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INTERNATIONAL

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

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[1] This test method standard is under the jurisdiction of ASTM Committee D-18 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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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 test method 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 test method, 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 test method standard, density shall be is given only in SI units. After the density has been determined, calculations for determining the unit weights shall be given. weight is calculated in SI or inch-pound units, or both.

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

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

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

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

1.4 The test method to be used should be specified by the individual assigning the test. If no test method is specified, the provisions of Test 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 D 4253. Test 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 (2 830 cm^3) or 0.500 ft^3 (14 200 cm^3) mold as required by Test 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 E 11).

1.5.1 TestMethod 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 1-½-inch (37.5-mm) sieve.

1.5.2 TestMethod 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 TestMethod 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.

Annual Book

[2] Kolbuszewski, J. J., "An Experimental Study of ASTM Standards the Maximum and Minimum Porosities of Sands," *Proceedings, Second International Conference on Soil Mechanics and Foundation Engineering*, Rotterdam Vol 04.02. I, 1948, pp. 158–165.

1.5.4 Soils, for the purposes of these test methods, shall be regarded as naturally occurring cohesionless soils, processed particles, or composites or mixtures of natural soils, or mixtures of natural and processed particles, provided they are free-draining.

1.6 *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 127 Test Method for Specific Gravity and Absorption of Coarse Aggregate

D 422 Method for Particle-Size Analysis of Soils[3]

D 653 Terminology Relating to Soil, Rock and Contained Fluids[3] 422 Test Method for Particle-Size Analysis of Soils[4]

D 854 Test Method for Specific Gravity of Soils[3] 653 Terminology Relating to Soil, Rock, and Contained Fluids[4]

D 2216854 Test Methods for Laboratory Determination Specific Gravity of Soil Solids by Water (Moisture) Content of Soil, Rock, and Soil-Aggregate Mixtures[3] Pycnometer[4]

D 21114870 Test Methods for Classification Amount of Materials in Soils for Engineering Purposes[3] Finer Than the No.200 (75–μm) Sieve[4]

D 2488 Practice 2216 Test Method for Description and Identification Laboratory Determination of Soils (Visual-Manual Procedure)[3] Water (Moisture) Content of Soil and Rock by Mass[4]

D 4253 Test Methods 2487 Practice for Maximum Index Density Classification of Soils Using a Vibratory Table[3] for Engineering Purposes (Unified Soil Classification System)[4]

D 4753 Specification 2488 Practice for Description and Identification of Soils (Visual-Manual Procedure)[4]

D 3740 Practice for Minimum Requirements for Agencies Engaged in the Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction[4]

D 4253 Test Methods for Maximum Index Density and Unit Weight of Soils Using a Vibratory Table[4]

D 4753 Specification for Evaluating, Selecting, and Specifying Balances and Scales for Use in Soil and Rock Testing in Soil, Rock, and Related Construction Materials[4]

D 6026 Practice for Using Significant Digits in Geotechnical Data[5]

E 11 Specification for Wire-Cloth Sieves for Testing Purposes[6]

E 319 Methods 177 Practice for Use of Testing Single-Arm Balances[4] the Terms Precision and Bias in ASTM Test Methods[7]

E 380691 Practice for Use of Conducting an Interlaboratory Study to Determine the International System Precision of Units (SI) (The Modernized Metric System)[4] a Test Method[7]

3. Terminology

3.1 *Definitions:* For common definitions in this standard refer to Terminology D 653

3.2 *Definitions of Terms Specific to This Standard:*

3.1.1 Except as listed below, all definitions are in accordance with Terminology D 653.

3.1.2 *maximum index density/unit weight,* ρ_{dmax} or γ_{dmax}—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.

3.1.3 *minimum index void ratio, e min*—the reference void ratio of a soil at the maximum index density/unit weight.

3.1.4 *minimum index density/unit weight* ρ_{dmin} or γ_{dmin}—the 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.

3.2.1 *maximum index void ratio, edry density/unit weight max*ρ_d *or* γ_d*, n*—the reference void ratio dry density/unit weight of a soil deposit or fill at the minimum index density/unit weight. 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 *drymaximum index density/unit weight ρd or γ weight,* $\rho_{dd\ dmax}$ *or* γ_{dmax}*, n*—the reference dry density/unit weight of a soil deposit or fill at in the g densest state of compactness that can be attaivned usin vg 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.

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[3] *Annual Book of ASTM Standards*, Vol 04.082.

[4] *Annual Book of ASTM Standards*, Vol 14.02. 04.08.

[5] Selig, E. T., and Ladd, R. S., eds., *Evaluation*

[5] *Annual Book of Relative Density and its Role in Geotechnical Projects Involving Cohesionless Soils, ASTM STP 523 Standards*, ASTM, 1973. Vol 04.09.

[6] Kolbuszewski, J. J., "An Experimental Study

[6] *Annual Book of the Maximum and Minimum Porosities of Sands," Proceedings, Second International Conference on Soil Mechanics and Foundation Engineering ASTM Standards, Rotterdam* Vol I, 1948, pp. 158–165. 14.02.

[7] *Annual Book of ASTM Standards*, Vol 14.04.

3.2.5 *minimum index density/unit weight* ρ_{dmin} or γ_{dmin}, *n*—the 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. The equation is:

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

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

or, in terms of corresponding dry densities:

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

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

or, in terms of corresponding dry unit weights:

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

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

~~3.1.9~~

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. The equation is:

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

or, in terms of corresponding dry unit weights:

$$I_d = \frac{\gamma_d - \gamma_{dmin}}{\gamma_{dmax} - \gamma_{dmin}} \quad (5)$$

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

4. Summary of Test Methods

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. Any particular procedure selected will consist of determining 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.[8] However, the variability can be greatly reduced by careful calibration of equipment, ~~including the vibrating table,~~ and careful attention to proper test procedure and technique.

5.4 The use of the standard molds (6.3.1) has been found to be satisfactory for most soils requiring minimum index density/unit weight testing. Special molds (6.3.2) shall only be used when the test results are to be applied in conjunction with design or special

[8] 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.

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 D 3740, generally, are considered capable of competent and objective testing/sampling/inspection/etc. Users of this standard are cautioned that compliance with Practice D 3740 does not in itself assure reliable results. Reliable results depend on many factors; Practice D 3740 provides a means of evaluating some of those factors.

6. Apparatus

6.1 *Apparatus for ~~Test~~ 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), 1-½-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 E 11.

6.2 The apparatus for determining the minimum index density/unit weight of cohesionless soil by ~~Test~~ Methods A and B is specified in 6.3. Apparatus required for ~~Test~~ Method C is specified in 6.4.

6.3 *Apparatus for ~~Test~~ Methods A and B*:

6.3.1 *Standard Molds*—Cylindrical metal molds having nominal volumes of 0.1000 ft^3 (2 830 cm^3) and 0.500 ft^3 (14 200 cm^3). The molds shall conform to the requirements shown in Fig. 1. The actual volume of the molds shall be within ±1.5 % of the specified nominal volume.

6.3.2 *Special Molds*—Cylindrical metal molds having a capacity less than 0.100 ft^3 (2 830 cm^3), an inside diameter equal to or greater than 2-¾ 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 (2 830 cm^3) mold.

6.3.3 *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:

6.3.3.1 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 D 4753 for a Class GP 10 (readability of 5 g).

6.3.3.2 For 0.100-ft^3 (2 830-cm^3) molds, use a balance having a minimum capacity of at least 15 kg and meeting the requirements of Specification D 4753 for Class GP 5 (readability of 1 g).

6.3.3.3 For special molds that are less than 0.1 ft^3 (2 830 cm^3) in capacity, use a balance having a minimum capacity of at least 2 ~~kd~~ kg and meeting the requirements of Specification D 4753 for a Class GP 2 (readability of 0.1 g).

6.3.4 *Pouring Devices*~~—The pouring devices~~, are used in conjunction with the 0.100 ft^3 (2 830 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.

6.3.5 *Rigid, Thin-Walled Tubes*, for use with ~~Test~~ 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.

6.3.6 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).

6.4 *Apparatus for ~~Test~~ Method C*:

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

6.4.2 *Balance*, of at least 2 kg capacity and otherwise consistent with 6.3.3.3.

6.4.3 *Sieves*, ⅜-in. (9.5-mm), No. 10 (2.00-mm), and No. 200 (75-µm) sieves conforming to the requirements of Specification E 11.

7. Sampling and Test Specimen

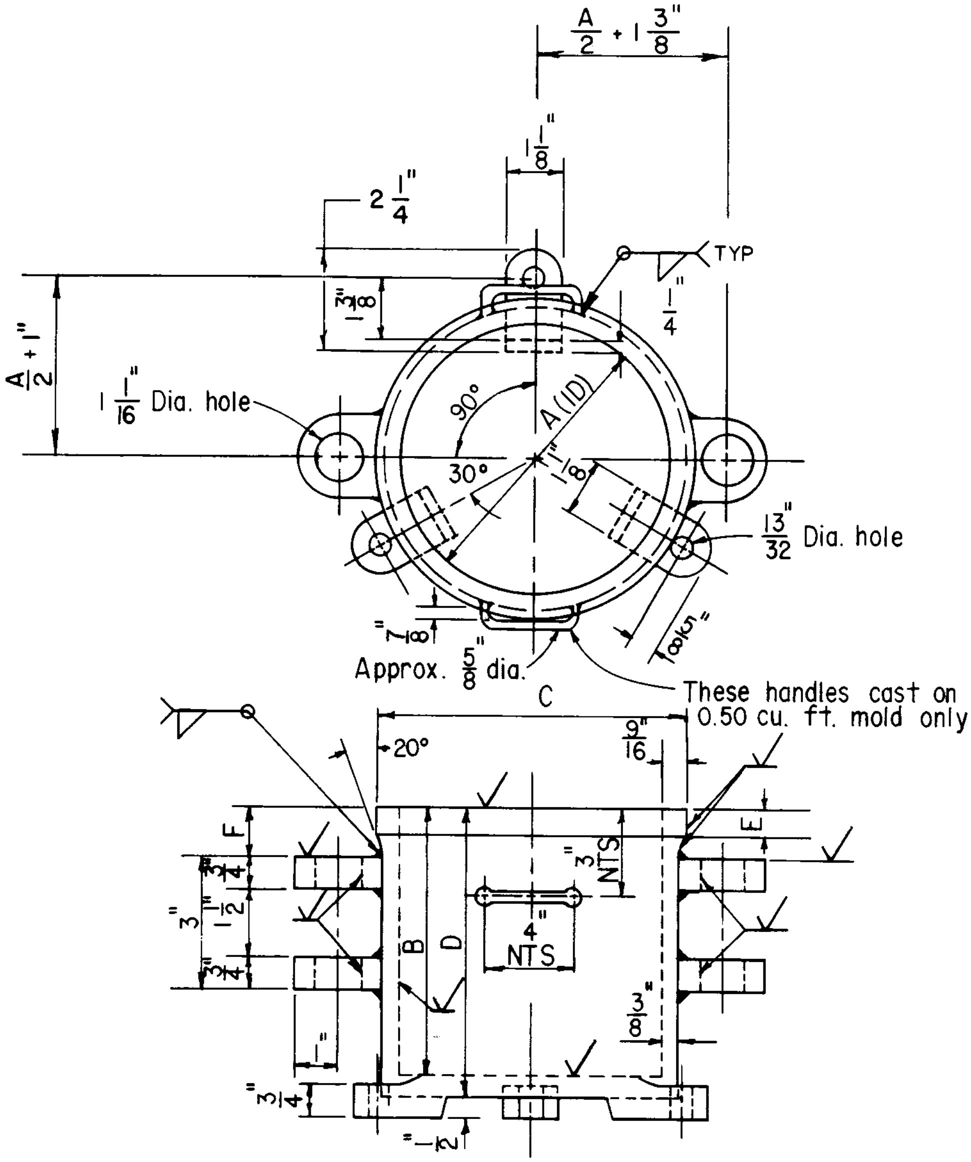
~~7.1 Sampling and test specimen requirements for Test Methods A and B are contained in the following paragraphs. Requirements for Test Method C begin at 7.4.~~

~~7.2 Prior~~

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).



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

Size Mold, ft^3(cm^3)	Dimensions, in. (mm)					
	A $^{+0.005}_{-0.000}$	B $^{+0.005}_{-0.000}$	C	D	E	F
0.100 (2830)	6.000 (152.4)	6.112 (155.2)	7⅛ (181.0)	6½ (105.1)	½ (12.7)	1⅛ (28.6)
0.500 (14 200)	11.000 (279.4)	9.092 (230.9)	12⅛ (308.0)	9½ (241.3)	⅝ (15.9)	2 (50.8)

FIG. 1 Details of Molds

7.3.1 Using a visual method or Test Method D 422 (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), 1-½-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.

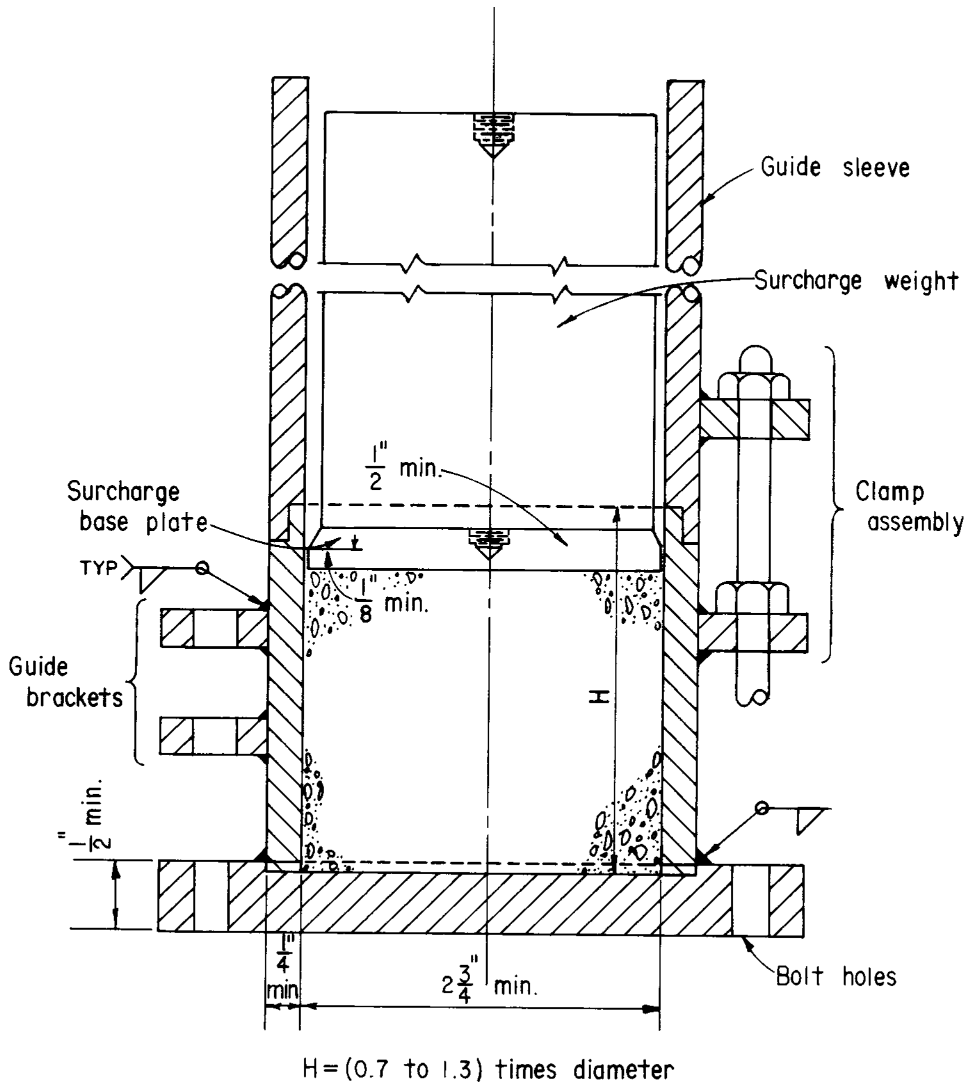
7.3.2 The determination of the minimum index density/unit weight should not be performed in accordance with these test methods unless the requirements of 1.5 are met. If these conditions are met, then the mold size, pouring device, and specimen mass required can be determined in accordance with the maximum 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:

$$M_r = 0.0024 V_m \quad (6)$$

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



SD	Equivalents
in.	mm
⅛	3.2
¼	6.4
½	13
2¾	70

FIG. 2 Special Cylindrical Metal Molds

TABLE 1 Required Mass of Specimen

Maximum Size ~~of~~ ~~Soil~~100% Pa~~rt~~ssi~~cle~~ng, 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 (2 830)
~~⅜ (9.5)~~	~~11~~	~~pouring device (1-in. (25-mm) dia spout)~~	~~0.100 (2 830)~~
⅜ (9.5)	11	pouring device with 1-in. (25-mm) diameter spout	0.100 (2 830)
~~No. 4 (4.75) or less~~	~~11~~	~~pouring device (½-in. (13-mm) dia spout)~~	~~0.100 (2 830)~~
No. 4 (4.75) or less	11	pouring device with ½-in. (13-mm) diameter spout)	0.100 (2 830)

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 ~~Test~~ 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 ~~Test~~ 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 D 2216.

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~~s~~*—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, millimeters, or centimeters to ~~three~~ four significant digits (in accordance with Practice ~~E 380).~~ D 6026). Calculate and record the volume, V_m (cm^3 ~~or cm^3)~~)) to four significant digits (in accordance with Practice ~~E 380).~~ D 6026).

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 ~~and temperature~~ of ~~the~~ water required to fill the ~~mold. The temperature should be determined to~~ mold, using the ~~nearest 1°C. The mass of~~ appropriate balance specified in 6.3.3. Determine the temperature of this water ~~must be determined~~ to ~~at least~~ the nearest ~~5 g for the 0.100-ft^3 (2830-cm ^{3}) mold and to the nearest 50 g for the 0.500-ft^3 (14 200-cm ^{3}) mold.~~ 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

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

Temperature °C	Temperature °F	Volume of Water~~,~~ per Gram ~~L/g~~ mL/g
~~12~~	~~53.6~~	~~1.00048~~
15	59.0	1.00090
~~14~~	~~57.2~~	~~1.00073~~
16	60.8	1.00106
~~16~~	~~60.8~~	~~1.00103~~
17	62.6	1.00122
~~18~~	~~64.4~~	~~1.00138~~
18	64.4	1.00140
19	66.2	1.00129
~~20~~	~~68.0~~	~~1.00177~~
20	68.0	1.00180
21	69.8	1.00201
~~22~~	~~71.6~~	~~1.00221~~
22	71.6	1.00223
23	73.4	1.00246
~~24~~	~~75.2~~	~~1.00268~~
24	75.2	1.00271
25	77.0	1.00296
~~26~~	~~78.8~~	~~1.00320~~
26	78.8	1.00322
27	80.6	1.00350
~~28~~	~~82.4~~	~~1.00375~~
28	82.4	1.00378
~~30~~	~~86.0~~	~~1.00435~~
29	84.2	1.00407
~~32~~	~~89.6~~	~~1.00497~~
30	86.0	1.00437

[A] Values other than shown may be obtained by referring to the *CRC Handbook of Chemistry and Physics*, ~~Chemic~~ Dalvid Rubb. Lide, Editor ~~Publ~~ ishing Co., Clhievelandf, O 74th Edition, 1993–1994.

cubic metres (m^3 or), multiply volume in cm^3) to the appropriate number of significant digits, as follows:

8.1.2.1 For mass measurements in grams, calculate the volume in cubic feet by multiplying the mass of water, in grams, used to fill the mold by the unit volume of water, from Table 2, and dividing the result by 28 320 mL/ft^3 1×10^{-6}.

8.1.2.2 For mass measurements in pounds, calculate the volume in cm^3 by multiplying the mass of water, in pounds, used to fill the mold by the unit volume of water, from Table 2.

8.2 Determine and record the mass of the empty mold, using the appropriate balance specified in 6.3.3.

9. Procedure

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

9.2 *Test Method* *Method A*:

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

9.2.2 If the pouring devices (as required in Table 1) are 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 ½ 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 23—Static electricity in dry sand can cause bulking similar to that produced by a trace of moisture on the particles; a static-eliminating balance brush can be applied to the equipment in contact with the sand when this effect becomes bothersome.

9.2.2.1 Fill the mold approximately ½ 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 Screen

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 scoope 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 or 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 and soil. plus soil, using the appropriate balance specified in 6.3.3. 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, ρ_{dmin}, γ_{dmin} $\rho_{dmin,n}$ 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 (preferably within 1 %) are obtained.

9.3 *Test Method* *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 6.3.5.

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 UsFollowing procedures of 9.2.2.1 and 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 and soil. plus soil, using the appropriate balance specified in 6.3.3. 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 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 (preferably within 1 %) are obtained.

9.4 *Test Method* *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, of the graduated cylinder the sand occupies.. 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 (preferably within 1 %) are obtained.

10. Calculation

10.1 For each trial, calculate

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

$$\rho_{dmin} = M_s/V \quad (7)$$

$$\rho_{dmin,n} = \frac{M_s}{V} \quad (7)$$

where:

$\rho_{dmin,n}$ = dry minimumminimum index density of the specimen, for given trial, Mg/m^3 or g/cm^3

M_s = mass of dry specimen, the tested-dry soil, Mg or g, and

V = volume of specimen, 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)

For Test Methods A and B, $V = V_c$ or calibrated volume of mold; and for Test 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/unit weight ρ density, ρ_{dmin}, or γ_{dmin} from of the trails which agree within 1 %.

10.1.2 Calculate test specimen.

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

$$\gamma_{dmin} = 9.807 \times \rho_{dmax}, N/m^3 \quad (8)$$

$$\gamma_{dmin} = 9.807 \cdot \rho_{dmin}, kN/m^3 \quad (8)$$

or

$$= 62.43 \times \rho_{dmax}, \text{lbf/ft}^3$$

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

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

$$e_{max} = \frac{\rho_w G_{avg}}{\rho_{dmin}} - 1 \quad (9)$$

$$e_{max} = \frac{\rho_w \cdot G_{avg}}{\rho_{dmin}} - 1 \quad (9)$$

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

$$G_{avg} = \frac{1}{\frac{R_1}{100G_1} + \frac{P1}{100\,G_2}} \quad (10)$$

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

G2 at 20°CRP

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 C 127 and corrected to 20°C (see Test Methods D 854),

$G_{2\ at\ 20°C}$ = specific gravity of the soil particles passing the No. 4 (4.75-mm) sieve as determined by Test Methods D 854,

$R1$ = percentage of soil particles from the sample retained on the No. 4 (4.75-mm) sieve, and

$P1$ = percentage of soil particles from the sample passing the No. 4 (4.75-mm) sieve, and

ρ_{dmin} = is in units of Mg/m^3 or g/cm^3. sieve.

10.3 If the maximum index density/unit weight, ρ_{dmax} or γ_{dmax}, has been determined in accordance with Test Methods D 4253 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:

$$D_d = \frac{\rho_{dmax}(\rho_d - \rho_{dmin})}{\rho_d(\rho_{dmax} - \rho_{dmin})} \times 100, \text{ or} \quad (11)$$

$$D_d = \frac{\gamma_{dmax}(\gamma_d - \gamma_{dmin})}{\gamma_d(\gamma_{dmax} - \gamma_{dmin})} \text{ or}$$

$$D_d = \frac{e_{max} - e}{e_{max} - e_{min}} \times 100$$

as calculated by any of the equations given in 3.2.7, i.e., Equations 1, 2, or 3.

11. Report

11.1 Report the following information:

11.1.1 Origin of material used in the test.

11.1.2 Description of appearance of test specimen, based on Practice D 2488 (Test Method (Practice D 2487 may be used as an alternative).

11.1.3 The test method (Test Methods (Methods A, B, or C) and size of mold used.

11.1.4 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 E 380), calculated in 10.1.1. D 6026).

12. Precision and Bias

12.1 *Precision*—Criteria for judging the acceptability of minimum-index density/unit weight test results, performed results obtained by T these test methods, using Method A, and testing a poorly graded sand (SP), is given in Tables 3 and . No statement is made for the4. These estimates of precision are based on the results of the interlaboratory program conducted by the ASTM

TABLE 3 PSummary of Tecist Results from Triplicate Test Labonratofries (Minimum Index Density/ Unit Weight Test Results by Method^A)

(1)	(2)	(3)	(4)	(5)		
Standard Deviations	Coil Type		Number of Trinplicated S Test Landabord Deviationries	Aceveptrable Range of Two ResuValtsue^A Expresse (lbf/ft^3)	Standas Percentd of MDeviation Value^B Unit Weight, (lbf/ft^3)	DAcceptable Range of Two Resiulty, Mg/ms (lbf/ft^3 Density,
)						
Multilaboratoryprecision:						
Single-Operator Results (Within-Laboratory Repeatability):						
Fine to medium sands	1.7	0.027	...	...	4	
SP	8	98.17	0.50	1....	4	
7.0						
Gravelly sands	2.5	0.040	...	...	8.8	
Singleoperatorprecision: Multilaboratory Results (Between-Laboratory Reproducibility):						
Fine to medium sands	...	...	0.5	0.008	1.9	
SP	8	98.17	2.49	0.008	1.9	
Gravelly sands	...	...	1.0	0.0163.7		
Gravelly sands	...	...	1.0	0.016.9		

^A All valThe numbes shr owf significanth disgits ablnd decimal places pre based onted avre rage testpresults oenta ltimive of the input d varietya. In accofrdiffance with Prenact soils (Scee No D 6026, the 1) standard de subjeviation and accept table range of resulturs can not have morev decimal places than the ionput data.

^B ThStandard deviation is coalcumnlated in accordiance with Practice E 691 and is referred to as the 1*s* limiting.

^C Acceptable range of val two results is referred to as w the d2*s* lichmit. It isho calculd noat bed as $1.960\sqrt{2} \cdot 1s$, as dexefineeded by Practice E 177. The difference between any two propesurly conducts,exprd testsed a s a phould not erxcentage ofd this limit. The av number of significant digits/de vcimalu place. As pproximaesented is equaly 95 % tof theat prestcribed by thesule tes frot methe cods oper Practivce test progr D 6026. In amsdditiono, thexe value pred thse limintied cang hacevep the same numbler of decimangl places as the standard deviatiown (, even if that ressult has more singnormificallynt digits tribuhan the standard deviata)ion.

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.

Reference soils and Testing Program.[9] 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 ~~Test Methods B~~ 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 ~~lack of sufficient data.~~

~~12.1.1 *Variations Between Laboratories (Variability)*:~~

~~12.1.1.1 The~~ another soil or method.

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,~~S~~ Column 4 were obtained in accordance with Practice E 691, which recommends each testing laboratory perform a minimum of three replicate tests. Resul~~a~~ts of two properly cond~~f~~ucted tests performed by the ~~equation:~~

$$S^2 = \frac{1}{N-1} \Sigma_1^N (X - \bar{X})^2 \tag{12}$$

~~where:~~ 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*

~~*N* = number~~ limits shown in Table 3, Column 5. For definition of ~~determinations,~~

~~*X* = individual value~~ d2*s*, see Footnote C in Table 3. Results of ~~each determination, and~~

~~$\bar{X}$ = numerical average~~ 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 ~~determinations.~~

~~12.1.2 *Variations Between Duplicate Tests (Reproducibility)*:~~

~~12.1.2.1 The combined standard deviation, *S′*,~~ laboratories performed only a single test. This is common pra~~l~~ctice in the design and constru~~l~~ction industry. The data in Table 4 are based upon the first test results from the ~~equation:~~

$$S'^2 = \frac{1}{2K} \Sigma D^2 \tag{13}$$

~~where:~~ 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 using different equipment and on different days should not vary by more than the d2*s*

~~*D* = difference between duplicate tests, and~~

~~*K* = number~~ 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 accor~~s~~dance with Practice E 691 from pre-qualified~~up~~ laboratori~~e~~es. Table 4 is derived from test data that represents common practice.

12.1.4 *Soil Type*—

[9] Supporting data are available from ASTM Headquarters. Request RR: D18-1012.

BP—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 D-18 policy, this section identifies the location of changes to this standard since the last edition(91(Reapproved 1996)) that may impact the use of this standard:

(*1*) A Summary of Changes Section was added.

(*2*) "Test Method(s)" was changed to "Method(s)" where applicable.

(*3*) Reworded 1.1-1.2.3 and in 1.1 added sentence covering the usage of "dry".

(*4*) Under Terminology, changed the order in which some terms are presented and corrected equations so the resultant is in percent.

(*5*) References to Practices D 3740, D 6026, E 177, and E 691 were included throughout the text where applicable. References to Practice E 380 were deleted as Practice D 6026 replaces it.

(*6*) Added Note 2 to Section 5 and all subsequent notes were renumbered.

(*7*) In 6.3.3.1-6.3.3.3 under balances gave the required readability for the specified balance.

(*8*) Under Sampling and Test Specimen in 7, changed the order in which the first two subsections are presented.

(*9*) Under Calibrations in 8.1.2, reworded how the mass of water is to be determined (use the appropriate balance specified in the Apparatus section). In 8.1.2, reworded so the calculated volume is in cm^3 or m^3, not ft^3. Removed 8.1.2.2.

(*10*) The mL/g constants in Table 2 were updated to agree with the density of water given in Test Methods D 854. Also, values at one °C intervals were included and the reference was changed to agree with Test Methods D 854.

(*11*) Under Procedures in 9.2.4 and 9.3.6, reworded to define which balance is to be used.

(*12*) In 10.1, changed notation in the equation to indicate the density is for given trial.

(*13*) In 10.1.1, reworded to define the average density for acceptable trials is the minimum index density of the test specimen.

(*14*) In 10.1.2 and 10.2, reworded to indicate the calculation is not required. In addition, the equation in 10.1.2 for minimum-index unit weight was corrected, and equation in 10.2 for void ratio was modified so the applicable values are at 20°C.

(*15*) Section 11.1.4 was revised to be compliant with Practice D 6026.

(*16*) In Table 1, the title for maximum particle size was modified to agree with that give in Test Methods D 1140.

(*17*) Section 12 was thoroughly revised.