Designation: D4254 – 16

Standard Test Methods for Minimum Index Density and Unit Weight of Soils and Calculation of Relative Density[1]

This standard is issued under the fixed designation D4254; 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 U.S. Department of Defense.

1. Scope*

1.1 These test methods cover the determination of the minimum-index dry density/unit weight of cohesionless, free-draining soils. The adjective "dry" before density or unit weight is omitted in the title and remaining portions of this standards to be be consistent with the applicable definitions given in Section 3 on Terminology.

1.2 *System of Units:*

1.2.1 The testing apparatus described in this standard has been developed and manufactured using values in the gravimetric or inch-pound system. Therefore, test apparatus dimensions and mass given in inch-pound units are regarded as the standard.

1.2.2 It is common practice in the engineering profession to concurrently use pounds to represent both a unit of mass (lbm) and a unit 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. This test method has been written using the gravitational system of units when dealing with the inch-pound system. In this system, the pound (lbf) represents a unit of force (weight). However, balances or scales measure mass; and weight must be calculated. In the inch-pound system, it is common to assume that 1 lbf is equal to 1 lbm. While reporting density is not regarded as nonconformance with this standard, unit weights should be calculated and reported since the results may be used to determine force or stress.

1.2.3 The terms density and unit weight are often used interchangeably. Density is mass per unit volume, whereas unit weight is force per unit volume. In this standard, density is given only in SI units. After the density has been determined, the unit weight is calculated in SI or inch-pound units, or both.

1.3 Three alternative methods are provided to determine the minimum index density/unit weight, as follows:

1.3.1 Method A—Using a funnel pouring device or a hand scoop to place material in mold.

1.3.2 Method B—Depositing material into a mold by extracting a soil filled tube.

1.3.3 Method C[2]—Depositing material by inverting a graduated cylinder.

1.4 The method to be used should be specified by the agency requesting the test. If no method is specified, the provisions of Method A shall govern. Test Method A is the preferred procedure for determining minimum index density/unit weight as used in conjunction with the procedures of Test Methods D4253. Methods B and C are provided for guidance of testing used in conjunction with special studies, especially where there is not enough material available to use a 0.100 ft^3 (2830 cm^3) or 0.500 ft^3 (14 200 cm^3) mold as required by Method A.

1.5 These test methods are applicable to soils that may contain up to 15 %, by dry mass, of soil particles passing a No. 200 (75-μm) sieve, provided they still have cohesionless, free-draining characteristics (nominal sieve dimensions are in accordance with Specification E11).

1.5.1 Method A is applicable to soils in which 100 %, by dry mass, of soil particles pass a 3-in. (75-mm) sieve and which may contain up to 30 %, by dry mass, of soil particles retained on a 1½-inch (37.5-mm) sieve.

1.5.2 Method B is applicable to soils in which 100 %, by dry mass, of soil particles pass a ¾-inch (19.0-mm) sieve.

1.5.3 Method C is applicable only to fine and medium sands in which 100 %, by dry mass, of soil particles pass a ⅜-in. (9.5-mm) sieve and which may contain up to 10 %, by dry mass, of soil particles retained on a No. 10 (2.00-mm) sieve.

1.5.4 Soils, for the purposes of these test methods, shall be regarded as naturally occurring cohesionless soils, processed

[1] This test method is under the jurisdiction of ASTM Committee D18 on Soil and Rock and is the direct responsibility of Subcommittee D18.03 on Texture, Plasticity and Density Characteristics of Soils.

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[2] Kolbuszewski, J. J., "An Experimental Study of the Maximum and Minimum Porosities of Sands," *Proceedings, Second International Conference on Soil Mechanics and Foundation Engineering*, Rotterdam Vol I, 1948, pp. 158–165.

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

particles, or composites or mixtures of natural soils, or mixtures of natural and processed particles, provided they are free-draining.

1.6 All observed and calculated values shall conform to the guidelines for significant digits and rounding established in Practice D6026.

1.6.1 For purposes of comparing a measured or calculated value(s) to specified limits, the measured or calculated value(s) shall be rounded to the nearest decimal or significant digits in the specified limits.

1.6.2 The procedures used to specify how data are collected/recorded or calculated in this standard are regarded as the industry standard. In addition, they are representative of the significant digits that generally should be retained. The procedures used do not consider material variation, purpose for obtaining the data, special purpose studies, or any considerations for the user's objectives; and it is common practice to increase or reduce significant digits of reported data to be commensurate with these considerations. It is beyond the scope of this standard to consider significant digits used in analysis methods for engineering design.

1.7 *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:*[3]

C127 Test Method for Relative Density (Specific Gravity) and Absorption of Coarse Aggregate
D653 Terminology Relating to Soil, Rock, and Contained Fluids
D854 Test Methods for Specific Gravity of Soil Solids by Water Pycnometer
D2216 Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass
D2487 Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)
D2488 Practice for Description and Identification of Soils (Visual-Manual Procedure)
D3740 Practice for Minimum Requirements for Agencies Engaged in Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction
D4253 Test Methods for Maximum Index Density and Unit Weight of Soils Using a Vibratory Table
D4753 Guide for Evaluating, Selecting, and Specifying Balances and Standard Masses for Use in Soil, Rock, and Construction Materials Testing
D6026 Practice for Using Significant Digits in Geotechnical Data
D6913 Test Methods for Particle-Size Distribution (Gradation) of Soils Using Sieve Analysis
E11 Specification for Woven Wire Test Sieve Cloth and Test Sieves
E177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods
E691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method

3. Terminology

3.1 *Definitions*—For common definitions in this standard refer to Terminology D653.

3.2 *Definitions of Terms:*

3.2.1 *dry density/unit weight ρ_d or γ_d, n*—the dry density/unit weight of a soil deposit or fill at the given void ratio.

3.2.2 *given void ratio, e, n*—the in-situ or stated void ratio of a soil deposit or fill.

3.2.3 *maximum index density/unit weight, ρ_{dmax} or γ_{dmax}, n*—the reference dry density/unit weight of a soil in the densest state of compactness that can be attained using a standard laboratory compaction procedure that minimizes particle segregation and breakdown.

3.2.4 *maximum-index void ratio, e_{max}, n*—the reference void ratio of a soil at the minimum index density/unit weight.

3.2.5 *minimum index density/unit weight ρ_{dmin} or γ_{dmin}, n*—reference dry density/unit weight of a soil in the loosest state of compactness at which it can be placed using a standard laboratory procedure that prevents bulking and minimizes particle segregation.

3.2.6 *minimum-index void ratio, e_{min}, n*—the reference void ratio of a soil at the maximum index density/unit weight.

3.2.7 *relative density, D_d, n*—the ratio, expressed as a percentage, of the difference between the maximum index void ratio and any given void ratio of a cohesionless, free-draining soil to the difference between its maximum and minimum index void ratios.

3.2.7.1 *Discussion*—The equation for relative density is:

$$D_d = \frac{e_{max} - e}{e_{max} - e_{min}} \times 100 \quad (1)$$

or, in terms of corresponding dry densities:

$$D_d = ((\rho_{dmax}(\rho_d - \rho_{dmin})) / (\rho_d(\rho_{dmax} - \rho_{dmin}))) \times 100 \quad (2)$$

or, in terms of corresponding dry unit weights:

$$D_d = (\gamma_{dmax}(\gamma_d - \gamma_{dmin})) / (\gamma_d(\gamma_{dmax} - \gamma_{dmin})) \quad (3)$$

3.2.8 *density index/unit weight, I_d, n*—the ratio, expressed as a percentage, of the difference between any given dry density/unit weight and the minimum index density/unit weight of a given cohesionless soil to the difference between its maximum and minimum index densities/unit weights.

3.2.8.1 *Discussion*—The equation for density index/unit weight is:

$$I_d = ((\rho_d - \rho_{dmin}) / (\rho_{dmax} - \rho_{dmin})) \times 100 \quad (4)$$

or, in terms of corresponding dry unit weights:

$$I_d = ((\gamma_d - \gamma_{dmin}) / (\gamma_{dmax} - \gamma_{dmin})) \times 100 \quad (5)$$

[3] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

4. Summary of Test Method

4.1 The minimum index density/unit weight represents the loosest condition of a cohesionless, free-draining soil that can be attained by a standard laboratory procedure, which prevents bulking and minimizes particle segregation. All three methods determine the density/unit weight of oven-dried soil placed into a container of known volume in such a manner that prevents bulking and particle segregation, and minimizes compaction of the soil.

5. Significance and Use

5.1 The density/unit weight of a cohesionless soil may be determined by various in-place methods in the field or by the measurement of physical dimensions and masses by laboratory soil specimens. The dry density/unit weight of a cohesionless soil does not necessarily, by itself, reveal whether the soil is loose or dense.

5.2 Relative density/unit weight expresses the degree of compactness of a cohesionless soil with respect to the loosest and densest condition as defined by standard laboratory procedures. Only when viewed against the possible range of variation, in terms of relative density/unit weight, can the dry density/unit weight be related to the compaction effort used to place the soil in a compacted fill or indicate volume change and stress-strain tendencies of soil when subjected to external loading.

5.3 An absolute minimum density/unit weight is not necessarily obtained by these test methods.

NOTE 1—In addition, there are published data to indicate that these test methods have a high degree of variability.[4] However, the variability can be greatly reduced by careful calibration of equipment, and careful attention to proper test procedure and technique.

5.4 The use of the standard molds (6.2.1) has been found to be satisfactory for most soils requiring minimum index density/unit weight testing. Special molds (6.2.2) shall only be used when the test results are to be applied in conjunction with design or special studies and there is not enough soil to use the standard molds. Such test results should be applied with caution, as minimum index densities/unit weights obtained with the special molds may not agree with those that would be obtained using the standard molds.

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 D3740, generally, are considered capable of competent and objective testing/sampling/inspection/etc. Users of this standard are cautioned that compliance with Practice D3740 does not in itself assure reliable results. Reliable results depend on many factors; Practice D3740 provides a means of evaluating some of those factors.

6. Apparatus

6.1 *Apparatus for Methods A, B, and C:*

6.1.1 *Drying Oven,* thermostatically controlled, preferably of the forced-draft type, capable of maintaining a uniform temperature of 230 ± 9°F (110 ± 5°C) throughout the drying chamber.

6.1.2 *Sieves,* 3-in. (75-mm), 1½-in. (37.5-mm), ¾-in. (19-mm), ⅜-in. (9.5-mm), No. 4 (4.75-mm), No. 10 (2.00-mm), and No. 200 (75-µm) conforming to the requirements of Specification E11.

6.2 *Apparatus for Methods A and B:*

6.2.1 *Standard Molds*—Two cylindrical metal molds, one having a nominal volume of 0.100 ft^3 (2830 cm^3) and one having a nominal volume of 0.500 ft^3 (14 200 cm^3), conforming to the design methodology presented in Fig. 1. The molds shall conform to the requirements shown in the table in Fig. 1. The actual volume of the molds shall be within ±1.5 % of the specified nominal volume.

6.2.2 *Special Molds*—Cylindrical metal molds having a capacity less than 0.100 ft^3 (2830 cm^3), an inside diameter equal to or greater than 2.75 in. (70 mm) but less than 4 in. (100 mm) and conforming to the design methodology presented in Fig. 2. Such molds may only be used when the test results are to be used in conjunction with design or special studies, and there is not enough soil to use the 0.100 ft^3 (2830 cm^3) mold.

6.2.3 *Balances(s),* of sufficient capacity to determine the total mass of the specimen and mold, having sufficient accuracy that the mass of the soil is determined to the nearest 0.1 %. Balances capable of satisfying these requirements for most conditions have specifications as follows:

6.2.3.1 For 0.500-ft^3 (14 200-cm^3) molds, use a balance having a minimum capacity of 40-kg and meeting the requirements of Specification D4753 for a Class GP 10 (readability of 5 g).

6.2.3.2 For 0.100-ft^3 (2830-cm^3) molds, use a balance having a minimum capacity of at least 15 kg and meeting the requirements of Specification D4753 for Class GP 5 (readability of 1 g).

6.2.3.3 For special molds that are less than 0.1 ft^3 (2830 cm^3) in capacity, use a balance having a minimum capacity of at least 2 kg and meeting the requirements of Specification D4753 for a Class GP 2 (readability of 0.1 g).

6.2.4 *Pouring Devices,* are used in conjunction with the 0.100 ft^3 (2830 cm^3) standard mold and with special molds. Pouring devices consist of relatively rigid containers having volumes about 1.25 to 2 times greater than the volumes of the mold(s) used, and fitted with spouts or tubes about 6 in. (150 mm) long. Two pouring spouts are required, one having an inside spout diameter of 0.50 in. (13 mm) and another with an inside spout diameter of 1.0 in. (25 mm). A lipped brim, or other means, must be provided to securely connect the spout to the container that permits free and even flow of the soil from the container into the spout, and then into the mold.

6.2.5 *Rigid, Thin-Walled Tubes,* for use with Method B. The size of the tubes is dependent upon the mold size selected. The volume of the tubes shall be between 1.25 and 1.30 times the volume of the mold. The inside diameter of the tube shall be about 0.7 times the inside diameter of the mold.

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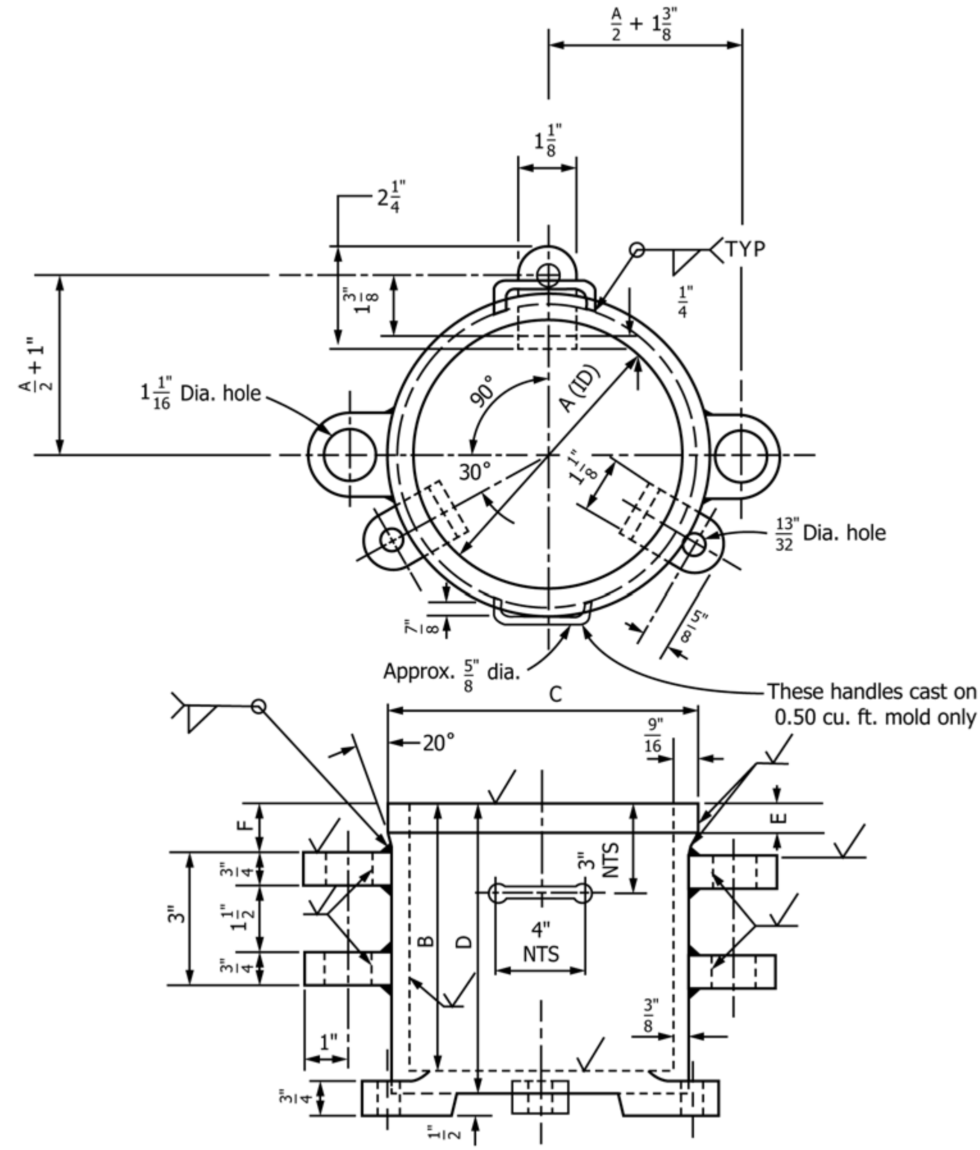
[4] Selig, E. T., and Ladd, R. S., eds., *Evaluation of Relative Density and its Role in Geotechnical Projects Involving Cohesionless Soils, ASTM STP 523*, ASTM, 1973.



Note 1—Tolerances are ±1⁄64 in. (±0.4 mm) unless otherwise noted.

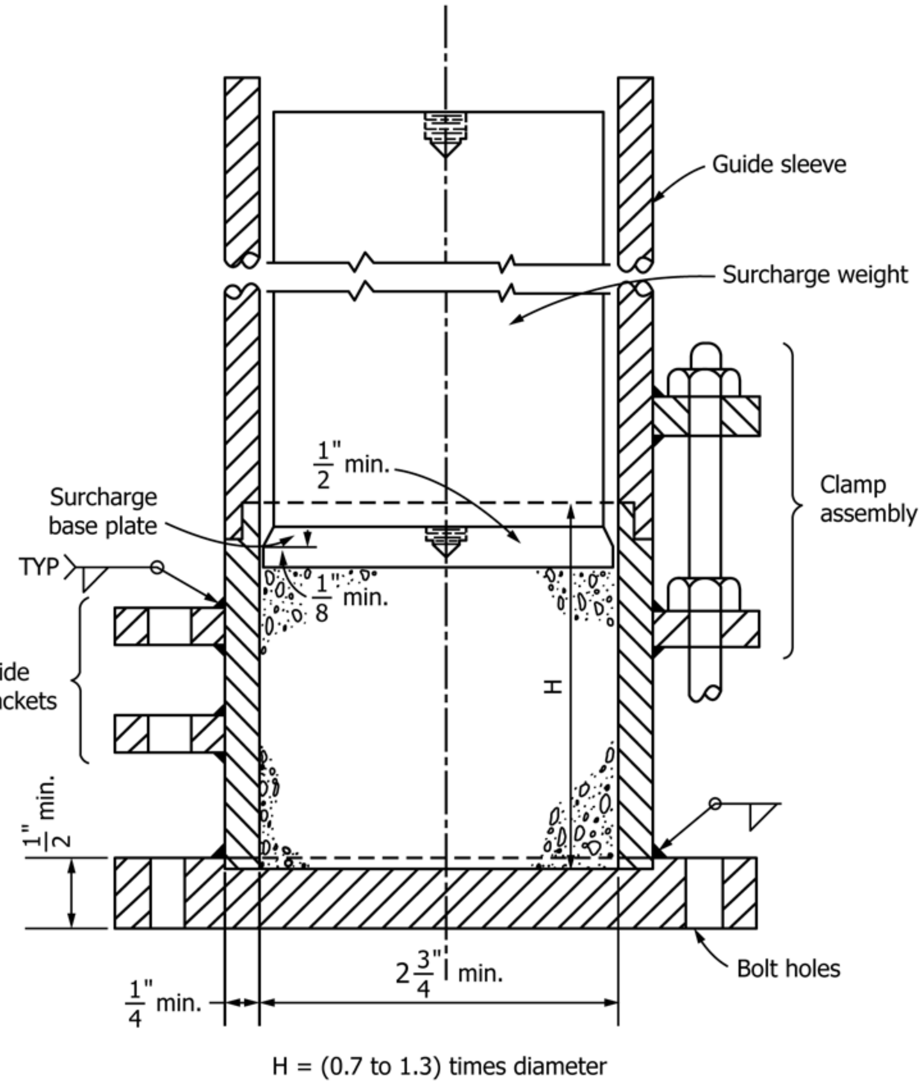
Size Mold, ft^3 (cm^3)	Dimensions, in. (mm)					
	A	B	C	D	E	F
Tolerance	+0.005, −0.000 (+0.13 −0.00)	+0.005, −0.000 (+0.13 −0.00)	±0.016 (±0.4)	±0.016 (±0.4)	±0.016 (±0.4)	±0.016 (±0.4)
0.100 (2830)	6.000 (152.40)	6.112 (155.24)	7.13 (181.1)	6.50 (165.1)	0.50 (12.7)	1.13 (28.7)
0.500 (14 200)	11.000 (279.40)	9.092 (230.94)	12.13 (308.0)	9.50 (241.3)	0.63 (16.0)	2.00 (50.8)

FIG. 1 Details of Molds

6.2.6 Other equipment such as mixing pans, a large metal scoop, a hair-bristled dusting brush, and a metal straightedge (for trimming excess soil after it has been placed in the mold).

6.3 *Apparatus for Method C:*

6.3.1 *Glass Graduated Cylinder,* having a volume of 2000 mL, graduated to 20 mL, with about a 3-in. (75-mm) inside diameter.



SD	Equivalents
in.	mm
0.125	3.2
0.25	6.4
0.50	13
2.75	70

FIG. 2 Special Cylindrical Metal Molds

6.3.2 *Balance,* of at least 2 kg capacity and otherwise consistent with 6.2.3.3.

6.3.3 *Sieves,* ⅜-in. (9.5-mm), No. 10 (2.00-mm), and No. 200 (75-µm) sieves conforming to the requirements of Specification E11.

7. Sampling and Test Specimen

7.1 Prior to testing, the sample should be stored in a manner to prevent freezing, contamination with other matter, loss of soil, or loss of identification.

7.2 Sampling and test specimen requirements for Methods A and B are contained in the following paragraphs. Requirements for Method C begin at 7.4.

7.3 The required size (mass) of the test specimen and mold is a function of the maximum particle size contained in the sample and the particle-size distribution (gradation) of the sample (see Table 1).

7.3.1 Using a visual method or Test Method D6913 (depending upon the complexity of the gradation of the sample and operator experience, determine the percentage of particles retained on the 3-in. (75-mm), 1½-in. (37.5-mm), ¾-in. (19.0-mm), ⅜-in. (9.5-mm), No. 4 (4.75-mm), No. 10 (2.00-mm), and No. 200 (75-µm) sieves.

7.3.2 The determination of the minimum index density/unit weight should not be performed in accordance with these test methods unless the requirements of 1.5 are met. If these

TABLE 1 Required Mass of Specimen

Maximum Size 100% Passing, in. (mm)	Mass of Specimen Required, kg	Placement Device to be Used in Minimum Density Test	Size of Mold to Be Used, ft^3 (cm^3)
3 (75)	34	shovel or extra large scoop	0.500 (14 200)
1½ (38.1)	34	scoop	0.500 (14 200)
¾ (19.0)	11	scoop	0.100 (2830)
⅜ (9.5)	11	pouring device with 1-in. (25-mm) diameter spout	0.100 (2830)
No. 4 (4.75) or less	11	pouring device with ½-in. (13-mm) diameter spout)	0.100 (2830)

conditions are met, then the mold size, pouring device, and specimen mass required can be determined in accordance with the maximum particle size as prescribed in Table 1.

7.3.3 When it is applicable to use special molds, 100 % of the specimen shall pass the ¾-in. (19.0 mm) sieve and have less than 10 % retained on the ⅜-in. (9.5-mm) sieve.

7.3.3.1 The selected test specimen shall have a mass not less than that determined using the following equation:

$$M_r = 0.0024 \cdot V_m \qquad (6)$$

where:

M_r = mass required, kg, and
V_m = volume of mold, cm^3.

7.4 Select a representative specimen of soil that meets the requirements of 7.3, using a splitter, riffle, or other method such as quartering. For Method C, the specimen should have a mass of about 1.5 kg.

7.5 Dry the specimen in the drying oven, maintained at 110 ± 5°C to a constant mass. Oven-dried sand, for use with Method C, shall be permitted to cool in an airtight container. It is often desirable to obtain the water content of the field sample. If this is the case, determine the water content in accordance with Test Method D2216.

7.5.1 After drying, thoroughly break up the weakly cemented aggregations as to avoid reducing the natural size of the particles.

8. Calibration

8.1 *Molds*—The volume and cross-sectional area of each mold should be calibrated before initial use and at intervals not exceeding each 1000 times the mold is used for testing, or annually, whichever occurs first. Determine the volume of each mold by either the direct-measurement method or the water-filling method as provided in 8.1.1 and 8.1.2. The volume obtained by either method should be within ±1.5 % of the nominal value. It is recommended that both the direct-measurement and water-filling methods be used. If the difference between the volumes calculated from the two methods exceeds 0.5 % of the nominal value of the mold being calibrated, then the calibration should be repeated. Failure to obtain agreement between the two calibration methods within the stated tolerances, even after several trials, is an indication that the mold is badly deformed and should be replaced. If both calibration methods are performed, the volume obtained by the water-filling method should be assigned to the mold (this method more accurately reflects the conditions over the entire mold).

8.1.1 *Direct Measurement Method*—The volume of the mold is calculated from the average of at least three internal-diameter and three height measurements, evenly spaced throughout the mold, made to the nearest 0.001 in. (0.025 mm). Calculate and record the height in inches, millimetres, or centimetres to four significant digits (in accordance with Practice D6026). Calculate and record the volume, V_m (cm^3) to four significant digits (in accordance with Practice D6026).

8.1.2 *Water-Filling Method*—Completely fill the mold with water. Slide a glass plate carefully over the top surface (rim) of the mold as to ensure that the mold is completely filled with water. A thin film of grease or silicone lubricant on the rim of the mold will make a watertight joint between the glass plate and rim of the mold. Determine the mass of water required to fill the mold, using the appropriate balance specified in 6.2.3. Determine the temperature of this water to the nearest 1°C. From Table 2 obtain the unit volume of water in millilitres per gram (mL/g) at the observed temperature. Calculate and record the volume of the mold (m^3 or cm^3) to four significant digits, as follows:

8.1.2.1 For mass measurements in grams, calculate the volume in cubic centimetres (cm^3) by multiplying the mass of water (g) used to fill the mold by the volume of water per gram (mL/g), from Table 2 and noting mL = cm^3. To determine the volume in cubic metres (m^3), multiply volume in cm^3 by 1×10^{-6}.

8.2 Determine and record the mass of the empty mold, using the appropriate balance specified in 6.2.3.

9. Procedure

9.1 The steps for performing Method A, the preferred procedure, shall be in accordance with 9.2. The Method B procedure is given in 9.3 and Method C in 9.4.

TABLE 2 Volume of Water per Gram Based on Temperature[A]

Temperature		Volume of Water per Gram
°C	°F	mL/g
15	59.0	1.00090
16	60.8	1.00106
17	62.6	1.00122
18	64.4	1.00140
19	66.2	1.00160
20	68.0	1.00180
21	69.8	1.00201
22	71.6	1.00223
23	73.4	1.00246
24	75.2	1.00271
25	77.0	1.00296
26	78.8	1.00322
27	80.6	1.00350
28	82.4	1.00378
29	84.2	1.00407
30	86.0	1.00437

[A] Values other than shown may be obtained by referring to the *CRC Handbook of Chemistry and Physics*, David R. Lide, Editor-in-Chief, 74th Edition, 1993–1994.

9.2 *Method A:*

9.2.1 Mix the oven-dried specimen to provide an even distribution of particle sizes.

9.2.2 If the pouring device (as required in Table 1) is used, place the soil as loosely as possible in the mold by pouring the soil from the spout (Table 1) in a steady stream, holding the pouring device upright and vertical or nearly vertical. Continuously adjust the height of the spout to maintain a free fall of the soil of about 0.5 in. (13 mm) or just high enough to maintain continuous flow of soil particles without the spout contacting the already deposited soil. Move the pouring device in a spiral path from the outside to the center of the mold to form each layer of nearly uniform thickness. Spiraling motion should be just sufficient to minimize particle segregation.

NOTE 3—Static electricity in dry sand can cause bulking similar to that produced by a trace of moisture on the particles; a static-eliminating brush can be used on the equipment in contact with the sand if this effect becomes bothersome.

9.2.2.1 Fill the mold approximately 0.5 in. (13 mm) to 1 in. (25 mm) above the top of the mold (or until all points of the soil surface are above the plane of the mold rim).

9.2.2.2 Trim off the excess soil level with the top by carefully trimming the soil surface with a straightedge. Great care must be exercised during filling and trimming operations to avoid jarring the mold or excessively disturbing the soil surface and causing rearrangement and settlement of the soil particles. Making one continuous pass with the straightedge, or if necessary, two passes, has produced the most reproducible results.

9.2.3 If the scoop or shovel (as required in Table 1) are used, place the soil as loosely as possible by holding the scoop or shovel just above the soil surface to cause the material to slide rather than fall onto the previously placed soil. If necessary, holding large particles back by hand to prevent them from rolling off the scoop/shovel.

9.2.3.1 Fill the mold to overflowing but not more than 1 in. (25 mm) above the top. For soils where the maximum particle size passes the ¾-in. (19.0-mm) sieve, use the steel straightedge (and the fingers when needed) to level the surface of the soil with the top of the mold. For soils with a large maximum particle size, use the fingers in such a way that any slight projections of the larger particles above the top of the mold shall approximately balance the larger voids in the surface below the top of the mold.

9.2.4 Determine and record the mass of the mold plus soil, using the appropriate balance specified in 6.2.3. Calculate and record the mass of the soil filling the mold by subtracting the mass of the empty mold, as determined in 8.2, from the mass of the mold and soil. Calculate the minimum index density/unit weight, $\rho_{dmin,n}$ or $\gamma_{dmin,n}$, in accordance with Section 10.

9.2.5 Steps 9.2.1 – 9.2.4 should be repeated until consistent values of minimum index density/unit weight (within 2 %) are obtained.

9.3 *Method B:*

9.3.1 Mix the oven-dried specimen to provide an even distribution of particle sizes.

9.3.2 Select the proper sized thin-walled tube in accordance with the requirements of 6.2.5.

9.3.3 Place the tube inside the mold. Place cohesionless soil into the tube with a pouring device, scoop, or spoon, being careful to minimize segregation of material during filling. Fill the tube within ⅛ in. (3 mm) to ¼ in. (6 mm) of the top.

9.3.4 Quickly raise the tube allowing the cohesionless material to overfill the mold, see 9.2.2.1.

9.3.5 Following procedures given in 9.2.2.2 or 9.2.3.1, trim the soil surface level with the top of the mold.

9.3.6 Determine and record the mass of the mold plus soil, using the appropriate balance specified in 6.2.3. Calculate and record the mass of the soil filling the mold by subtracting the mass of the empty mold, as determined in 8.2, from the mass of the mold plus soil. Calculate the minimum index density/unit weight, $\rho_{dmin,n}$ or $\gamma_{dmin,n}$, in accordance with Section 10.

9.3.7 Steps 9.3.1 – 9.3.6 should be repeated until consistent values of minimum index density/unit weight (within 2 %) are obtained.

9.4 *Method C*[2]:

9.4.1 Place 1000 ±1 g of sand in a 2000-mL graduated cylinder and place a stopper in the top of the cylinder. Tip the cylinder upside down, and then quickly tilt it back to the original vertical position.

9.4.2 Record the volume that the sand occupies in the graduated cylinder, V_g. Calculate the minimum index density/unit weight in accordance with Section 10.

9.4.3 Repeat the procedure until three consistent values of the minimum index density/unit weight (within 2 %) are obtained.

10. Calculation

10.1 Calculate the minimum (dry) index density for each trial as follows:

$$\rho_{dmin,n} = \frac{M_s}{V} \tag{7}$$

where:

$\rho_{dmin,n}$ = minimum index density for given trial, Mg/m^3 or g/cm^3
M_s = mass of the tested-dry soil, Mg or g, and
V = volume of the tested-dry soil, m^3 or cm^3. For Methods A and B, $V=V_c$ or calibrated volume of mold; and for Method C, $V=V_g$ (see 9.4.2)

10.1.1 Calculate the average of the minimum-index density values, $\rho_{dmin,n}$, from the trials that agree within 1 %. This average value is to be recorded/reported as the minimum index density, ρ_{dmin}, of the test specimen.

10.1.2 If requested, calculate the minimum-index unit weight of the specimen as follows:

$$\gamma_{dmin} = 9.807 \times \rho_{dmin},\ kN/m^3 \tag{8}$$

or

$$\gamma_{dmin} = 62.428 \times \rho_{dmin},\ \text{lbf/ft}^3$$

10.2 If requested, calculate the maximum-index void ratio, e_{max}, as follows:

$$e_{max} = (\rho_w \times G_{avg} / \rho_{dmin}) - 1 \tag{9}$$

where:

e_{max} = maximum-index void ratio,
ρ_w = density of water at 20°C (0.99821) or equal to 1.0 Mg/m^3 or g/cm^3
$G_{avg\ at\ 20°C}$ = weighted average specific gravity of soils composed of particles larger and smaller than the No. 4 (4.75-mm) sieve, or

$$G_{avg\ at\ 20°C} = \frac{1}{\frac{R}{100 \cdot G_{1\ at\ 20°C}} + \frac{P}{100 \cdot G_{2\ at\ 20°C}}} \quad (10)$$

where:

$G_{1\ at\ 20°C}$ = apparent specific gravity of the soil particles retained on the No. 4 (4.75-mm) sieve as determined by Test Method C127 and corrected to 20°C (see Test Methods D854),
$G_{2\ at\ 20°C}$ = specific gravity of the soil particles passing the No. 4 (4.75-mm) sieve as determined by Test Methods D854,
R = percentage of soil particles from the sample retained on the No. 4 (4.75-mm) sieve, and
P = percentage of soil particles from the sample passing the No. 4 (4.75-mm) sieve.

10.3 If the maximum index density/unit weight, ρ_{dmax} or γ_{dmax}, has been determined in accordance with Test Methods D4253 and the soil deposit or fill dry density/unit weight, ρ_d or γ_d, or void ratio, e, is known, the relative density, D_d, can be calculated as calculated by any of the equations given in 3.2.7, that is, Equations 1, 2, or 3.

11. Report: Test Data Sheet(s)/Form(s)

11.1 The methodology used to specify how data are recorded on the test data sheet(s)/form(s), as given below, is covered in 1.6. Record as a minimum the following information:

11.1.1 Sample identifying information, such as Project No., Boring No., Sample No., and Depth.

11.1.2 Classification of the test specimen in accordance with Practice D2488 or identification in accordance with D2487.

11.1.3 Method (Methods A, B, or C) used.

11.1.4 Mass, height and diameter of mold.

11.1.5 Mass of specimens.

11.1.6 Any testing abnormalities noticed.

11.1.7 The minimum index density/unit weight, ρ_{dmin}, in Mg/m^3 or g/cm^3 or minimum index unit weight, γ_{dmin}, in lbf/ft^3 (kN/m^3) to three or four significant digits (in accordance with Practice D6026).

12. Precision and Bias[5]

12.1 *Precision*—Criteria for judging the acceptability of test results obtained by these test methods, using Method A and testing a poorly graded sand (SP), is given in Tables 3 and 4. These estimates of precision are based on the results of the interlaboratory program conducted by the ASTM Reference soils and Testing Program. In this program, some laboratories performed three replicate tests per soil type (triplicate-test laboratory), while other laboratories performed a single test per soil type (single-test laboratory). A description of the soil tested is given in 12.1.4. The precision estimates may vary with soil type and method used (Method A, B, or C). Judgment is required when applying these estimates to another soil or method.

TABLE 3 Summary of Test Results from Triplicate Test Laboratories (Minimum Index Unit Weight)

(1) Soil Type	(2) Number of Triplicate Test Laboratories	(3) Average Value[A] (lbf/ft^3)	(4) Standard Deviation[B] (lbf/ft^3)	(5) Acceptable Range of Two Results[C] (lbf/ft^3)
Single-Operator Results (Within-Laboratory Repeatability):				
SP	8	98.17	0.50	1.4
Multilaboratory Results (Between-Laboratory Reproducibility):				
SP	8	98.17	2.49	6.9

[A] The number of significant digits and decimal places presented are representative of the input data. In accordance with Practice D6026, the standard deviation and acceptable range of results can not have more decimal places than the input data.
[B] Standard deviation is calculated in accordance with Practice E691 and is referred to as the 1*s* limit.
[C] Acceptable range of two results is referred to as the d2*s* limit. It is calculated as $1.960\sqrt{2} \cdot 1s$, as defined by Practice E177. The difference between two properly conducted tests should not exceed this limit. The number of significant digits/decimal places presented is equal to that prescribed by these test methods or Practice D6026. In addition, the value presented can have the same number of decimal places as the standard deviation, even if that result has more significant digits than the standard deviation.

TABLE 4 Summary of Single-Test Result from Each Laboratory (Minimum Index Unit Weight)[A]

(1) Soil Type	(2) Number of Test Laboratories	(3) Average Value[A] (lbf/ft^3)	(4) Standard Deviation[B] (lbf/ft^3)	(5) Acceptable Range of Two Results[C] (lbf/ft^3)
Multilaboratory Results—Reproducibility (Single-Test Performed by Each Laboratory)				
SP	12	97.54	2.63	7.3

[A] See Footnotes in Table 3.

12.1.1 The data in Table 3 are based on three replicated tests performed by each triplicate test laboratory on the SP sand. The single operator and multilaboratory standard deviation shown in Table 3, Column 4 were obtained in accordance with Practice E691, which recommends each testing laboratory perform a minimum of three replicate tests. Results of two properly conducted tests performed by the same operator on the same material, using the same equipment, and in the shortest practical period of time should not differ by more than the single-operator d2*s* limits shown in Table 3, Column 5. For definition of d2*s*, see Footnote C in Table 3. Results of two properly conducted tests performed by different operators and on different days should not differ by more than the multilaboratory d2*s* limits show in Table 3, Column 5.

12.1.2 In the ASTM Reference Soils and Testing Program, many of the laboratories performed only a single test. This is common practice in the design and construction industry. The data in Table 4 are based upon the first test results from the triplicate test laboratories and the single test results from the other laboratories. Results of two properly conducted tests performed by two different laboratories with different operators

[5] Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:D18-1011.

using different equipment and on different days should not vary by more than the d2*s* limits shown in Table 4, Column 5. The results in Table 3 and Table 4 are dissimilar because the data sets are different.

12.1.3 Table 3 presents a rigorous interpretation of triplicate test data in accordance with Practice E691 from pre-qualified laboratories. Table 4 is derived from test data that represents common practice.

12.1.4 *Soil Type:*

SP—Poorly graded sand, SP 20 % coarse sand, 48 % medium sand, 30 % fine sand, 2 % fines, yellowish brown. Local name—Frederick sand.

12.2 *Bias*—There is no accepted reference value for these test methods, therefore, bias cannot be determined.

13. Keywords

13.1 minimum index density; minimum index unit weight; relative density

SUMMARY OF CHANGES

In accordance with D18 policy, this section identifies the location of changes to this standard since the last edition (2014) that may impact the use of this standard. (March 1, 2016)

(1) Revised 6.2.1 to clarify design requirements of mold.