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AMERICAN SOCIETY FOR TESTING AND MATERIALS
100 Barr Harbor Dr., West Conshohocken, PA 19428
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Standard Test Methods for Moisture-Density 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-ft^3 (944-cm^3) mold and a 5.5-lb (2.49-kg) rammer dropped from a height of 12 in. (304.8 kg) 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	5
Test Method B, using soil material passing a ¾-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 ¾-in. (19.0-mm) sieve	6

1.3 The values stated in inch-pound units are to be regarded as the standard. The SI units given in parentheses are for information only.

1.4 *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 Cement[2]

C 595 Specification for Blended Hydraulic Cements[2]

D 559 Test Methods for Wetting-and-Drying Tests of Compacted Soil-Cement Mixtures[3]

D 560 Test Methods for Freezing-and-Thawing Tests of Compacted Soil-Cement Mixtures[3]

D 698 Test Methods for Moisture-Density Relations of Soils and Soil-Aggregate Mixtures Using 5.5-lb (2.49-kg) Rammer and 12-in. (305-mm) Drop[3]

D 2168 Test Methods for Calibration of Laboratory Mechanical-Rammer Soil Compactors[3]

D 3740 Practice for the Minimum Requirements for Agencies Engaged in the Testing and/or Inspection of Soil and Rock Used in Engineering Design and Construction[3]

E 11 Specification for Wire-Cloth Sieves for Testing Purposes[4]

3. Significance and Use

3.1 These tests determine the optimum water content and maximum density 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.

NOTE 2—The agency performing these test methods can be evaluated in accordance with Practice D 3740. Not withstanding statements on precision and bias contained in these test methods: the precision of these test methods 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. Users of these test methods are cautioned that compliance with Practice D 3740 does not, in itself, ensure reliable testing. Reliable testing depends on many factors; Practice D 3740 provides a means of evaluating some of these factors.

4. Apparatus

4.1 *Mold*—A cylindrical metal mold having a capacity of 1/30 ± 0.0004 ft^3 (944 ± 11 cm^3) with an internal diameter of 4.0 ± 0.016 in. (101.60 ± 0.41 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 2½ 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).

4.2 *Rammer*:

4.2.1 *Manual Rammer*—A manually operated metal rammer having a 2.0 ± 0.005-in. (50.80 ± 0.13-mm) diameter circular face and weighing 5.5 ± 0.02 lb (2.49 ± 0.01 kg). The rammer shall be equipped with a suitable guidesleeve to

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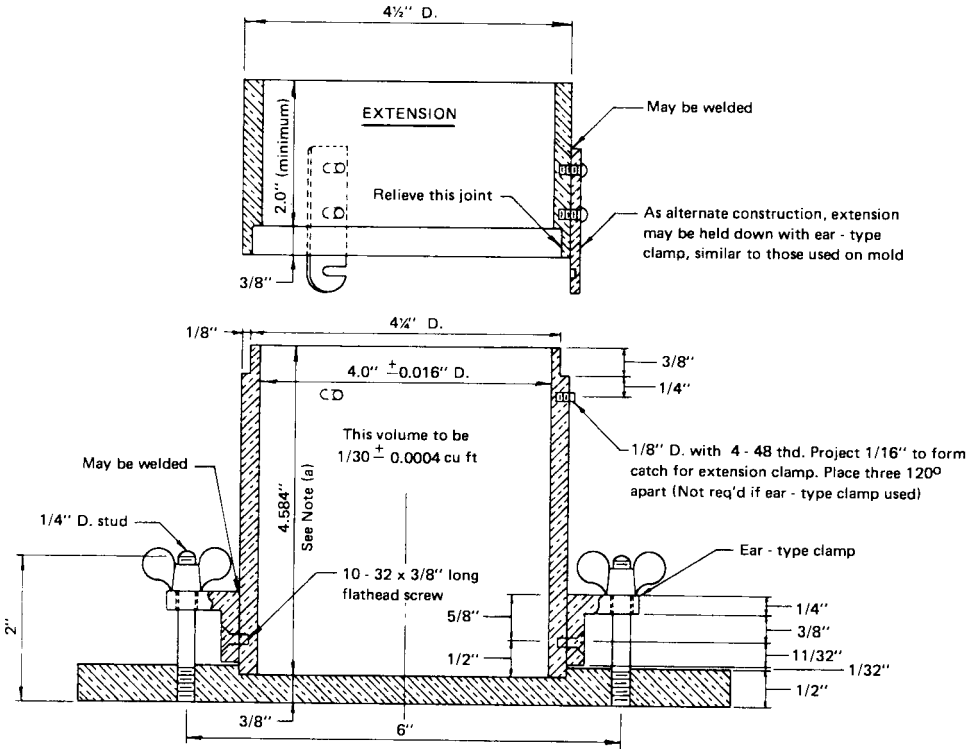
[2] *Annual Book of ASTM Standards*, Vols 04.01 and 04.02.

[3] *Annual Book of ASTM Standards*, Vol 04.08.

[4] *Annual Book of ASTM Standards*, Vols 04.01, 04.06, and 14.02.

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



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
2½	63.5
4	101.6
4¼	108.0
4½	114.3
4.584	116.43
6	152.4
6½	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

control the height of drop to a free fall of 12.0 ± 1/16 in. (304.8 ± 1.6 mm) above the elevation of the soil-cement. The guidesleeve shall have at least four vent holes not smaller than 3/8 in. (9.5 mm) spaced 90° apart and located with centers 3/4 ± 1/16 in. (19.0 ± 1.6 mm) from each end and shall provide sufficient clearance that free-falls of the rammer shaft and head will not be restricted.

4.2.2 *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 5.5 ± 0.02 lb (2.49 ± 0.01 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 ± 1/16 in. (304.8

± 1.6 mm) above the elevation of the soil-cement.

4.2.3 *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.

4.3 *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.

4.4 *Balances*—A balance or scale of at least 25-lb (11.3-kg) capacity sensitive to 0.01 lb (0.005 kg) and a balance of at least 1000-g capacity sensitive to 0.1 g.

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

4.6 *Straightedge*—A rigid steel straight-edge 12 in. (305 mm) in length and having one beveled edge.

4.7 *Sieves*—3-in. (75-mm), ¾-in. (19.0-mm), and No. 4 (4.75-mm) sieves conforming to the requirements of Specification E 11.

4.8 *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.

4.9 *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.

4.10 *Moisture Cans*—Suitable containers for moisture samples.

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

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

5.1 *Sample*:

5.1.1 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).

5.1.2 Select a representative sample, weighing approximately 6 lb (2.7 kg) or more, of the soil prepared as described in 5.1.1.

5.2 *Procedure*:

5.2.1 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.

5.2.2 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 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.

5.2.3 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 4.2 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.

5.2.4 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.

5.2.5 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. (304.8 mm) above the elevation of the soil-cement when a sleeve-type rammer is used, or from 12 in. (304.8 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 weighing not less than 200 lb (91 kg).

5.2.6 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.

5.2.7 Multiply the mass of the compacted specimen and mold, minus the mass of the mold, by 30 (or divide by 942.95); record the result as the wet unit mass, γ_m, in pounds per cubic foot or grams per cubic centimetre, of the compacted soil-cement mixture.

5.2.8 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, weigh immediately, and dry in an oven at 230 ± 9°F (110 ± 5°C) for at least 12 h or to constant mass.

5.2.9 Calculate the water content of the sample as directed in Section 7. Record the result as the moisture content, *w*, of the compacted soil-cement mixture.

5.2.10 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.

5.2.11 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 5.2.5-5.2.10 for each increment of water added.

5.2.12 Continue this series of determinations until there is either a decrease or no change in the wet unit mass, γ_m, in pounds per cubic foot or grams per cubic centimetre of the compacted soil-cement mixture.

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 determination.

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

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

6.1 *Sample*:

6.1.1 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).

6.1.2 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.

6.1.3 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.

6.1.4 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 11 lb (4.99 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.

6.2 *Procedure*:

6.2.1 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 6.1.4. Mix the cement and soil thoroughly to a uniform color.

6.2.2 When needed, add water to this soil-cement mixture and facilitate moisture dispersion as described for Method A in 5.2.2-5.2.4. 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.

6.2.3 Form a specimen by compacting the prepared soil-cement mixture in the mold (with the collar attached) and trim and weigh the compacted specimen as described for Method A in 5.2.5 and 5.2.6. 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.

6.2.4 Multiply the mass of the compacted specimen and mold, minus the mass of the mold, by 30 (or divide by 942.95); record the result as the wet unit mass, γ_m, in pounds per cubic foot or grams per cubic centimetre of the compacted soil-cement mixture.

6.2.5 Remove the material from the mold and take a sample for determining the water content as described for Method A in 5.2.8 and 5.2.9 except that the moisture sample shall weigh not less than 500 g. Record the result as the water content, *w*, of the compacted soil-cement mixture.

6.2.6 Thoroughly break up the remainder of the material as before until it will pass a ¾-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 moisture sample.

6.2.7 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 6.2.3-6.2.6 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, γ_m, in pounds per cubic foot or grams per cubic centimetre of the compacted soil-cement mixture (Note 3 and Note 4).

7. Calculation

7.1 Calculate the water content and dry unit mass, γ_d, in pounds per cubic foot or grams per cubic centimetre of the compacted soil-cement mixture for each trial as follows:

$$w = [(A - B)/(B - C)] \times 100 \quad (1)$$

$$\gamma = [\gamma_m/(w + 100)] \times 100$$

where:

w = percentage of water 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,
γ_d = dry unit mass of compacted soil cement, lb/ft^3 or g/cm^3, and
γ_m = wet unit mass of compacted soil-cement, lb/ft^3 or g/cm^3.

8. Moisture-Density Relationship

8.1 The calculations in Section 7 shall be made to determine the water content and corresponding dry unit mass, γ_d, in pounds per cubic foot or grams per cubic centimetre (density) for each of the compacted soil-cement samples. The dry unit mass, γ_d, in pounds per cubic foot or grams per cubic centimetre (densities) of the soil-cement mixture shall be plotted as ordinates and the corresponding moisture contents as abscissas.

8.2 *Optimum Water Content, w_o*—When the densities and corresponding moisture contents for the soil-cement mixture have been determined and plotted as indicated in 8.1 it will be found that by connecting the plotted points with a smooth line, a curve is produced. The water 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.

8.3 *Maximum Density, γ_{max}*—The dry unit mass, γ_d, in pounds per cubic foot or grams per cubic centimetre of the soil-cement mixture at "optimum water content" shall be termed "maximum density" under the compaction prescribed in these test methods.

9. Report

9.1 The report shall include the following:

9.1.1 Optimum water content, and
9.1.2 Maximum density.

10. Precision and Bias

10.1 *Precision*—Data are being sought by the subcommittee for the preparation of a statement on the precision of this test procedure. Until a statement is developed, the user may be guided by the statement in Test Method D 698, for which the precision is expected to be similar.

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

11. Keywords

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

SUMMARY OF CHANGES

This section identifies the principal changes to these test methods that have been incorporated since the last issue.

(1) Added new sentence at the end of Section 1.2, Test Method B, to clarify the applicable materials as required in Test Method D 698 when using a 4-in. (101.60-mm) mold.
(2) Added safety caveat in 1.4 to comply with present policy.
(3) Added Practice D 3740 as a referenced document in Section 2 to conform to the recommended D-18 practice.
(4) Added new Note 2 in Section 3 to reference Practice D 3740. Renumbered the remaining notes.
(5) Revised Section 11 on Keywords.
(6) Added Summary of Changes to reflect the changes made in this revision.
(7) Changed “moisture content” to “water content” in Sections 1.1, 3.1, 4.5, 5.2.2, 5.2.9, 5.2.11, 6.2.5, 6.2.7, 7.1, 8.1, 8.2, 8.3, and 9 to agree with current D-18 Terminology.