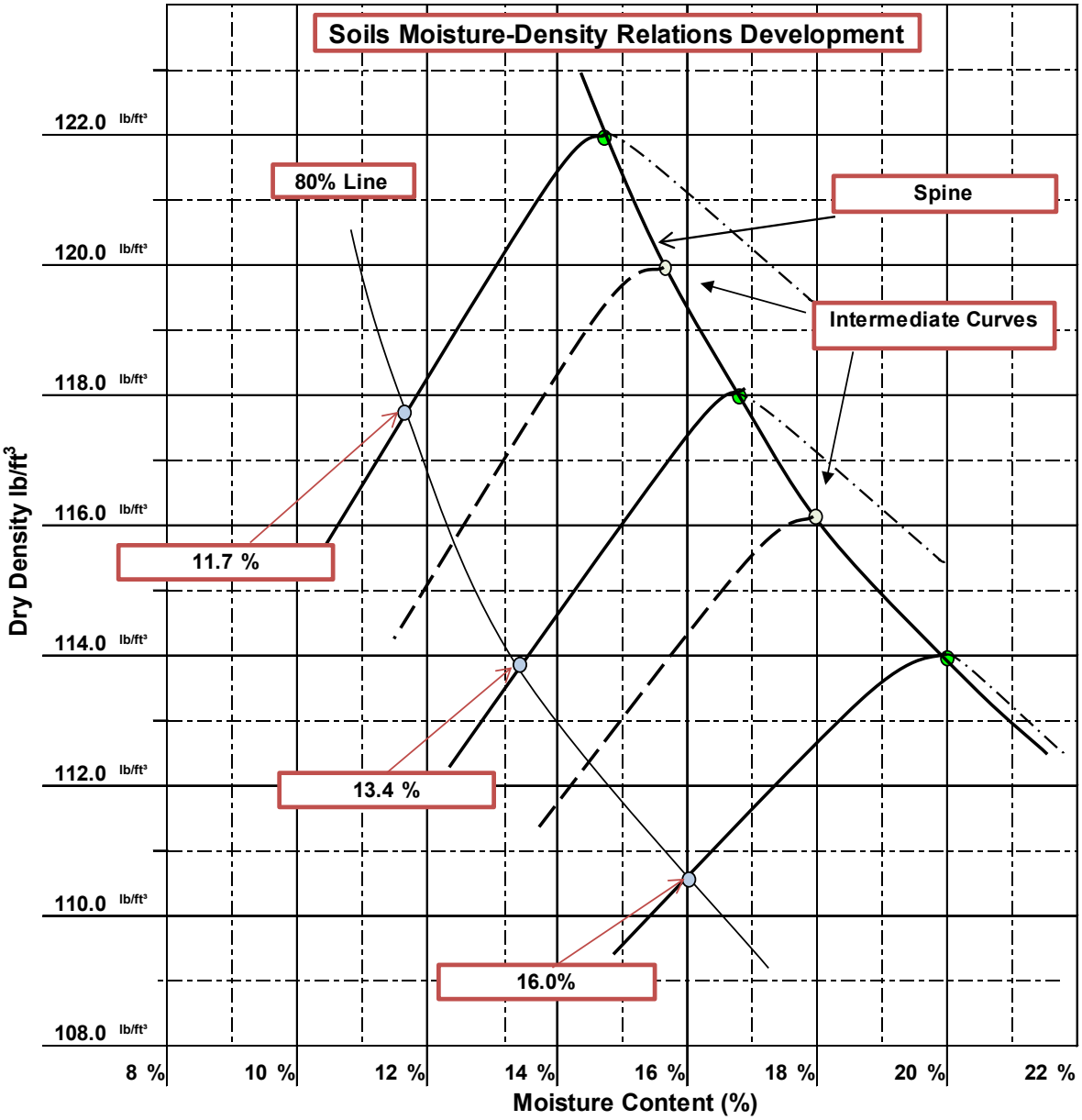
Note 1—Intermediate curves using slopes similar to those of the original moisture-density curves may be included when maximum density points are more than 2.0 lb/ft^3 apart. Intermediate curves are indicated by a dashed line.

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 group.
   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%

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