



Standard Test Methods for Moisture-Density (Unit Weight) Relations of Soil-Cement Mixtures ¹

This standard is issued under the fixed designation D 558; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope *

1.1 These test methods cover the determination of the relationship between the water content and the density of soil-cement mixtures when compacted before cement hydration as prescribed.

1.2 A 1/30-ft³ (944-cm³) mold and a 5.5-lb (2.49-kg) rammer dropped from a height of 12.0 in. (30.5 cm) are used and two methods, depending on soil gradation, are covered, as follows:

	Sections
Test Method A, using soil material passing a No. 4 (4.75-mm) sieve. This method shall be used when 100 % of the soil sample passes the No. 4 (4.75-mm) sieve	7
Test Method B, using soil material passing a 3/4-in. (19.0-mm) sieve. This method shall be used when part of the soil sample is retained on the No. 4 (4.75-mm) sieve. This test method may be used only on materials with 30 % or less retained on the 3/4-in. (19.0-mm) sieve	8

1.3 All observed and calculated values shall conform to the guidelines for significant digits and rounding established in Practice D 6026.

1.4 The values stated in inch-pound units are to be regarded as the standard, except as noted below. The values given in parentheses are mathematical conversions to SI units, and are provided for information only and are not considered standard.

1.4.1 The gravitational system of inch-pound units is used when dealing with inch-pound units. In this system, the pound (lbf) represents a unit of force (weight), while the unit for mass is slugs.

1.4.2 The slug unit of mass is almost never used in commercial practice (density, scales, balances, etc.). Therefore, the standard unit for mass in this standard is either kilogram (kg) or gram (g) or both. Also, the equivalent inch-pound unit (slug) is not given.

1.4.3 It is common practice in the engineering/construction profession to concurrently use pounds to represent both a unit of mass (lbm) and of force (lbf). This implicitly combines two separate systems of units; that is, the absolute system and the

gravitational system. It is scientifically undesirable to combine the use of two separate sets of inch-pound units within a single standard. As stated in 1.4.2, this standard includes the gravitational system of inch-pound units and does not use/present the slug unit for mass. However, the use of balances or scales recording pounds of mass (lbm) or recording density in lbm/ft³ shall not be regarded as nonconformance with this standard.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 ASTM Standards:

- C 150 Specification for Portland Cement²
- C 595 Specification for Blended Hydraulic Cements²
- D 559 Test Methods for Wetting-and-Drying Compacted Soil-Cement Mixtures³
- D 560 Test Methods for Freezing-and-Thawing Compacted Soil-Cement Mixtures³
- D 653 Terminology Relating to Soil, Rock, and Contained Fluids
- D 698 Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (12,400ft-lbf/ft³(600kN-m/m³))³
- D 2168 Test Methods for Calibration of Laboratory Mechanical-Rammer Soil Compactors³
- D 2216 Test Method for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass³
- D 3740 Practice for Minimum Requirements for Agencies Engaged in the Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction³
- D 4753 Specification for Evaluating, Selecting, and Specifying Balances and Scales for Use in Soil, Rock, and Construction Materials Testing
- D 6026 Practice for Using Significant Digits in Geotechnical Data

¹ These test methods are under the jurisdiction of ASTM Committee D18 on Soil and Rock and are the direct responsibility of Subcommittee D18.15 on Stabilization of Additives.

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² Annual Book of ASTM Standards, Vol 04.01.

³ Annual Book of ASTM Standards, Vol 04.08.

***A Summary of Changes section appears at the end of this standard.**

- E 11 Specification for Wire-Cloth and Sieves for Testing Purposes⁴
 E 145 Specifications for Gravity-Convection and Forced-Ventilation Ovens

3. Terminology

3.1 For common definitions of terms used in this standard, refer to Terminology D 653.

4. Significance and Use

4.1 These tests determine the optimum water content and maximum density (unit weight) to be used for molding soil-cement specimens in accordance with Methods D 559 and D 560.

NOTE 1—Since these tests are used in conjunction with Methods D 559 and D 560 and the criteria referenced therein, the test differs in several aspects from Test Methods D 698. There are three main differences between this standard and Test Method D 698. Firstly, this standard allows a maximum particle size of $\frac{3}{4}$ -in. (19.0 mm) for a 4-in. (101.6-mm) mold while D 698 allows a maximum particle size of $\frac{3}{8}$ -in. (9.5-mm) for the same size mold. Secondly, this standard permits the material leftover after the water content specimen has been obtained to be mixed with the rest of the sample and reused for the next determination. Test Method D 698 does not permit the material to be reused. Thirdly, this standard allows the material that is retained on the $\frac{3}{4}$ -in. (19.0-mm) and passing the 3-in. (75-mm) to be discarded (scalping technique) and replaced with an equal mass of material that passes the $\frac{3}{4}$ -in. (19.0-mm) sieve and is retained on the No.4 (4.75-mm) sieve. Test Method D 698 does not permit the scalp and replacement technique.

NOTE 2—The quality of the result produced by this standard is dependent on the competence of the personnel performing it, and the suitability of the equipment and facilities used. Agencies that meet the criteria of Practice D 3740 are generally considered capable of competent and objective testing/sampling/inspection/etc. Users of this standard are cautioned that compliance with Practice D 3740 does not in itself assure reliable results. Reliable results depend on many factors; Practice D 3740 provides a means of evaluating some of those factors.

5. Apparatus

5.1 *Mold*—A cylindrical metal mold having a volume of $\frac{1}{30} \pm 0.00040 \text{ ft}^3$ ($944 \pm 11 \text{ cm}^3$) with an internal diameter of $4.0 \pm 0.016 \text{ in.}$ ($101.60 \pm 0.41 \text{ mm}$) and conforming to Fig. 1 to permit preparing compacted specimens of soil-cement mixtures of this size. The mold shall be provided with a detachable collar assembly approximately $2\frac{1}{2}$ -in. (63.5 mm) in height. The mold may be of the split type consisting of two half-round sections or section of pipe with one side split perpendicular to the pipe circumference and that can be securely locked in place to form a closed cylinder having the dimensions described above. The mold and collar assembly shall be so constructed that it can be fastened firmly to a detachable base (Fig. 1).

5.2 *Rammer*:

5.2.1 *Manual Rammer*—A manually operated metal rammer having a 2.000 ± 0.005 -in. (50.80 ± 0.13 -mm) diameter circular face and a mass of $2.49 \pm 0.01 \text{ kg}$. The rammer shall be equipped with a suitable guidesleeve to control the height of drop to a free fall of $12.0 \pm \frac{1}{16}$ in. ($304.8 \pm 1.6 \text{ mm}$) above the elevation of the soil-cement. The guidesleeve shall have at

least four vent holes not smaller than $\frac{3}{8}$ in. (9.5 mm) spaced 90° apart and located with centers $\frac{3}{4} \pm \frac{1}{16}$ in. ($19.0 \pm 1.6 \text{ mm}$) from each end and shall provide sufficient clearance that free-falls of the rammer shaft and head will not be restricted.

5.2.2 *Mechanical Rammer*—A mechanically operated metal rammer having a 2.0 ± 0.005 -in. (50.80 ± 0.13 -mm) diameter face and a manufactured mass of $2.49 \pm 0.01 \text{ kg}$. The operating mass of the rammer shall be determined from a calibration in accordance with Methods D 2168. The rammer shall be equipped with a suitable arrangement to control the height of drop to a free-fall of $12.0 \pm \frac{1}{16}$ in. ($304.8 \pm 1.6 \text{ mm}$) above the elevation of the soil-cement.

5.2.3 *Rammer Face*—A sector face may be substituted with mechanical rammers provided the report shows that a sector face rammer was used. The sector face shall be a sector of a 4.0 ± 0.016 -in. (101.60 ± 0.41 -mm) diameter circle and shall have an area equal to that of the circular face rammer.

NOTE 3—The sector face rammer shall not be used to compact test specimens in accordance with Methods D 559 and D 560, unless previous tests on like soils show strength and resistance to wetting-and-drying and freezing-and-thawing of specimens compacted with this rammer are similar to that of specimens compacted with the circular face rammer.

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

5.4 *Balances*—A balance or scale conforming to the requirements of Class GP5 with a readability of 1g in Specification D 4753, except that a Class GP2 balance of 0.1g readability is required for water content determination.

5.5 *Drying Oven*—Thermostatically controlled, preferably of the forced-draft type, meeting the requirements of Specification E 145 and capable of maintaining a uniform temperature of $110 \pm 5^\circ \text{C}$ ($238 \pm 9^\circ \text{F}$) throughout the drying chamber.

5.6 *Straightedge*—A stiff steel straightedge of any convenient length but not less than 10-in. (254-mm). The total length of the straightedge shall be machined straight to a tolerance of ± 0.005 -in. (± 0.1 -mm). The scraping edge shall be beveled if it is thicker than $\frac{1}{8}$ -in. (3-mm).

5.7 *Sieves*—3-in. (75-mm), $\frac{3}{4}$ -in. (19.0-mm), and No. 4 (4.75-mm) sieves conforming to the requirements of Specification E 11.

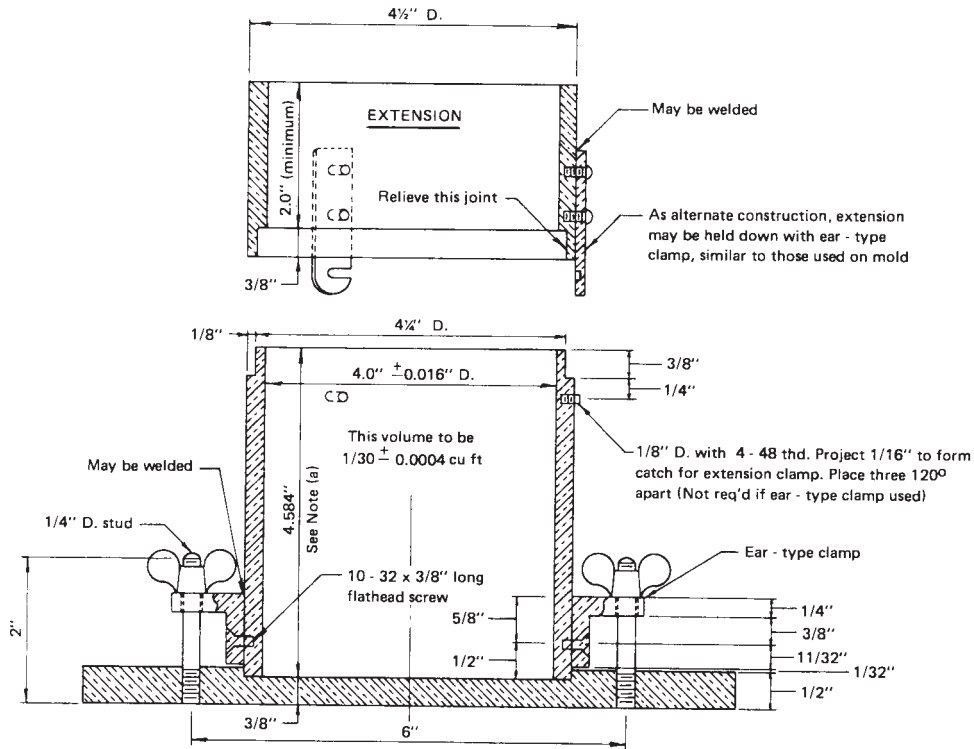
5.8 *Mixing Tools*—Miscellaneous tools such as mixing pan, spoon, trowel, and spatula, or a suitable mechanical device for thoroughly mixing the sample of soil with cement and with increments of water.

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

5.10 *Water Content Cans*—Suitable containers made of material resistant to corrosion and change in mass upon repeated heating, cooling, exposure to materials of varying pH, and cleaning. Unless a desiccator is used, containers with close fitting lids shall be used for testing specimens having a mass of about 200g; while for specimens having a mass greater than about 200g, containers without lids may be used. One container is needed for each water content determination.

5.11 *Butcher Knife*—A butcher knife approximately 10 in. (250 mm) in length for trimming the top of the specimens.

⁴ Annual Book of ASTM Standards, Vol 14.02.



Metric Equivalents

in.	mm
0.016	0.41
0.026	0.66
1/32	0.80
1/16	1.6
1/8	3.2
1/4	6.4
11/32	8.7
3/8	9.5
1/2	12.7
5/8	15.9
2	50.8
2 1/2	63.5
4	101.6
4 1/4	108.0
4 1/2	114.3
4.584	116.43
6	152.4
6 1/2	165.1
8	203.2
ft ³	cm
1/30	944
0.004	11
1/13.333	2124
0.0009	25

NOTE 1—(a)—The tolerance on the height is governed by the allowable volume and diameter tolerances.

NOTE 2—(b)—The methods shown for attaching the extension collar to the mold and the mold to the base plate are recommended. However, other methods are acceptable, providing the attachments are equally as rigid as those shown.

FIG. 1 Cylindrical Mold

6. Calibration

6.1 Perform calibrations before initial use, after repairs or other occurrences that might affect the test results, at intervals not exceeding 500 test specimens, or annually, whichever occurs first, for the following apparatus:

6.1.1 *Balance*—Evaluate in accordance with Specification D 3740.

6.1.2 *Molds*—Determine the volume as described in D 698, Annex 1.

6.1.3 *Manual Rammer*—Verify the free fall distance, rammer mass, and rammer force in accordance with 5.2. Verify the sleeve requirements in accordance with 5.2.1.

6.1.4 *Mechanical Rammer*—Calibrate and adjust the mechanical rammer in accordance with Test Method D 2168.

7. Test Method A, Using Soil Material Passing a No. 4 (4.75-mm) Sieve

7.1 Sample:

7.1.1 Prepare the sample for testing by breaking up the soil aggregations to pass the No. 4 (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 140°F (60°C).

7.1.2 Select a representative sample, having a mass of approximately 2.7 kg or more, of the soil prepared as described in 7.1.1.

7.2 Procedure:

7.2.1 Add to the soil the required amount of cement conforming to Specification C 150 or Specification C 595. Mix the cement and soil thoroughly to a uniform color.

7.2.2 When needed, add sufficient potable water to dampen the mixture to approximately four to six percentage points below the estimated optimum water content and mix thoroughly. At this water 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.

7.2.3 When the soil is a heavy-textured clayey material, compact the mixture of soil, cement, and water in the container to a depth of about 2 in. (50 mm) using the rammer described in 5.2 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.

7.2.4 After the absorption period, thoroughly break up the mixture, without reducing the natural size of individual particles, until it will pass a No. 4 (4.75-mm) sieve and then remix.

7.2.5 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. (130 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 such as provided by a cylinder or a cube of concrete with a mass not less than 91 kg.

7.2.6 Remove the extension collar after compaction and carefully trim the compacted mixture even with the top of the mold by means of a knife and straightedge. Determine and record the mass of the mixture and mold to four significant digits.

7.2.7 Remove the material from the mold and slice vertically through the center. Take a representative sample of the material, weighing not less than 100 g, from the full height of one of the cut faces. Immediately, determine and record the mass of the moist material and container to four significant digits. Dry in an oven at 230 + 9°C (110 + 5°C) for at least 12 hours or to a constant mass. Determine the mass of the dry soil and container to four significant digits.

7.2.8 Thoroughly break up the remainder of the material as before until it will pass a No. 4 (4.75-mm) sieve, as judged by eye, and add all other material remaining after obtaining the moisture sample.

7.2.9 Add water in sufficient amount to increase the water content of the soil-cement mixture by one or two percentage points, mix, and repeat the procedure given in 7.2.5-7.2.8 for each increment of water added.

7.2.10 Continue this series of determinations until there is either a decrease or no change in the mass of the moist material and mold.

NOTE 4—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 (unit weight) determination.

NOTE 5—To minimize the effect of cement hydration, perform the test expeditiously and continuously to completion.

8. Test Method B, Using Soil Material Passing a ¾-in. (19.0-mm) Sieve

8.1 Sample:

8.1.1 Prepare the sample for testing by segregating the aggregate retained on a No. 4 (4.75-mm) sieve and breaking up the remaining soil aggregations to pass the No. 4 (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 140°F (60°C).

8.1.2 Sieve the prepared soil over the 3-in. (75-mm) (Note 2), ¾-in., (19.0-mm), and No. 4 (4.75-mm) sieves. Discard the material retained on the 3-in. (75-mm) sieve. Determine the percentage of material, by oven-dry mass, retained on the ¾-in. (19.0-mm) and No. 4 sieves.

8.1.3 Saturate the aggregate passing the ¾-in. (19.0-mm) sieve and retained on the No. 4 (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 3 in. (75 mm) or less.

8.1.4 Select and maintain separate representative samples of soil passing the No. 4 (4.75-mm) sieve and of saturated, surface-dry aggregate passing the ¾-in. (19.0-mm) sieve and retained on the No. 4 sieve so that the total sample will weigh approximately 5 kg or more. The percentage, by oven-dry mass, of aggregate passing the ¾-in. (19.0-mm) sieve and retained on the No. 4 (4.75-mm) sieve shall be the same as the percentage passing the 3-in. (75-mm) sieve and retained on the No. 4 sieve in the original sample.

8.2 Procedure:

8.2.1 Add to the portion of the soil sample passing the No. 4 sieve, the amount of cement conforming to Specification C 150 or Specification C 595, required for the total sample specified in 8.1.4. Mix the cement and soil thoroughly to a uniform color.

8.2.2 When needed, add water to this soil-cement mixture and facilitate moisture dispersion as described for Method A in 7.2.2-7.2.4. After this preparation, add the saturated, surface-dry aggregate to the soil-cement mixture passing the No. 4 (4.75-mm) sieve and mix thoroughly.

8.2.3 Form a specimen by compacting the prepared soil-cement mixture in the mold (with the collar attached) and trim the compacted specimen as described for Method A in 7.2.5 and 7.2.6. 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. Determine and record the mass of the mixture and the mold to four significant digits.

8.2.4 Remove the material from the mold and take a sample for determining the water content as described for Method A in 7.2.7 except that the water content sample shall have a mass of at least 500 g. Record the result as the water content, w , of the compacted soil-cement mixture.

8.2.5 Thoroughly break up the remainder of the material as before until it will pass a $\frac{3}{4}$ -in. (19.0-mm) sieve and at least 90 % of the soil particles smaller than a No. 4 (4.75-mm) sieve will pass a No. 4 sieve, as judged by eye, and add all other material remaining after obtaining the water content sample.

8.2.6 Add sufficient water to increase the water content of the soil-cement mixture by one or two percentage points, mix, and repeat the procedure described in 8.2.3-8.2.5 for each increment of water added. Continue this series of determinations until there is either a decrease or no change in the mass of the moist material and the mold (Note 3 and Note 4).

9. Calculations

9.1 Calculate the volume of the mold used to compact the soil-cement mixture for each trial in accordance with Test Method D 698, Annex A1, to four significant digits.

9.2 Calculate the water content of the soil-cement mixture for each trial in accordance with D 2216 to 0.1 %

9.3 Calculate the moist density (Eq 1), the dry density (Eq 2), and then the dry unit weight (Eq 3) for each trial as follows:

$$\rho_m = (M_m - M_{md}) / 1000 V \quad (1)$$

where:

- ρ_m = moist density of compacted soil-cement specimen, Mg/m³,
- M_m = mass of moist specimen and mold, kg,
- M_{md} = mass of compaction mold, kg, and
- V = volume of compaction, m³ (see D 698, Annex A1).

$$\rho_d = \rho_m / (1 + w/100) \quad (2)$$

where:

- ρ_d = dry density of compacted soil-cement specimen, Mg/m³,
- ρ_m = moist density of compacted soil-cement specimen, Mg/m³, and
- w = water content, %.

$$\gamma_d = 62.43 \rho_d, \text{ in lbf/ft}^3 \quad (3)$$

or

$$\gamma_d = 9.087 \rho_d, \text{ in kN/m}^3 \quad (4)$$

where:

γ_d = dry unit weight of compacted soil-cement specimen

10. Moisture-Density (Unit Weight) Relationship

10.1 The values of water content and dry unit weight calculated in Section 9 for each compacted soil-cement specimen are then plotted. The dry unit weight in lbf/ft³ shall be plotted to the nearest 0.1 lbf/ft³ on the ordinate scale and the corresponding water content to the nearest 0.1 % on the abscissa scale. Draw the compaction curve as a smooth curve through the plotted points.

NOTE 7—Experience has shown that it is very important to use consistent scales when plotting these curves. One satisfactory approach is to plot the dry unit weight using a scale of 1" = 5 lbf/ft³ for the ordinate and the water content using a scale of 1" = 2 % as the abscissa.

10.2 *Optimum Water Content, w_o* —The water content corresponding to the peak of the curve plotted according to 10.1 shall be termed the “optimum water content” of the soil-cement mixture under the compaction process described in these methods.

10.3 *Maximum Dry Unit Weight, γ_{dmax}* —The dry unit weight, in lbf/ft³ corresponding to the optimum water content shall be termed “maximum dry unit weight” under the compaction process described in these test methods.

11. Report

11.1 The report shall include the following:

11.1.1 Sample identification (i.e., sample number, project, location, depth, etc.),

11.1.2 Procedure used (Method A or Method B),

11.1.3 Optimum water content, to the nearest 0.5 %,

11.1.4 Maximum dry unit weight, to the nearest 0.5 lbf/ft³, and

11.1.5 Compaction curve plot showing compaction points used to establish the compaction curve, point of maximum dry unit weight and optimum water content.

12. Precision and Bias

12.1 *Precision*—Test data on precision are not presented due to the nature of the materials being tested by this test method. It is either not feasible or too costly at this time to have ten or more laboratories participate in a round-robin testing program. Subcommittee D 18.15 is seeking any data from the users of this test method that might be used to make a limited statement on precision.

12.2 *Bias*—There are no accepted reference values for this test method, therefore, bias cannot be determined.

13. Keywords

13.1 compaction; dry density; optimum water content; soil-cement; soil-stabilization; unit weight

SUMMARY OF CHANGES

In accordance with D 18 policy, this section identifies the location of changes to this standard since the last edition (1996) that may impact the use of this standard.

- (1) Changed title to reflect definitions used in the test method.
- (2) Corrected typo in section 1.2.
- (3) Changed referenced sections for Method A and Method B in section 1.2.
- (4) Added new paragraph section 1.3 to reference D 6026.
- (5) Revised section 1.4 to clarify units used in the test method.
- (6) Updated the standard titles and added D 653, D 2216, D 4753, D 6026 and E 145 to section 2 on “Referenced Documents”.
- (7) Added the term “unit weight” in sections 3.1, Note 4 and Section 10.
- (8) Added new information to Note 1.
- (9) Updated Note 2 statement on Practice D 3740.
- (10) Added new Section 3 on “Terminology” and renumbered subsequent sections.
- (11) Revised sections 5.1, 5.4, 5.5, 5.6, and 5.10 to conform to D 18 guidelines and policies.
- (12) Added new Section 6 on “Calibration”. Renumbered subsequent sections.
- (13) Revised 7.2.6 for clarity and to include significant digits.
- (14) Moved the information in Section 7.2.7 to Section 9 “Calculations”. Renumbered subsequent sections.
- (15) Revised Section 7.2.8 for clarity.
- (16) Moved the information in Section 7.2.9 to Section 9 “Calculations”. Renumbered subsequent sections.
- (17) Revised wording of 7.2.10.
- (18) Added new sentence to end of Section 8.2.3 to clarify instructions and include significant digits.
- (19) Moved information in Section 8.2.4 to Section 9 “Calculations”. Renumbered subsequent sections.
- (20) Revised Section 9 “Calculations” to include all calculations associated with the test method.
- (21) Revised Section 10 “Moisture-Density (Unit Weight) Relationship” to include additional instructions.
- (22) Revised Section 11 “Report” to include additional items.
- (23) Revised Section 12.1 to conform to D 18 guidelines.
- (24) Corrected errors with respect to significant digits throughout standard.
- (25) Updated “Summary of Changes” section.

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