Standard Method of Test for

Moisture–Density Relations of Soil–Cement Mixtures

AASHTO Designation: T 134-22

Technically Revised: 2022

Technical Subcommittee: 1b, Geotechnical Exploration, Instrumentation, Stabilization, and Field Testing

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1. SCOPE

1.1. These methods of test are intended for determining the relation between moisture content and density of soil–cement mixtures when compacted before cement hydration. Appendix X1 provides commentary and protocols to characterize soil–cement mixtures that are susceptible to the effects of time delay between cement addition and compaction. Appendix X1 protocols are primarily intended for soil–cement mixtures having a maximum dry density, as determined in Section 9.3, lower than the maximum dry density of the same soil evaluated under the compaction prescribed in these methods without cement addition (i.e., soil and water only).

1.2. A 944-cm^3 (1/30-ft^3) mold and a 2.5-kg (5.5-lb) rammer dropped from a height of 305 mm (12 in.) are used and two methods, depending on soil gradation, are covered, as follows:

1.2.1. *Method A*—Soil material passing a 4.75-mm (No. 4) sieve. This method shall be used when 100 percent of the soil sample passes the 4.75-mm (No. 4) sieve; or

1.2.2. *Method B*—Soil material passing a 19.0-mm ($^3/_4$-in.) sieve. This method shall be used when part of the soil sample is retained on the 4.75-mm (No. 4) sieve.

1.3. This test method applies to soil–cement mixtures that have 30 percent or less retained on the 19.0-mm ($^3/_4$-in.) sieve, when Method B is used. The material retained on the 19.0 mm ($^3/_4$-in.) sieve shall be defined as oversized particles (coarse particles).

1.4. The following applies to all specified limits in this standard: For the purposes of determining conformance with these specifications, an observed value or a calculated value shall be rounded off "to the nearest unit" in the last right-hand place of figures used in expressing the limiting value, in accordance with ASTM E29.

1.5. *The quality of the results produced by this standard are dependent on the competence of the personnel performing the procedure and the capability, calibration, and maintenance of the equipment used. Agencies that meet the criteria of R 18 are generally considered capable of competent and objective testing/sampling/inspection/etc. Users of this standard are cautioned that compliance with R 18 alone does not completely assure reliable results. Reliable results depend on many factors; following the suggestions of R 18 or some similar acceptable guideline provides a means of evaluating and controlling some of those factors.*

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 85, Portland Cement
- M 145, Classification of Soils and Soil-Aggregate Mixture for Highway Construction Purposes
- M 231, Weighing Devices Used in the Testing of Materials
- M 240M/M 240, Blended Hydraulic Cement
- R 18, Establishing and Implementing a Quality Management System for Construction Materials Testing Laboratories
- T 19M/T 19, Bulk Density ("Unit Weight") and Voids in Aggregate
- T 99, Moisture–Density Relations of Soils Using a 2.5-kg (5.5-lb) Rammer and 305-mm (12-inch) Drop
- T 134, Moisture Density Relations of Soil–Cement Mixtures
- T 265, Laboratory Determination of Moisture Content of Soils

2.2. *ASTM Standards*:

- D2168, Standard Practices for Calibration of Laboratory Mechanical-Rammer Soil Compactors
- E11, Standard Specification for Woven Wire Test Sieve Cloth and Test Sieves
- E29, Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications

2.3. *Other Document*:

- Sullivan, W. G., Howard, I. L. Time Delay Effects on Compactability of Soil-Cement Materials during Proctor Testing. In *Transportation Research Record 2675*. Available from doi.org/10.1177/03611981211998700.

3. APPARATUS

3.1. *Molds*—Molds shall conform to T 99, Sections 3.1 and 3.1.1.

3.2. *Rammer and Rammer Face*—Rammers and rammer faces shall conform to T 99, Section 3.2.1 or 3.2.2, and 3.2.3. Note 1 below applies to Section 3.2.2.

Note 1—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 305 mm (12 in.) 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 305-mm (12-in.) drop is determined. Subsequent blows on the layer of soil–cement may all be applied by dropping the rammer from a height of 305 mm (12 in.) above the initial-setting elevation, or when the mechanical apparatus is designed with a height adjustment for each blow, all subsequent blows should have rammer free fall of 305 mm (12 in.) measured from the elevation of the soil–cement as compacted by the previous blow.

3.3. *Sample Extruder*—A jack, lever, frame, or other device adopted for the purpose of extruding compacted specimens from the mold. Not required when a split-type mold is used.

3.4. *Balances and Scales*—A balance or scale conforming to the requirements of M 231, Class G 20. Also, a balance conforming to the requirements of M 231, Class G 2.

3.5. *Drying Oven*—A thermostatically controlled drying oven capable of maintaining a temperature of 110 ± 5°C (230 ± 9°F) for drying moisture samples.

3.6. *Straightedge*—A hardened-steel straightedge at least 254 mm (10 in.) in length. It shall have one beveled edge, and at least one longitudinal surface (used for final trimming) shall be plane within 0.250 mm per 250 mm (0.01 in. per 10 in.) (0.1 percent) of length within the portion used for trimming the soil (Note 2).

Note 2—The beveled edge may be used for final trimming if the edge is true within a tolerance of 0.250 mm per 250 mm (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 with the cutting edge will cause a concave soil surface.

3.7. *Sieves*—75-mm (3-in.), 19.0-mm ($^3/_4$-in.), and 4.75-mm (No. 4) sieves conforming to the requirements of ASTM E11.

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 cement and with increments of water.

3.9. *Container*—A flat, round pan for moisture absorption by soil–cement mixtures, about 305 mm (12 in.) in diameter and 50 mm (2 in.) deep.

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 250 mm (10 in.) in length for trimming the top of the specimens.

METHOD A

4. SAMPLE

4.1. If the soil sample is damp when received from the field, dry it until it becomes friable under a trowel. Drying may be in air or by use of a drying apparatus that is maintained at a temperature not exceeding 60°C (140°F). Then thoroughly break up the aggregations to pass the 4.75-mm (No. 4) sieve, in such a manner as to avoid reducing the natural size of individual particles.

4.2. Select a representative sample, with a mass of approximately 2.7 kg (6 lb) or more, of the soil prepared as described in Section 4.1.

5. PROCEDURE

5.1. Add to the soil the required amount of cement conforming to M 85 or M 240M/M 240. Mix the cement and soil thoroughly to a uniform color.

5.2. When needed, add sufficient potable water to dampen the mixture to approximately four to six percentage points below 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.

5.3. When the soil is a heavy textured clayey material, compact the mixture of soil, cement, and water in the container to a depth of 50 mm (2 in.) using the rammer described in Section 3.2 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.

5.4. 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 (No. 4) sieve, and then remix.

5.5. Form a specimen by compacting the prepared soil–cement mixture in the mold (with collar attached) in three approximately equal layers to give a total compacted depth of about 130 mm (5 in.). Compact each layer by 25 uniformly distributed blows from the rammer dropping free from a height of 305 mm (12 in.) above the elevation of the soil–cement when a sleeve-type rammer is used, or from 305 mm (12 in.) above the approximate elevation of compacted soil when a stationary mounted type of rammer is used. During compaction, the mold shall rest firmly on a dense, uniform, rigid, and stable foundation or base. This base shall remain stationary during the compaction process (Note 3).

Note 3—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, with a mass not less than 90 kg (200 lb), 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.

5.6. Following compaction, remove the extension collar, carefully trim the compacted soil–cement mixture even with the top of the mold by means of the knife and straightedge, and determine the mass of the mold and moist soil in kilograms to the nearest 5 g, or determine the mass in pounds to the nearest 0.01 pounds. Calculate the wet density, W_1, as described in Section 8.1.

5.7. Remove the material from the mold using the extruder when necessary. Obtain a representative sample of the material by slicing vertically through the center of the molded material and removing one of the cut faces or from the center of the pile if the material falls apart. Weigh the sample immediately. Determine the moisture content in accordance with T 265 and record the results.

5.8. Thoroughly break up the remaining portion of the molded specimen until it will pass a 4.75-mm (No. 4) 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 one to two percentage points and repeat the above procedure for each increment of water added. Continue this series of determinations until there is either a decrease or no change in the wet unit mass, W_1, per cubic meter (cubic foot), of the compacted soil–cement mixture (Note 4).

Note 4—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 in each compaction test.

Note 5—To minimize the effect of cement hydration, perform the test expeditiously and continuously to completion. If the effects of time delay between cement addition and compaction completion are of concern, then record the time of cement addition and time of completion for each compaction test to the nearest 5 min. Appendix X1 contains additional testing procedures to account for time delay effects on measured density results.

METHOD B

6. SAMPLE

6.1. If the soil sample is damp when received from the field, dry it until it becomes friable under a trowel. Drying may be in air or by use of a drying apparatus that is maintained at a temperature not exceeding 60°C (140°F). Then thoroughly break up the aggregations in such a manner as to avoid reducing the natural size of individual particles. Prepare the sample for testing by segregating the material retained on a 4.75-mm (No. 4) sieve and breaking up the remaining soil aggregations to pass the 4.75-mm (No. 4) sieve in such a manner as to avoid reducing the natural size of the individual particles.

6.2. Sieve the prepared soil over the 75-mm (3-in.), 19.0-mm ($^3/_4$-in.), and 4.75-mm (No. 4) sieves. Discard the material retained on the 75-mm (3-in.) sieve. Determine the percentage of material, by oven-dry mass, retained on the 19.0-mm ($^3/_4$-in.) and 4.75-mm (No. 4) sieves.

6.3. Saturate the aggregate passing the 19.0-mm ($^3/_4$-in.) sieve and retained on the 4.75-mm (No. 4) 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.

6.4. Select and maintain separate representative samples of soil passing the 4.75-mm (No. 4) sieve and of saturated, surface dry aggregate passing the 19.0-mm ($^3/_4$-in.) sieve and retained on the 4.75-mm (No. 4) sieve so that the total sample will weigh approximately 5.0 kg (11 lb) or more. The percentage, by oven-dry mass, of aggregate passing the 19.0-mm ($^3/_4$-in.) sieve and retained on the 4.75-mm (No. 4) sieve shall be the same as the percentage passing the 75-mm (3-in.) sieve and retained on the 4.75-mm (No. 4) sieve in the original sample. The final oven-dry mass of material is prepared from the adjusted percent passing as shown in the example in Table 1.

Note 7—This oversize procedure is different than used in T 99. Scalp and replace is used here since it is not just a moisture–density relationship; cement is mixed in with the water to make the sample.

Table 1—Example of Adjusting for Oversize Particles[a]

Sieve	Original percent passing	Original sample weight, kg	Adjusted percent passing	Final test sample weight, kg
37 mm (1 $^1/_2$ in.)	100%	0.6	—	—
19 mm ($^3/_4$ in.)	88%	1.3	100%	0.6 + 1.3 = 1.9
4.75mm (No. 4)	62%	3.1	62%	3.1

[a] Original sample weight is based on original gradation where the example value presented represents material passing a particular sieve and retained on the subsequent sieve. For example, 0.6 kg of material passes the 37 mm (1 ½ in.) sieve and is retained on the 19 mm (¾ in.) sieve. The final test sample weight shall have the same amount of material passing the 4.75 mm (No. 4) sieve, and material passing the ¾ in. sieve and retained on the 4.75 mm (No. 4) sieve shall be increased to include the sum total of material larger than the 4.75 mm (No. 4) sieve.

7. PROCEDURE

7.1. Add to the portion of the soil sample passing the 4.75-mm (No. 4) sieve the amount of cement conforming to M 85 or M 240M/M 240, required for the total sample specified in Section 6.4. Mix the cement and soil thoroughly to a uniform color.

7.2. When needed, add water to this soil–cement mixture and facilitate moisture dispersion as described for Method A in Sections 5.2 to 5.4. After this preparation, add the saturated, surface-dry aggregate (material passing the 19.0-mm ($^3/_4$-in.) sieve and retained on the 4.75-mm (No. 4) sieve) to the soil–cement mixture passing the 4.75-mm (No. 4) sieve and mix thoroughly.

7.3. Form a specimen by compacting the prepared soil–cement mixture in the mold (with collar attached), and trim and weigh the compacted specimen as described for Method A in Sections 5.5 and 5.6. Holes developed in the surface by removal of coarse material shall be patched with smaller-sized material.

7.4. Remove the material from the mold and take a sample for determining the moisture content as described for Method A in Section 5.7, except the sample shall weigh not less than 500 g.

7.5. Thoroughly break up the remainder of the material as before until it will pass a 19.0-mm ($^{3}/_{4}$-in.) sieve and 90 percent of the soil aggregations will pass a 4.75-mm (No. 4) sieve as judged by eye, and add to the remaining portion of the sample being tested.

7.6. Add water in sufficient amounts to increase the moisture content of the soil–cement mixture by one or two percentage points, and repeat the above procedure for each increment of water added. Continue this series of determinations until there is either a decrease or no change in the wet mass, W_1, per cubic meter (cubic foot) of compacted soil (Notes 4 and 5).

CALCULATIONS AND REPORT

8. CALCULATIONS

8.1. Wet density (W_1) shall be determined using the mold volume. For masses recorded in kilograms, the unit of wet density is kilograms per cubic meter of soil–cement. For masses recorded in pounds, the unit of density is pounds per cubic foot of soil–cement. Calculate the moisture content and the dry unit mass of the soil–cement mixture as compacted for each trial, as follows:

$$W_1 = (A\text{-}B)/V \qquad (1)$$

and

$$W = \frac{W_1}{w+100} \times 100 \qquad (2)$$

where:

w = percentage of moisture in the specimen, based on oven-dry mass of soil–cement;

A = mass of container and wet soil–cement;

B = mass of (mold and baseplate) container;

W = dry density of compacted soil–cement, in kilograms per cubic meter, or pounds per cubic foot;

W_1 = wet density of compacted soil–cement, in kilograms per cubic meter, or pounds per cubic foot; and

V = volume of mold as determined in T 99.

9. MOISTURE–DENSITY RELATIONSHIP

9.1. The calculations in Section 8 shall be made to determine the moisture content and corresponding oven-dry unit mass (density) in kilograms per cubic meter or pounds per cubic foot of the compacted soil–cement samples. The oven-dry densities (unit mass) of the soil–cement mixture shall be plotted as ordinates and the corresponding moisture content as abscissas.

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 Section 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 density in kilograms per cubic meter or pounds per cubic foot 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, as a percentage, to the nearest whole number.

10.1.3. The maximum density in kilograms per cubic meter to the nearest 10 kg/m^3 or in pounds per cubic foot to the nearest whole number.

10.1.4. Type of rammer face, if other than 50.8-mm (2-in.) circular.

11. PRECISION STATEMENT

11.1. Precision of this test method has not yet been established.

12. KEYWORDS

12.1. Coarse particles; moisture–density relationship; soil–cement mixtures; soil material.

APPENDIX

(Nonmandatory Information)

X1. PROCEDURES TO CONSIDER TIME DELAY EFFECTS

X1.1. *Purpose*—This Appendix provides standard protocols to characterize the effect of time delay between cement, water, and soil mixing and compaction. These protocols apply to soil–cement mixtures as described in Section 1.1. Most evaluation of these procedures has been in conjunction with soils classifying as A2-4 to A6 according to M 145, but protocols can be performed on any soil–cement mixture. Users of this Appendix can apply these protocols within several construction scenarios or specification frameworks. Sullivan and Howard (2021) provides data and analysis used to develop these protocols and provides representative but not exhaustive scenarios to apply these protocols.

X1.2. *Procedure:*

X1.2.1. Perform T 134 standard test procedures without cement addition (i.e., soil and water only) and plot resulting moisture–density curve.

X1.2.2. Perform the normal T 134 standard test procedures (i.e., soil, cement, and water) and plot the resulting moisture–density curve on the same graph as T 134 curve without cement. During testing, record the amount of time delay (t_D) between cement addition and compaction for each compaction test to the nearest 5 min as described in Note 5. Figure X1.1a shows an example of T 134 curves with and without cement.

X1.2.3. Prepare a minimum of four individual soil samples of sufficient quantity according to the appropriate T 134 method (i.e., Method A or Method B). Additional samples may be prepared, if desired.

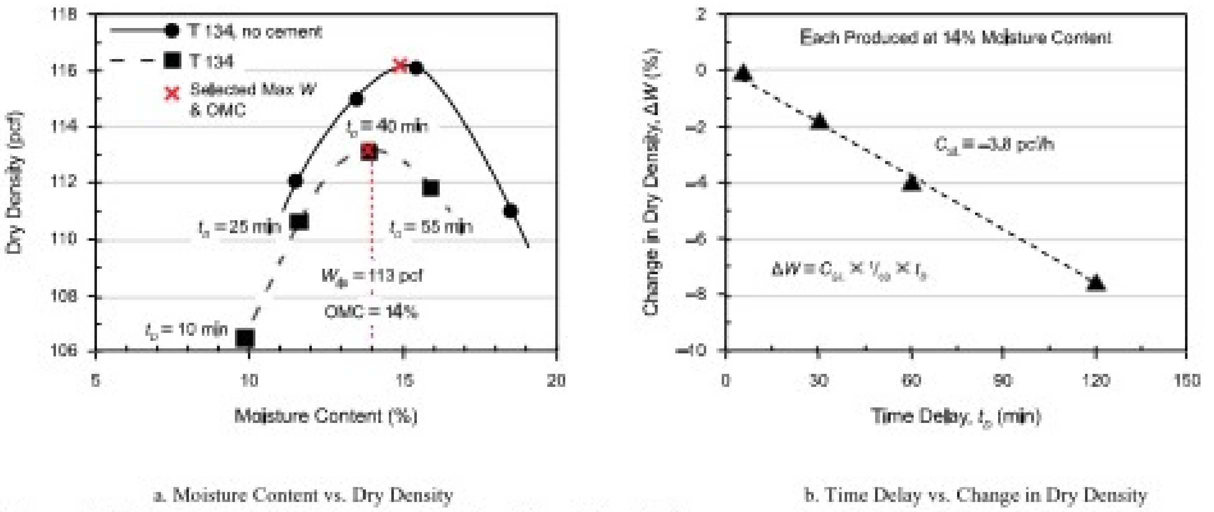
X1.2.4. Add to each soil sample the required amount of cement. Mix the cement and soil thoroughly to a uniform color. Immediately after mixing of the soil and cement, add the required amount of water to achieve the optimum moisture content determined from Section 9.2. The time interval between cement addition and water addition should not exceed 2 min. Mix thoroughly to obtain a uniform mixture of soil, cement, and water.

X1.2.5. Form a specimen from each of the individual soil–cement samples by compacting the prepared mixture in the mold (with collar attached), and trim and weigh the compacted specimen described by Sections 5.5 and 5.6. One specimen shall be compacted immediately after mixing, and the remaining specimens should be compacted after a prescribed amount of time delay. Delay times at least 30 min apart are recommended.

X1.2.6. Determine specimen dry density according to Section 8. Subtract the dry density of the specimen compacted immediately from each of the specimens compacted at a different time delay; for example, specimen dry density after 30 min of time delay minus the dry density after immediate compaction. This difference represents the change in dry density (ΔW) due to a given amount of time delay.

X1.2.7. Plot the change in dry density (ΔW) versus the time delay for each compaction test on the same graph. Fit a linear trendline through all data points, with the trendline forced to intersect the y-axis at 0. The slope of the liner trendline is C_{SL}. Figure X1.1b shows an example of determining C_{SL}.

X1.3. *Reporting*—The report shall include all information in Section 10 with the following additions: the amount of time delay (t_D) associated with the reported maximum dry density, and the determined linear trendline slope (C_{SL}) of the change in dry density (ΔW) and time delay. For consistency in terminology notation, W shall represent dry density and the amount of time delay (t_D), in minutes, associated with that dry density value shall be noted in subscript after W. For the example shown in Figure X1.1a, a maximum dry density value was compacted after 40 min of time delay; therefore, max W_{40} = 113 pcf. OMC was 14 percent, and C_{SL} was –3.8 pcf/h.



a. Moisture Content vs. Dry Density

b. Time Delay vs. Change in Dry Density

Figure X1.1—Example Procedures to Consider Time Delay Effects