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HALLIBURTON NUS
Environmental Corporation

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C-49-2-2-39

February 6, 1992

HALLIBURTON NUS Project No. 2K68.232

Mr. Leon Collins
EG&G Rocky Flats, Inc.
5932 McIntyre Street
Golden, Colorado 80403

Subject: Rocky Flats Solar Pond Project
Transmittal of Durability Test Methods

Dear Mr. Collins:

As you requested during our recent meeting in Denver, I am forwarding to your attention copies of the Wetting and Drying Test (ASTM D 559) and the Freezing and Thawing Test (ASTM D 560) being used during the ongoing treatability study. Please be aware that the methods have been modified by reducing the time per cycle in each test to reduce the duration of the overall test during the initial screening phases of the treatability study. This was necessary to meet the overall project schedule objectives while still obtaining useful durability data. During the final regulatory confirmation phase for each waste, the method will be used as written.

If you have any questions concerning this information, please call me at 800-245-2730 or 412-921-8746.

Sincerely,

Richard M. Ninesteel

RMN:lcj

Enclosure

cc: T. Bittner
J. Schmidt
D. Brenneman

Designation: D 559 – 82

# Standard Methods for Wetting-and-Drying Tests of Compacted Soil-Cement Mixtures[1]

This standard is issued under the fixed designation D 559; 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.

*These methods have been approved for use by agencies of the Department of Defense and for listing in the DoD Index of Specifications and Standards.*

## 1. Scope

1.1 These methods cover procedures for determining the soil-cement losses, moisture changes, and volume changes (swell and shrinkage) produced by repeated wetting and drying of hardened soil-cement specimens. The specimens are compacted in a mold, before cement hydration, to maximum density at optimum moisture content using the compaction procedure described in Test Methods D 558.

1.2 Two methods, depending on soil gradation, are covered for preparation of material for molding specimens and for molding specimens as follows:

| | Sections |
|---|---|
| *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 |
| *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 | 6 |

## 2. Referenced Documents

2.1 *ASTM Standards:*

C 150 Specification for Portland Cement[2]

C 595 Specification for Blended Hydraulic Cements[2]

D 558 Test Methods for Moisture-Density Relations of Soil-Cement Mixtures[3]

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

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

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

## 3. Significance and Use

3.1 These methods are used to determine the resistance of compacted soil-cement specimens to repeated wetting and drying. These methods were developed to be used in conjunction with Methods D 560 and criteria given in the *Soil-Cement Laboratory Handbook*[5] to determine the minimum amount of cement required in soil-cement to achieve a degree of hardness adequate to resist field weathering.

## 4. Apparatus

4.1 *Mold*—A cylindrical metal mold having a capacity of 1/30 ± 0.0004 ft³ (944 ± 11 cm³) 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 a 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.

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 control the height of drop to a free fall of 12 ± 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 ⅜ in. (9.5 mm) spaced 90° apart and located with centers ¾ ± 1/16 in. (19.0 ± 1.6 mm) from each end and shall provide sufficient clearance that freefalls 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 weight of 5.5 ± 0.02 lb (2.49 ± 0.01 kg). The operating weight 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*—Strength and resistance to wetting-and-drying of specimens compacted with the sector face rammer may differ from that of specimens compacted with the circular face rammer. Therefore, the sector face rammer shall not be used unless previous tests on like soil-cement mixtures show that similar resistance to wetting and drying is obtained with the two types of rammers.

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.

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[1] These methods are under the jurisdiction of the ASTM Committee D-18 on Soil and Rock and are the direct responsibility of Subcommittee D18.15 on Stabilization of Additives.

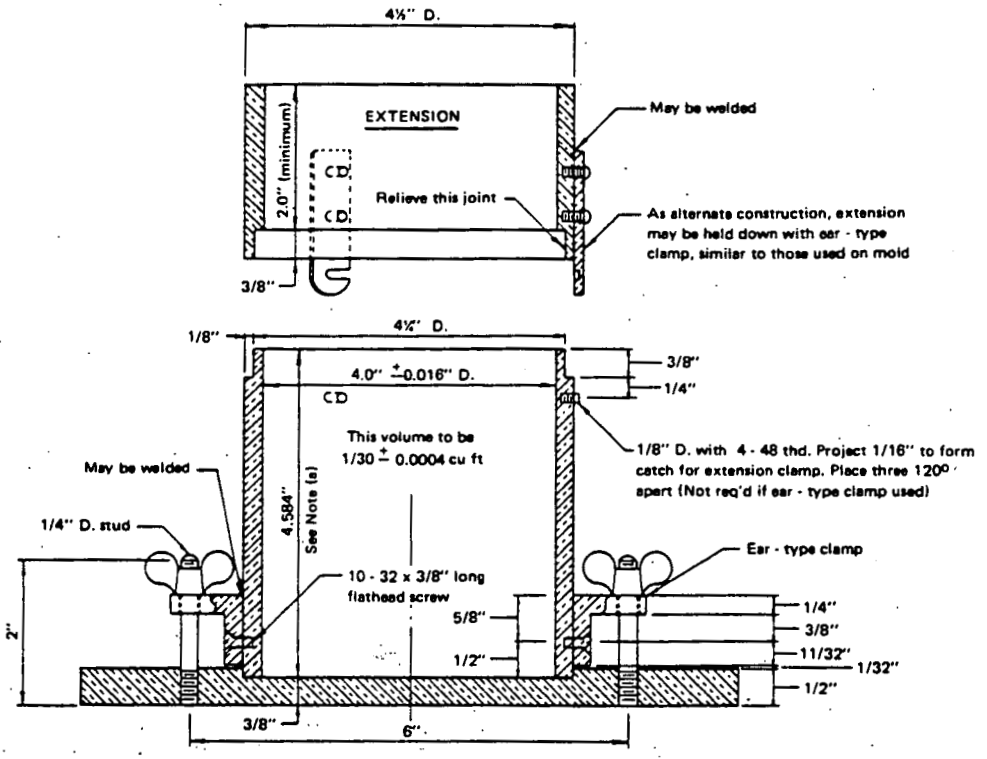
Current edition approved July 30, 1982. Published September 1982. Originally published as D 559 – 39. Last previous edition D 559 – 57 (1976).

[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.

[5] *Soil-Cement Laboratory Handbook*, Portland Cement Assn., 1971.




**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 (a)—The tolerance on the height is governed by the allowable volume and diameter tolerances.
NOTE (b)—The methods shown for attaching the extension collar to the mold and the mold to the base plate are recommended. However, others methods are acceptable, providing the attachments are equally as rigid as those shown.

**FIG. 1 Cylindrical Mold**

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 Ovens*—A thermostatically controlled drying oven capable of maintaining temperatures of 230 ± 9°F (110 ± 5°C) for drying moisture samples, and a thermostatically controlled drying oven capable of maintaining temperatures of 160 ± 5°F (71 ± 3°C) for drying compacted soil-cement specimens.

4.6 *Moist Room*—A moist room or suitable covered container capable of maintaining a temperature of 70 ± 3°F (21 ± 1.7°C) and a relative humidity of 100 % for 7-day storage of compacted specimens.

4.7 *Water Bath*—Suitable tank for submerging compacted specimens in water at room temperature.

4.8 *Wire Scratch Brush*—A wire scratch brush made of 2 by 1/16-in. (50.8 by 1.588-mm) flat No. 26 gage (0.46-mm) wire bristles assembled in 50 groups of 10 bristles each and mounted to form 5 longitudinal rows and 10 transverse rows of bristles on a 7½ by 2½-in. (190 by 63.5-mm) hardwood block.

4.9 *Straightedge*—A rigid steel straightedge 12 in. (305 mm) in length and having one beveled edge.

4.10 *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.

4.11 *Mixing Tools*—Miscellaneous tools such as mixing pan, and trowel, or a suitable mechanical device for thoroughly mixing the soil with cement and water.

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

4.13 *Scarifier*—A six-pronged ice pick or similar apparatus to remove the smooth compaction plane at the top of the first and second layers of the specimen.

4.14 *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.

4.15 *Measuring Device*—A measuring device suitable for accurately measuring the heights and diameters of test specimens to the nearest 0.01 in. (0.2 mm).

4.16 *Pans and Carriers*—Suitable pans for handling materials and carriers or trays for handling test specimens.

4.17 *Graduate*—A graduated cylinder of 250-mL capacity for measuring water.

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

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

5.1 *Preparation of Material for Molding Specimens:*

5.1.1 Prepare the soil sample in accordance with the procedure described in Method A of Test Methods D 558.

5.1.2 Select a sufficient quantity of the soil prepared as described in 5.1.1 to provide two (Note 1) compacted specimens and required moisture samples.

NOTE 1: (*Optional*)—Usually only one specimen (identified as No. 2) is required for routine testing. The other specimen (identified as No. 1) is made for research work and for testing unusual soils.

5.1.3 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.

5.1.4 Add sufficient potable water to raise the soil-cement mixture to optimum moisture content at the time of compaction and mix thoroughly. When the soil used 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.

5.1.5 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, as judged by eye, and then remix.

5.2 *Molding Specimens:*

5.2.1 Form a specimen by immediately compacting the soil-cement mixture in the mold (with the collar attached) and later trimming the specimen in accordance with Method A of Test Methods D 558, and in addition scarify the tops of the first and second layers to remove smooth compaction planes before placing and compacting the succeeding layers. This scarification shall form grooves at right angles to each other, approximately 1/8 in. (3.2 mm) in width and 1/8 in. (3.2 mm) in depth and approximately 1/4 in. (6.4 mm) apart.

5.2.2 During compaction, take from the batch a representative sample of the soil-cement mixture, weighing not less than 100 g, weigh immediately, and dry in an oven at 230 ± 9°F (110 ± 5°C) for at least 12 h or to constant weight. Calculate the percentage of moisture as prescribed in Test Methods D 558 to check against design moisture content.

5.2.3 Weigh the compacted specimen and mold, remove the specimen from the mold, and calculate the oven-dry weight of each specimen in $lb/ft^3$ ($g/cm^3$) to check against design density.

5.2.4 Identify the specimen on a metal tag (or other suitable device) as No. 1 (Note 1) together with other needed identification marks and use to obtain data on moisture and volume changes during the test.

5.2.5 Form a second specimen as rapidly as possible and determine the percentage of moisture and oven-dry weight as described in 5.2.1 to 5.2.3. Identify this specimen as No. 2, together with other needed identification marks and use to obtain data on soil-cement losses during the test.

5.2.6 Determine the average diameter and height of the No. 1 specimen and calculate its volume.

5.2.7 Place the specimens on suitable carriers in the moist room and protect them from free water for a period of 7 days.

5.2.8 Weigh and measure the No. 1 specimen at the end of the 7-day storage period to provide data for calculating its moisture content and volume.

NOTE 2—It is important that all height and diameter measurements be accurate to within 0.01 in. (0.2 mm) and be taken at the same points on the specimen at all times.

5.3 *Procedure:*

5.3.1 At the end of the storage in the moist room, submerge the specimens in potable water at room temperature for a period of 5 h and remove. Weigh and measure the No. 1 specimen (volume and moisture change specimen).

5.3.2 Place both specimens in an oven at 160°F (71°C) for 42 h and remove. Weigh and measure the No. 1 specimen.

5.3.3 Give specimen No. 2 (soil-cement loss specimen) two firm strokes on all areas with the wire scratch brush. The brush shall be held with the long axis of the brush parallel to the longitudinal axis of the specimen or parallel to the ends as required to cover all areas of the specimen. Apply these strokes to the full height and width of the specimen with a firm stroke corresponding to approximately 3-lbf (13.3-N) force (Note 3). Eighteen to twenty vertical brush strokes are required to cover the sides of the specimen twice and four strokes are required on each end.

NOTE 3—This pressure is measured as follows: clamp a specimen in a vertical position on the edge of a platform scale and zero the scale. Apply vertical brushing strokes to the specimen and note the force necessary to register approximately 3 lbf (13.3 N).

5.3.4 The procedures described in 5.3.1 to 5.3.3 constitute one cycle (48 h) of wetting and drying. Again submerge the specimens in water and continue the procedure for 12 cycles.

NOTE 4—Weight determinations of specimen No. 2 before and after brushing are usually made at the end of each cycle when conducting research and making special investigations.

5.3.5 The No. 1 specimen may be discontinued prior to 12 cycles should the measurements become inaccurate due to soil-cement loss of the specimen.

NOTE 5—If it is not possible to run the cycles continuously because of Sundays, holidays, or for any other reason, hold the specimens in the oven during the layover period if possible.

5.3.6 After 12 cycles of test, dry the specimens to constant weight at 230°F (110°C) and weigh to determine the oven-dry weight of the specimens.

5.3.7 The data collected will permit calculations of volume and moisture changes of specimen No. 1 and the soil-cement losses of specimen No. 2 after the prescribed 12 cycles of test.

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

6.1 *Preparation of Material for Molding Specimens:*

6.1.1 Prepare the soil sample in accordance with Method B of Test Methods D 558.

6.1.2 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 (4.75-mm) sieve so that the total sample will be enough to provide two (Note 1) compacted specimens and required moisture samples. The percentage, by oven-dry weight, 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 (4.75-mm) sieve in the original sample.

6.1.3 Add to the sample passing the No. 4 (4.75-mm) sieve, the amount of cement conforming to Specification C 150 or Specification C 595, required for the total sample specified in 6.1.2 Mix the cement and soil thoroughly to a uniform color.

6.1.4 Add to the sample passing the No. 4 (4.75-mm) sieve, sufficient water to raise the total soil-cement mixture prescribed in 6.1.2 to optimum moisture content at time of compaction and facilitate moisture dispersion as described for Method A in 5.1.4 to 5.1.6.

6.1.5 After preparation of the mixture as described in 6.1.1 to 6.1.4, add the saturated, surface-dry aggregate to the mixture and mix thoroughly.

6.2 *Molding Specimens:*

6.2.1 Form a specimen by immediately compacting the soil-cement mixture in the mold (with the collar attached) and later trimming the specimen in accordance with Method B of Test Methods D 558, and in addition as the mixture for each layer is placed in the mold, spade along the inside of the mold with a butcher knife before compaction to obtain uniform distribution of the material retained on the No. 4 (4.75-mm) sieve and scarify the tops of the first and second layers as described for Method A of this method.

6.2.2 During compaction, take from the batch a representative sample of the soil-cement mixture weighing not less than 500 g, weigh immediately, and dry in an oven at 230 ± 9°F (110 ± 5°C) for at least 12 h or to constant weight to determine the moisture content to check against design moisture content.

6.2.3 Form a second specimen as rapidly as possible in the same manner.

6.2.4 Weigh each compacted specimen to check against design density, identify, measure the No. 1 specimen (Note 1), place in the moist room, and measure the No. 1 specimen again at the end of the 7-day storage period as described for Method A in 5.2.3 to 5.2.8 (Note 2).

6.3 *Procedure:*

6.3.1 Proceed as directed in Method A (see 5.3).

## 7. Calculations

7.1 Calculate the volume and moisture changes and the soil-cement losses of the specimens as follows:

7.1.1 Calculate the difference between the volume of specimen No. 1 at the time of molding and subsequent volumes as a percentage of the original volume.

7.1.2 Calculate the moisture content of specimen No. 1 at the time of molding and subsequent moisture contents as a percentage of the original oven-dry weight of the specimen.

7.1.3 Correct the oven-dry weight of specimen No. 2 as obtained in 5.3.6 for water that has reacted with the cement and soil during the test and is retained in the specimen at 230°F (110°C), as follows:

$$\text{Corrected oven-dry weight} = (A/B) \times 100$$

where:

$A$ = oven-dry weight after drying at 230°F (100°C), and

$B$ = percentage of water retained in specimen plus 100.

The percentage of water retained in specimen No. 2 after drying at 110°C for use in the above formula can be assumed to be equal to the water retained in specimen No. 1. When No. 1 specimens are not molded, the foregoing data are not available and the average values prescribed in Table 1 are used.

7.1.4 Calculate the soil-cement loss of specimen No. 2 as a percentage of the original oven-dry weight of the specimen as follows:

$$\text{Soil-cement loss, \%} = (A/B) \times 100$$

where:

$A$ = original calculated oven-dry weight minus final corrected oven-dry weight, and

$B$ = original calculated oven-dry weight.

## 8. Report

8.1 The report shall include the following:

8.1.1 The designed optimum moisture and maximum density of the molded specimens,

**TABLE 1 Average Values**

| AASHTO Soil Classification | Average Water Retained After Drying at 230°F (110°C), % |
|---|---|
| A-1, A-3 | 1.5 |
| A-2 | 2.5 |
| A-4, A-5 | 3.0 |
| A-6, A-7 | 3.5 |

8.1.2 The moisture content and density obtained in molded specimens,

NOTE 6—Good laboratory practice permits the following tolerances between design factors and those obtained in the molded specimens:

| | |
|---|---|
| Moisture content | ±1 percentage point |
| Density | ±3 lb/ft$^3$ (0.048 g/cm$^3$) |

8.1.3 The designed cement content, in percent, of the molded specimens,

8.1.4 The maximum volume change, in percent, and maximum moisture content during test of specimen No. 1, and

8.1.5 The soil-cement loss, in percent, of specimen No. 2.

## 9. Precision and Accuracy

9.1 Precision and accuracy of this test procedure have not been established. Data are available on the variability of weight losses for duplicate specimens. These data will be analyzed and a statement will be included in the next revision.

Designation: D 560 – 82

# Standard Methods for Freezing-and-Thawing Tests of Compacted Soil-Cement Mixtures[1]

This standard is issued under the fixed designation D 560; 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.

*These methods have been approved for use by agencies of the Department of Defense and for listing in the DoD Index of Specifications and Standards.*

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1.1 These methods cover procedures for determining the soil-cement losses, moisture changes, and volume changes (swell and shrinkage) produced by repeated freezing and thawing of hardened soil-cement specimens. The specimens are compacted in a mold, before cement hydration, to maximum density at optimum moisture content using the compaction procedure described in Test Methods D 558.

1.2 Two methods, depending on soil gradation, are covered for preparation of material for molding specimens and for molding specimens as follows:

| | Sections |
|---|---|
| *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 |
| *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 | 6 |

## 2. Referenced Documents

2.1 *ASTM Standards:*

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

## 3. Significance and Use

3.1 These methods are used to determine the resistance of compacted soil-cement specimens to repeated freezing and thawing. These methods were developed to be used in conjunction with Methods D 559 and criteria given in the *Soil-Cement Laboratory Handbook*[5] to determine the minimum amount of cement required in soil-cement to achieve a degree of hardness adequate to resist field weathering.

## 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 a 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.

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 control the height of drop to a free fall of 12 ± 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 ⅜ in. (9.5 mm) spaced 90° apart and located with centers ¾ ± 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 weight of 5.5 ± 0.02 lb (2.49 ± 0.01 kg). The operating weight 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*—Strength and resistance to freezing and thawing of specimens compacted with the sector face rammer may differ from that of specimens compacted with the circular face rammer. Therefore, the sector face rammer shall not be used unless previous tests on like soil-cement mixtures show that similar resistance to freezing and thawing is obtained with the two types of rammers.

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.

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Current edition approved July 30, 1982. Published September 1982. Originally published as D 560 – 39. Last previous edition D 560 – 57 (1976).

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TABLE 1 Average Values

| AASHTO Soil Classification | Average Water Retained After Drying at 230°F (110°C), % |
|---|---|
| A-1, A-3 | 1.5 |
| A-2 | 2.5 |
| A-4, A-5 | 2.0 |
| A-6, A-7 | 3.5 |

by 1/16-in. (50.8 by 1.588-mm) flat No. 26 gage (0.46 mm) wire bristles assembled in 50 groups of 10 bristles each and mounted to form 5 longitudinal rows and 10 transverse rows of bristles on a 7½ by 2½-in. (190 by 63.5-mm) hardwood block.

4.9 *Straightedge*—A rigid steel straightedge 12 in. (305 mm) in length and having one beveled edge.

4.10 *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.

4.11 *Mixing Tools*—Miscellaneous tools such as mixing pan, and trowel, or a suitable mechanical device for thoroughly mixing the soil with cement and water.

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

4.13 *Scarifier*—A six-pronged ice pick or similar apparatus to remove the smooth compaction plane at the top of the first and second layers of the specimen.

4.14 *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.

4.15 *Measuring Device*—A measuring device suitable for accurately measuring the heights and diameters of test specimens to the nearest 0.01 in. (0.2 mm).

4.16 *Pans and Carriers*—Suitable pans for handling materials and carriers or trays for handling test specimens.

4.17 *Absorptive Pads*—¼-in. (6-mm) thick felt pads, blotters, or similar absorptive material for placing between specimens and specimen carriers.

4.18 *Graduate*—A graduated cylinder of 250-mL capacity for measuring water.

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

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

5.1 *Preparation of Material for Molding Specimens:*

5.1.1 Prepare the soil sample in accordance with Method A of Test Methods D 558.

5.1.2 Select a sufficient quantity of the soil prepared as described in 5.1.1 to provide two (Note 1) compacted specimens and required moisture samples.

NOTE 1: (*Optional*)—Usually only one specimen (identified as No. 2) is required for routine testing. The other specimen (identified as No. 1) is made for research work and for testing unusual soils.

5.1.3 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.

5.1.4 Add sufficient potable water to raise the soil-cement mixture to optimum moisture content at time of compaction and mix thoroughly.

5.1.5 When the soil used is a heavy textured clayey material, compact the mixture of soil, cement, and water in a container to a depth of about 2 in. (50 mm) using the rammer described in 4.2 or 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.

5.1.6 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, as judged by eye, and then remix.

5.2 *Molding Specimens:*

5.2.1 Form a specimen by immediately compacting the soil-cement mixture in the mold, with the collar attached, and later trimming the specimen in the same manner as directed for Method A of Test Methods D 558, and in addition scarify the tops of the first and second layers to remove smooth compaction planes before placing and compacting the succeeding layers. This scarification shall form grooves at right angles to each other, approximately 1/8 in. (3.2 mm) in width and 1/8 in. (3.2 mm) in depth and approximately ¼ in. (6.4 mm) apart.

5.2.2 During compaction, take from the batch a representative sample of the soil-cement mixture, weighing not less than 100 g, weigh immediately and dry in an oven at 230 ± 9°F (110 ± 5°C) for at least 12 h or to constant weight. Calculate the percentage of moisture as directed in Test Methods D 558 to check against design moisture content.

5.2.3 Weigh the compacted specimen and mold, remove the specimen from the mold, and calculate the oven-dry weight of each specimen in lb/ft$^3$ (g/cm$^3$) to check against design density.

5.2.4 Identify the specimen on a metal tag (or other suitable device) as No. 1 (Note 1) together with other needed identification marks and use to obtain data on moisture and volume changes during the test.

5.2.5 Form a second specimen as rapidly as possible and determine the percentage of moisture and oven-dry weight as described in 5.2.1 to 5.2.3. Identify this specimen as No. 2 together with other needed identification marks and use to obtain data on soil-cement losses during the test.

5.2.6 Determine the average diameter and height of the No. 1 specimen and calculate its volume.

5.2.7 Place the specimens on suitable carriers in the moist room and protect them from free water for a period of 7 days.

5.2.8 Weigh and measure the No. 1 specimen at the end of the 7-day storage period to provide data for calculating its moisture content and volume.

NOTE 2—It is important that all height and diameter measurements be accurate to within 0.01 in. (0.2 mm) and be taken at the same points on the specimen at all times.

5.3 *Procedure:*

5.3.1 At the end of the storage in the moist room, place water-saturated felt pads about ¼ in. (6 mm) thick, blotters, or similar absorptive material between the specimens and the carriers, and place the assembly in a freezing cabinet having a constant temperature not warmer than −10°F (−23°C) for 24 h and remove. Weigh and measure the No. 1 specimen (volume and moisture change specimen).

5.3.2 Place the assembly in the moist room or suitable covered container having a temperature of 70°F (21°C) and a relative humidity of 100 % for 23 h and remove. Free potable water shall be made available to the absorbent pads under the specimens to permit the specimens to absorb water by capillary action during the thawing period. Weigh and measure the No. 1 specimen.

5.3.3 Give specimen No. 2 (soil-cement loss specimen) two firm strokes on all areas with the wire scratch brush. The brush shall be held with the long axis of the brush parallel to the longitudinal axis of the specimen or parallel to the ends as required to cover all areas of the specimen. Apply these strokes to the full height and width of the specimen with a firm stroke corresponding to approximately 3-lbf (13.3-N) force (Note 3). Eighteen to twenty vertical brush strokes are required to cover the sides of the specimen twice and four strokes are required on each end.

NOTE 3—This pressure is measured as follows: clamp a specimen in a vertical position on the edge of a platform scale and zero the scale. Apply vertical brushing strokes to the specimen and note the force necessary to register approximately 3 lbf (13.3 N).

5.3.4 After being brushed, the specimens shall be turned over end for end before they are replaced on the water-saturated pads.

5.3.5 The procedures described in 5.3.1 to 5.3.4 constitute one cycle (48 h) of freezing and thawing. Again place the specimens in the freezing cabinet and continue the procedure for 12 cycles.

NOTE 4—Weight determinations of specimen No. 2 before and after brushing are usually made at the end of each cycle when conducting research and making special investigations. Some specimens made of silty and clayey soils tend to scale on sides and ends particularly after about the sixth cycle of test. This scale shall be removed with a sharp-pointed instrument such as an ice pick, since the regular brushing may not be effective.

5.3.6 The No. 1 specimen may be discontinued prior to 12 cycles should measurements become inaccurate due to soil-cement loss of the specimen.

NOTE 5—If it is not possible to run the cycles continuously because of Sundays, holidays, or for any other reason, the specimens shall be held in the freezing cabinet during the layover period if possible.

5.3.7 After 12 cycles of test, dry the specimens to constant weight at 230°F (110°C) and weigh to determine the oven-dry weight of the specimens.

5.3.8 The data collected will permit calculations of volume and moisture changes of specimen No. 1 and the soil-cement losses of specimen No. 2 after the prescribed 12 cycles of test.

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

6.1 *Preparation of Material for Molding Specimens:*

6.1.1 Prepare the soil sample in accordance with Method B of Test Methods D 558.

6.1.2 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 (4.75-mm) sieve so that the total sample will be enough to provide two (Note 1) compacted specimens and required moisture samples. The percentage, by oven-dry weight, 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 (4.75-mm) sieve in the original sample.

6.1.3 Add to the sample passing the No. 4 (4.75-mm) sieve, the amount of cement conforming to Specification C 150, or Specification C 595, required for the total sample described in 6.1.2. Mix the cement and soil thoroughly to a uniform color.

6.1.4 Add to the sample passing the No. 4 (4.75-mm) sieve, sufficient water to raise the total soil-cement mixture specified in 6.1.2 to optimum moisture content at time of compaction and facilitate moisture dispersion as described for Method A in 5.1.4 to 5.1.6.

6.1.5 After preparation of the mixture as described in 6.1.1 to 6.1.4, add the saturated, surface-dry aggregate to the mixture and mix thoroughly.

6.2 *Molding Specimens:*

6.2.1 Form a specimen by immediately compacting the soil-cement mixture in the mold (with the collar attached) and later trimming the specimen in accordance with Method B of Test Methods D 558, and in addition as the mixture for each layer is placed in the mold, spade along the inside of the mold with a butcher knife before compaction to obtain uniform distribution of the material retained on the No. 4 (4.75-mm) sieve and scarify the tops of the first and second layers as described for Method A of these methods.

6.2.2 During compaction take from the batch a representative sample of the soil-cement mixture weighing not less than 500 g, weigh immediately, and dry in an oven at 230 ± 9°F (110 ± 5°C) at least 12 h or to constant weight to determine the moisture content to check against design moisture content.

6.2.3 Form a second specimen as rapidly as possible in the same manner.

6.2.4 Weigh each compacted specimen to check against design density, identify, measure the No. 1 specimen (Note 1), place in the moist room, and measure the No. 1 specimen again at the end of the 7-day storage period as described for Method A in 5.2.3 to 5.2.8 (Note 2).

6.3 *Procedure*—Proceed as directed in Method A (see 5.3).

## 7. Calculations

7.1 Calculate the volume and moisture changes and the soil-cement losses of the specimens as follows:

7.1.1 Calculate the difference between the volume of specimen No. 1 at the time of molding and subsequent volumes as a percentage of the original volume.

7.1.2 Calculate the moisture content of specimen No. 1 at the time of molding and subsequent moisture contents as a percentage of the original oven-dry weight of the specimen.

7.1.3 Correct the oven-dry weight of specimen No. 2 as obtained in 5.3.7 for water that has reacted with the cement and soil during the test and is retained in the specimen at 230°F (110°C) as follows:

$$\text{Corrected oven-dry weight} = (A/B) \times 100$$

where:

$A$ = oven-dry weight after drying at 230°F (110°C), and

$B$ = percentage of water retained in specimen plus 100.

The percentage of water retained in specimen No. 2 after drying at 230°F (110°C) for use in the above formula can be assumed to be equal to the water retained in specimen No. 1. When No. 1 specimens are not molded, the foregoing data are not available and the average values prescribed in Table 1 are used.

7.1.4 Calculate the soil-cement loss of specimen No. 2 as a percentage of the original oven-dry weight of the specimen as follows:

$$\text{Soil-cement loss, \%} = (A/B) \times 100$$

where:

$A$ = original calculated oven-dry weight minus final corrected oven-dry weight, and

$B$ = original calculated oven-dry weight.

## 8. Report

8.1 The report shall include the following:

8.1.1 The designed optimum moisture and maximum density of the molded specimens,

8.1.2 The moisture content and density obtained in molded specimens.

NOTE 6—Good laboratory practice permits the following tolerances between design factors and those obtained in the molded specimens:

| | |
|---|---|
| Moisture content | ±1 percentage point |
| Density | ±3 lb/ft$^3$ (0.048 g/cm$^3$) |

8.1.3 The designed cement content, in percent, of the molded specimens,

8.1.4 The maximum volume change, in percent, and maximum moisture content during test of specimen No. 1, and

8.1.5 The soil-cement loss, in percent, of specimen No. 2.

## 9. Precision and Accuracy

9.1 Precision and accuracy of this test procedure have not been established. Data are available on the variability of weight losses for duplicate specimens. These data will be analyzed and a statement will be included in the next revision.