

**METHODS OF SAMPLING AND TESTING**  
**MT 211-04**  
**METHOD OF TEST FOR**  
**MOISTURE-DENSITY RELATIONS OF SOIL-CEMENT MIXTURES**  
*(Modified AASHTO T 134)*

**1 Scope:**

- 1.1** This method covers procedures for determining the relationship between the moisture content and the density of soil-cement mixtures when compacted before cement hydration as prescribed.
- 1.2** A 1/30 cu. ft. (0.9 liter) mold and a 5.5 lb. (2.5 kg) rammer dropped from a height of 12 in. (305 mm) are used and two methods, depending on soil gradation, are covered as follows:
- 1.2.1** *Method A* - Using soil material passing the 4.75 mm sieve. This method shall be used when 100 percent of the soil sample passes the 4.75 mm sieve, Sections 4 and 5.
- 1.2.2** *Method B* - Using soil sample passing the 19.0 mm sieve. This method shall be used when part of the soil sample is retained on the 4.75 mm sieve, Sections 6 and 7.

**2 Referenced Documents:****2.1 AASHTO:**

T 134 Moisture-Density Relations of Soil-Cement Mixtures

**MT Manual:**

MT-203 Unit Weight of Aggregate

MT-405 Wire Cloth Sieves for Testing Purposes

**3 Apparatus:**

- 3.1** *Molds* - The molds shall be solid-wall, metal cylinders manufactured with dimensions and capacities shown in 3.1.1. They shall have a detachable collar assembly approximately 2 3/4 in. (60 mm) in height, to permit preparation of compacted specimens of soil-cement mixtures of the desired weight and volume. The mold and collar assembly shall be so constructed that it can be fastened firmly to a detachable base plate made of the same material.

*Note 1 - Alternate types of molds with capacities as stipulated herein may be used, provided the test results are correlated with those of the solid-wall mold on several soil types and the same moisture-density results are obtained. Records of such correlations shall be maintained and readily available for inspection when alternate types of molds are used.*

- 3.1.1** A 4-inch mold having a capacity of  $1/30 \pm 0.0003$  cu. ft. ( $944 \pm 8.5$  cm<sup>3</sup>) with an internal diameter of  $4.000 \pm 0.016$  in. ( $101.6 \pm 0.4$  mm) and a height of  $4.584 \pm 0.005$  in. ( $116.4 \pm 0.1$  mm).
- 3.1.2** *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 Sec 6 (Calibration of Measure) of MT-203, Unit Weight of Aggregate, is used in the calculations:

**3.2 Rammer:**

- 3.2.1** *Manually Operated* - Metal rammer having a flat circular face of  $2.000 \pm 0.001$  in. ( $50.8 \pm 0.127$  mm) diameter, a wear tolerance of 0.005 (0.127 mm) and weighing  $5.50 \pm 0.02$  lb. ( $2.495 \pm 0.009$  kg) (Note 2). The rammer shall be equipped with a suitable guide-sleeve to control the height of drop to a free fall of  $12.00 \pm 0.06$  (or 1/16 in.) ( $304.8 \pm 1.524$  mm) above the elevation of the soil.

**3 Apparatus:** (continued)

The guide-sleeve shall have at least 4 vent holes, no smaller than 3/8 in. (9.5 mm) diameter spaced approximately 90 deg. apart and approximately 3/4 in. (19 mm) from each end, and shall provide sufficient clearance so the free fall of the rammer shaft and head is unrestricted.

- 3.2.2** *Mechanically Operated* - A metal rammer which is equipped with a device to control the height of drop to a free fall of  $12.00 \pm 0.06$  (or 1/16 in.) ( $304.8 \pm 1.524$  mm) above the elevation of the soil and uniformly distributes such drops to the soil surface. The rammer shall have a flat circular face  $2.000 \pm 0.001$  in. ( $50.8 \pm 0.127$  mm) in diameter, a wear tolerance of 0.005 (0.127 mm) and a manufactured mass of  $5.50 \pm 0.02$  lb. ( $2.495 \pm 0.009$  kg) (Note 2).

*Note 2 - The rammer apparatus shall be calibrated with several soil-cement mixtures and the mass of the rammer adjusted, if necessary, to give the same moisture-density results as with the manually operated rammer. It may be impractical to adjust the mechanical apparatus so the free fall is 12 in. (305 mm) each time the rammer is dropped, as with the manually operated rammer. To make the adjustment of free fall, the portion of loose soil to receive the initial blow should be slightly compressed with the rammer to establish the point of impact from which the 12 in. (305 mm) drop is determined. Subsequent blows on the layer of soil-cement may all be applied by dropping the rammer from a height of 12 in. (305 mm) above the initial-setting elevation, or when the mechanical apparatus is designed with a height adjustment for each blow, all subsequent blows should have a rammer free fall of 12 in. (305 mm) measured from the elevation of the soil as compacted by the previous blow.*

- 3.2.3** *Rammer Face* - The circular face rammer shall be used but a sector face rammer may be used as an alternative provided the report shall indicate type of face used other than the 2 in. (50.8 mm) circular face and it shall have an area equal to that of the circular face rammer.

- 3.3** *Sample Extruder* - A jack, lever, frame, or other device adopted for the purpose of extruding compacted specimens from the mold.

- 3.4** *Balances and Scales* - A balance or scale of at least 25 lb. capacity having a sensitivity and readability to 0.01 lb., or a balance or scale having a capacity of approximately 11.5 kg. and a sensitivity and readability to 5 grams. Also, a balance of at least 1 kg capacity with a sensitivity and readability to 0.1 gram.

- 3.5** *Drying Oven* - A thermostatically controlled drying oven capable of maintaining a temperature of  $110 \pm 5^\circ$  C ( $230 \pm 9^\circ$  F) for drying moisture samples.

- 3.6** *Straightedge* - A hardened steel straightedge at least 10 in. (254 mm) in length. It shall have one beveled edge, and at least one longitudinal surface (used for final trimming) shall be plane within 0.01 in. per 10 in. (0.1 percent) of length within the portion used for trimming the soil (Note 3).

*Note 3 - The beveled edge may be used for final trimming if the edge is true within a tolerance of 0.01 in. per 10 in. (0.1 percent) of length; however, with continued use, the cutting edge may become excessively worn and not suitable for trimming the soil to the level of the mold. The straightedge should not be so flexible that trimming the soil surface with the cutting edge will cause concave soil surface.*

- 3.7** *Sieves* - 50, 19.0, 4.75 mm sieves conforming to the requirements of MT-405, Sieves for Testing Purposes.

- 3.8** *Mixing Tools* - Miscellaneous tools such as mixing pan, spoon, trowel, spatula, etc., or a suitable mechanical device for thoroughly mixing the sample of soil with increments of water.

- 3.9** *Container* - A flat, round pan for moisture absorption by soil-cement mixtures about 12 in. (300 mm) in diameter and 2 in. (50 mm) deep.

**3 Apparatus:** (continued)

- 3.10** *Moisture Containers* - Suitable containers made of material resistant to corrosion and not subject to change in weight or disintegration on repeated heating and cooling. Containers shall have close-fitting lids to prevent loss of moisture from samples before initial weighing and to prevent absorption of moisture from the atmosphere following drying and before final weighing. One container is needed for each moisture content determination.
- 3.11** *Butcher Knife* - A butcher knife approximately 10 in. (250 mm) in length, for trimming the top of the specimens.

**METHOD A. USING SOIL MATERIAL  
PASSING A 4.75 mm SIEVE****4 Sample:**

- 4.1** Prepare the sample for testing by breaking up the soil aggregations to pass the 4.75 mm sieve in such a manner as to avoid reducing the natural size of the individual particles. When necessary, first dry the sample until it is friable under a trowel. Drying may be accomplished by air drying or by the use of drying apparatus such that the temperature of the sample does not exceed 60° C (140° F).
- 4.2** Select a representative sample weighing approximately 6 lb. (2.72 kg) or more, of the soil prepared as described in 4.1.

**5 Procedure:**

- 5.1** Add to the soil the required amount of cement conforming to AASHTO M 85, Specifications for Portland Cement, or AASHTO M 240, Blended Hydraulic Cements. Mix the cement and soil thoroughly to a uniform color. When needed, add sufficient potable water to dampen the mixture to approximately four to six percentage points below the estimated optimum moisture content and mix thoroughly. At this moisture content, plastic soils, tightly squeezed in the palm of the hand, will form a cast that will fracture with only slight pressure applied by the thumb and fingertips; nonplastic soils will bulk noticeably. When the soil is a heavy-textured clayey material, compact the mixture of soil, cement, and water in the container to a depth of about 2 in. (50 mm) using the rammer described in 3.2.1 or a similar hand tamper. Cover, and allow to stand for not less than 5 min. but not more than 10 min. to aid dispersion of the moisture and to permit more complete absorption by the soil-cement. After the absorption period thoroughly break up the mixture, without reducing the natural size of individual particles, until it will pass a 4.75 mm sieve and then remix.
- 5.2** Form a specimen by compacting the prepared soil-cement mixture in the mold, with the collar attached, in three equal layers so as to give a total compacted depth of about 5 in. (127 mm). Compact each layer by 25 blows from the rammer dropping free from a height of 12 in. (305 mm) above the elevation of the soil-cement when a sleeve-type rammer is used, or from 12 in. (305 mm) above the approximate elevation of each finally compacted layer when a stationary-mounted type rammer is used. The blows shall be uniformly distributed over the surface of the layer being compacted. During compaction, the mold shall rest on a uniform, rigid foundation (Note 4). Following compaction, remove the extension collar, carefully trim the compacted mixture even with the top of the mold by means of the knife and straightedge, and weigh to the nearest 0.01 lb. (0.004 kg). Multiply the mass of the compacted specimen and mold, minus the mass of the mold by 30; record the results as the wet mass per cubic foot ( $\text{kg}/\text{m}^3$ )  $W_1$  of the compacted soil-cement mixture.

**5 Procedure:** (continued)

*Note 4 - Each of the following has been found to be a satisfactory base on which to rest the mold during compaction of the soil; a block of concrete weighing not less than 200 lb. (90.8 kg), supported by a relatively stable foundation; a sound concrete floor; and for field application, such surfaces as found in concrete box culverts, bridges and pavements.*

**5.3** Remove the material from the mold and slice vertically through the center. Take a representative sample of the material, weighing not less than 100 grams, from the full height of one of the cut faces, weigh immediately, and dry in an oven at  $230 \pm 9^{\circ}\text{F}$  ( $110 \pm 5^{\circ}\text{C}$ ) for at least 12 hours or to constant mass. Calculate the moisture content of the sample as directed in Section 7. Record the results as the moisture content,  $w$ , of the compacted soil-cement mixture.

**5.4** Thoroughly break up the remaining portion of the molded specimen until it will pass a 4.75 mm sieve as judged by eye, and add to the remaining portion of the sample being tested. Add water in sufficient amount to increase the moisture content of the soil-cement mixture by one or two percentage points, mix, and repeat the procedure given in 5.2 and 5.3 for each increment of water added. Continue this series of determinations until there is either a decrease or no change in the wet mass per cubic foot ( $\text{kg}/\text{m}^3$ )  $W_1$  of the compacted soil-cement mixture.

*Note 5 - This procedure has been found satisfactory in most cases. However, in instances where the soil material is fragile in character and will reduce significantly in grain size due to repeated compaction, a separate and new sample shall be used for each moisture-density determination.*

**METHOD B. USING MATERIAL  
PASSING A 19.0 mm SIEVE**

**6 Sample:**

**6.1** Prepare the sample for testing by segregating the aggregate retained on a 4.75 mm sieve and breaking up the remaining soil aggregations to pass the 4.75 mm sieve in such a manner as to avoid reducing the natural size of individual particles. When necessary, first dry the sample until it is friable under a trowel. Drying may be accomplished by air drying or by the use of drying apparatus such that the temperature of the sample does not exceed  $60^{\circ}\text{C}$  ( $140^{\circ}\text{F}$ ).

**6.2** Sieve the prepared soil over the 75 mm (Note 6), 19.0 mm, and 4.75 mm sieves. Discard the material retained on the 75 mm sieve. Determine the percentage of material, by oven-dry mass, retained on the 19.0 mm and 4.75 mm sieves. Saturate the aggregate passing the 19.0 mm sieve and retained on the 4.75 mm sieve by soaking in potable water; surface-dry the material as required for later testing.

*Note 6 - Most soil-cement construction specifications covering soil gradation limit maximum size material to 75 mm (3 in.) or less.*

**6.3** Select and maintain separate representative samples of soil passing the 4.75 mm sieve and of saturated, surface-dry aggregate passing the 19.0 mm sieve and retained on the 4.75 mm sieve so that the total sample will weigh approximately 11 lb. (5 kg) or more. The percentage, by oven-dry mass, of aggregate passing the 19.0 mm sieve and retained on the 4.75 mm sieve shall be the same as the percentage passing the 75 mm sieve and retained on the 4.75 mm sieve in the original sample.

**7 Procedure:**

**7.1** Add to the portion of the soil sample passing the 4.75 mm sieve the amount of cement conforming to AASHTO M 85, Specifications for Portland Cement, AASHTO M 240. Blended Hydraulic Cement required for the total sample specified in 5.1. Mix the cement and soil thoroughly to a uniform color. When needed, add water to this soil-cement mixture and facilitate

moisture

**7 Procedure:** (continued)

dispersion as described for Method A in 4.1. After this preparation, add the saturated, surface-dry aggregate to the soil-cement mixture passing the 4.75 mm sieve and mix thoroughly.

- 7.2** Form a specimen by compacting the prepared soil-cement mixture in the mod (with the collar attached) and trim and weigh the compacted specimen as described for Method A in 5.2. During the trimming operation remove all particles that extend above the top level of the mold. Correct all irregularities in the surface by hand-tamping fine material into these irregularities and leveling the specimen again with the straightedge. Multiply the mass of the compacted specimen and mold, minus the mass of the mold, by 30; record the result as the wet mass per cubic foot,  $W_1$  of the compacted soil-cement mixture.
- 7.3** Remove the material from the mold and take a sample for determining the moisture content as described for Method A in 5.3, except that the moisture sample shall weigh not less than 500g. Record the result as the moisture content  $w$ , of the compacted soil-cement mixture.
- 7.4** Thoroughly break up the remainder of the material as before until it will pass a 19.0 mm sieve and at least 90 percent of the soil particles smaller than a 4.75 mm sieve will pass a 4.75 mm sieve, as judged by eye, and add all other material remaining after obtaining the moisture sample. Add sufficient water to increase the moisture content of the soil-cement mixture by one or two percentage points, mix, and repeat the procedure described in 7.2 and 7.3 for each increment of water added. Continue this series of determinations until there is either a decrease or no change in the wet mass per cubic foot ( $\text{kg}/\text{m}^3$ )  $W_1$  of the compacted soil-cement mixture (Note 5).

**CALCULATIONS AND REPORTS****8 Calculations:**

- 8.1** Calculate the moisture content and oven-dry mass per cubic foot of the compacted soil-cement mixture for each trial as follows:

$$w = \frac{A - B}{B - C} \times 100$$

$$W = \frac{W_1}{w + 100} \times 100$$

where:

- $w$  = percentage of moisture in the specimen,  
 $A$  = mass of moisture can and wet soil-cement,  
 $B$  = mass of moisture can and oven-dry soil cement,  
 $C$  = mass of moisture can,  
 $W$  = oven-dry mass in pounds per cubic foot ( $\text{kg}/\text{m}^3$ ) of compacted soil-cement, and  
 $W_1$  = wet mass in pounds per cubic foot ( $\text{kg}/\text{m}^3$ ) of compacted soil-cement.

**9 Moisture-Density Relationship:**

- 9.1** The calculations in Section 8 shall be made to determine the moisture content and corresponding oven-dry mass pounds per cubic foot ( $\text{kg}/\text{m}^3$ ) (density) for each of the compacted soil-cement samples. The oven-dry mass, pounds per cubic foot ( $\text{kg}/\text{m}^3$ ) (densities) of the soil-cement mixture shall be plotted as ordinates and the corresponding moisture contents as abscissas.

**9 Moisture-Density Relationship:** (continued)

**9.2** *Optimum Moisture Content* - When the densities and corresponding moisture contents for the soil-cement mixture have been determined and plotted as indicated in 9.1, it will be found that by connecting the plotted points with a smooth line, a curve is produced. The moisture content corresponding to the peak of the curve shall be termed the "Optimum moisture content" of the soil-cement mixture under the compaction prescribed in these methods.

**9.3** *Maximum Density* - The oven-dry mass, pounds per cubic foot ( $\text{kg/m}^3$ ) of the soil cement mixture at "optimum moisture content" shall be termed "maximum density" under the compaction prescribed in these methods.

**10 Report:**

**10.1** The report shall include the following:

**10.1.1** The method used (Method A or B).

**10.1.2** The optimum moisture content, and

**10.1.3** The maximum density.

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