Designation: D2167 – 15

Standard Test Method for Density and Unit Weight of Soil in Place by the Rubber Balloon Method[1]

This standard is issued under the fixed designation D2167; 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 This test method covers the determination of the in-place density and unit weight of compacted or firmly bonded soil using a rubber balloon apparatus.

1.2 This test method is suitable for use as a means of acceptance for compacted fill or embankments constructed of fine-grained soils or granular soils without appreciable amounts of rock or coarse material.

1.3 This test method also may be used for the determination of the in-place density and unit weight of undisturbed or in situ soils, provided the soil will not deform under the pressures imposed during the test.

1.4 This test method is not suitable for use in organic, saturated, or highly plastic soils that would deform under the pressures applied during this test. This test method may require special care for use on (*1*) soils consisting of unbonded granular materials that will not maintain stable sides in a small hole, (*2*) soils containing appreciable amounts of coarse material in excess of 37.5 mm (1½ in.), (*3*) granular soils having high void ratios, or (*4*) fill materials containing particles with sharp edges. For soils containing appreciable amounts of particles in excess of 37.5 mm (1½ in.), Test Methods D4914 or D5030 should be used.

1.5 The values stated in SI units are to be regarded as the standard. The values given in parentheses are for information only.

1.5.1 In the engineering profession it is customary to use units representing both mass and force interchangeably, unless dynamic calculations are involved. 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 standard 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, conversions are given in the SI system. The use of balances or scales recording pounds of mass lbm/ft^3 should not be regarded as nonconforming with this test method.

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values shall conform to the guidelines for significant digits and rounding established in Practice D6026 unless superseded by this standard.

1.6.1 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; 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 analytical 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:*[2]

D653 Terminology Relating to Soil, Rock, and Contained Fluids

D698 Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (12 400 ft-lbf/ft^3 (600 kN-m/m^3))

D1557 Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort (56,000 ft-lbf/ft^3 (2,700 kN-m/m^3))

[1] This test method is under the jurisdiction of ASTM Committee D18 on Soil and Rock and is the direct responsibility of Subcommittee D18.08 on Special and Construction Control Tests.

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[2] 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.

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

D2216 Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass
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
D4643 Test Method for Determination of Water (Moisture) Content of Soil by Microwave Oven Heating
D4718 Practice for Correction of Unit Weight and Water Content for Soils Containing Oversize Particles
D4753 Guide for Evaluating, Selecting, and Specifying Balances and Standard Masses for Use in Soil, Rock, and Construction Materials Testing
D4914 Test Methods for Density and Unit Weight of Soil and Rock in Place by the Sand Replacement Method in a Test Pit
D4944 Test Method for Field Determination of Water (Moisture) Content of Soil by the Calcium Carbide Gas Pressure Tester
D4959 Test Method for Determination of Water (Moisture) Content of Soil By Direct Heating
D5030 Test Method for Density of Soil and Rock in Place by the Water Replacement Method in a Test Pit
D6026 Practice for Using Significant Digits in Geotechnical Data

3. Terminology

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

3.2 *Definitions of Terms Specific to This Standard:*
3.2.1 *compacted lift, n*—a layer of compacted soil.

4. Summary of Test Method

4.1 The volume of an excavated hole in a given soil is determined using a liquid-filled calibrated vessel for filling a thin flexible rubber membrane; this membrane is displaced to fill the hole. The in-place wet density is determined by dividing the wet mass of the soil removed by the volume of the hole. The water (moisture) content and the in-place wet density are used to calculate the dry in-place density and dry unit weight.

5. Significance and Use

5.1 This test method can be used to determine the in-place density and unit weight of natural inorganic soil deposits, soil-aggregate mixtures, or other similar firm materials. It is often used as a basis of acceptance for earthen material compacted to a specified density or percentage of a maximum density determined by a test method, such as Test Methods D698, D1557 or D4253.

5.1.1 Test Methods D698 and D1557 require that mass measurements of laboratory compacted test specimens be determined to the nearest 1 g so that computed water contents and densities can be reported to three and four significant digits, respectively. This standard is a field procedure requiring mass measurements to the nearest 5 g. As such, water content calculations should only be reported to two significant digits and density to three significant digits.

5.2 This test method may be used to determine the density and unit weight of compacted soils used in construction of earth embankments, road fill, and structural backfill. This test method often is used as a basis of acceptance for soils compacted to a specified density or a percentage of maximum density or unit weight, as determined by a standard test method.

5.3 The use of this test method is generally limited to soil in an unsaturated condition and is not recommended for soils that are soft or that deform easily. Such soils may undergo a volume change during the application of pressure during testing. This test method may not be suitable for soils containing crushed rock fragments or sharp edge materials, which may puncture the rubber membrane.

NOTE 1—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 the facilities used. Agencies that meet the criteria of Practice D3740 are generally considered capable of competent and objective testing. Users of this standard are cautioned that compliance with Practice D3740 does not in itself ensure reliable results. Reliable results depend on many factors; Practice D3740 provides a means of evaluating some of those factors.

6. Apparatus

6.1 *Balloon Apparatus*—This is a calibrated vessel containing a liquid within a relatively thin, flexible, elastic membrane (rubber balloon) designed for measuring the volume of the test hole under the conditions of this test method. An example of the essential elements for this apparatus is shown in Fig. 1. The apparatus shall be equipped so that an externally controlled pressure or partial vacuum can be applied to the contained liquid. It shall be of such weight and size that will not cause distortion of the excavated test hole and adjacent test area during the performance of the test. The apparatus shall provide for the use of an integral pressure gauge or other means for controlling the applied pressure during calibration and testing. Provision shall be made for placing loads (surcharge) on the apparatus. There shall be an indicator for determining the volume of the test hole to the nearest 1 %. The flexible membrane shall be of such size and shape as to fill the test hole completely without wrinkles or folds when inflated within the test hole, and the membrane strength shall be sufficient to withstand such pressure as is necessary to ensure complete filling of the test hole without loss of liquid. Withdrawal of the membrane from the test hole shall be accomplished by the application of a partial vacuum to the liquid or by other means.

6.1.1 The description and requirements given are intended to be nonrestrictive. Any apparatus using a flexible (rubber) membrane and liquid that can be used to measure within an accuracy of 1 % the volume of a test hole in soil under the conditions of this test method is satisfactory. Larger apparatus and test hole volumes are required when particles over 37.5 mm (1½ in.) are prevalent in the material being tested.

6.2 *Base Plate*—A rigid metal plate machined to fit the base of the balloon apparatus. The base plate shall have a minimum dimension of at least twice the test hole diameter to prevent deformation of the test hole while supporting the apparatus and surcharge loads (if used).

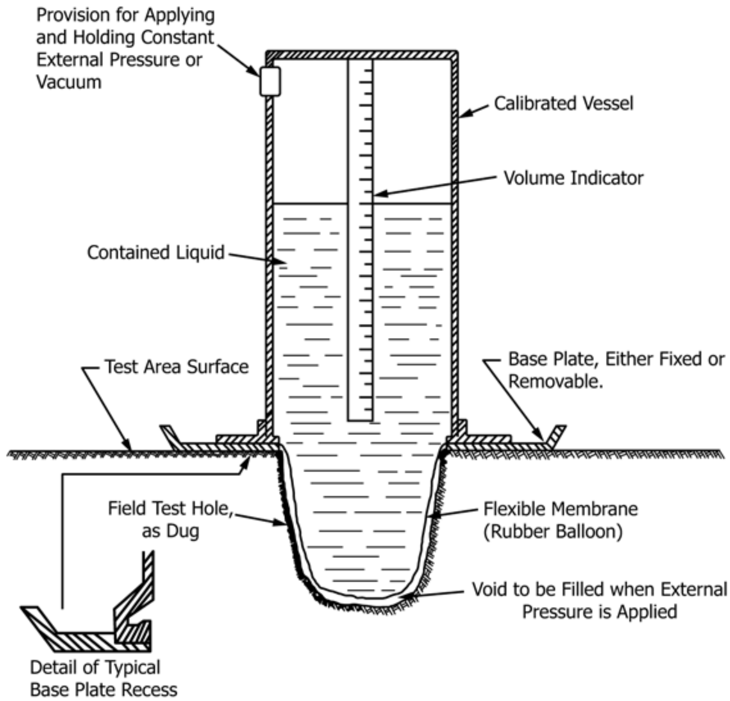

FIG. 1 Schematic Drawing of Calibrated Vessel Indicating Principle (Not to Scale)

6.3 *Balances or Scales*—A balance or scale having a minimum capacity of 20 kg meeting the requirements of Specification D4753 for a balance of 5.0 g readability. Balances or scales required for moisture determination or oversize correction are contained in those standards.

6.4 *Drying Apparatus*—Equipment or ovens, or both, for the determination of moisture content in accordance with Test Methods D2216, D4643, D4959, or D4944.

6.5 *Miscellaneous Equipment*—Equipment including: small picks, chisels, spoons, brushes, and screwdrivers for digging test holes; plastic bags, buckets with lids, or other suitable moisture proof containers with snug fitting lids for retaining the soil taken from the test hole; shovels or spades and a straight edge for leveling and preparing test location; calculator or slide rule for calculations; and surcharge weights, if required, for apparatus.

7. Calibration

7.1 Prior to the first use, verify the procedure to be used and the accuracy of the volume indicator by using the apparatus to measure containers or molds of known volume in accordance with Annex A1.

TABLE 1 Minimum Test Hole Volumes Based on Maximum Size of Included Particles

Maximum Particle Size		Minimum Test Hole Volumes	
mm	(in.)	cm^3	ft^3
12.5	(0.5)	1420	0.05
25.0	(1)	2120	0.075
37.5	(1.5)	2840	0.1

7.2 Apparatus calibration checks should be periodically performed. These should be performed annually, as a minimum, and whenever damage, repair, or change of membrane that may affect the pressure or volume indicating portions of the apparatus occurs.

8. Procedure

8.1 Prepare the surface at the test location so that it is reasonably plane and level. Dependent on the water (moisture) content and texture of the soil, the surface may be leveled using a bulldozer or other heavy equipment blades, provided the test area is not deformed, compressed, torn, or otherwise disturbed.

8.2 Assemble the base plate and rubber balloon apparatus on the test location. Using the same pressure and surcharge determined during the calibration of the apparatus, take an initial reading on the volume indicator and record. The base plate shall remain in place through completion of the test.

8.3 Remove the apparatus from the test hole location. Using spoons, trowels, and other tools necessary, dig a hole within the base plate. Exercise care in digging the test hole so that soil around the top edge of the hole is not disturbed. The test hole shall be of the minimum volume shown in Table 1 based on the maximum particle size in the soil being tested. When material being tested contains a small amount of oversize or isolated large particles are encountered, the test can be moved to a new location or changed to another test method, such as Test Method D4914 or D5030. When particles larger than 37.5 mm (1½ in.) are prevalent, larger test apparatus and test volumes are required. Larger test-hole volumes will provide improved accuracy and shall be used where practical. The optimum dimensions of the test hole are related to the design of the apparatus and the pressure used. In general, the dimensions shall approximate those used in the calibration check procedure. The test hole shall be kept as free of pockets and sharp obtrusions as possible, since they may affect accuracy or may puncture the rubber membrane. Place all soil removed from the test hole in a moisture tight container for later mass and water (moisture) content determination.

8.4 After the test hole has been dug, place the apparatus over the base plate in the same position as used for the initial reading. Applying the same pressure and surcharge load as used in the calibration check, take and record the reading on the volume indicator. The difference between the initial and final readings is the volume of the test hole, V_h.

8.5 Determine the mass of all the moist soil removed from the test hole to the nearest 5 g. Mix all the soil thoroughly and select a representative water (moisture) content sample and determine the water (moisture) content in accordance with Test Methods D2216, D4643, D4959, or D4944. If oversize particles are present in the material removed from the test hole, perform field corrections in accordance with Test Method D4718.

9. Calculation

9.1 Calculate the in-place wet density, ρ_{wet}, of the soil removed from the test hole as follows:

$$\rho_{wet} = \frac{M_{wet}}{V_h\,(1 \times 10^3)} \quad (1)$$

where:

ρ_{wet} = in-place wet density, Mg/m^3,
M_{wet} = mass of the moist soil removed from the test hole, kg, and
V_h = volume of the test hole, m^3.

NOTE 2—Calculations shown are for using units in kilograms and cubic metres. Other units are permissible provided the appropriate conversion factors are used to maintain consistency of units throughout the calculations.

9.2 Calculate the in-place dry density, ρ_d, of the soil as follows:

$$\rho_d = \frac{\rho_{wet}}{\left(1 + \frac{w}{100}\right)} \quad (2)$$

where:

ρ_d = in-place dry density, Mg/m^3,
ρ_{wet} = in-place wet density, Mg/m^3, and
w = water (moisture) content of the soil removed from the test hole, expressed as a percentage of the dry mass of the soil to the nearest 1 %.

9.3 Calculate the in-place dry unit weight, γ_d, as follows:

$$\gamma_d = \rho_d \times 62.43 \quad (3)$$

where:

γ_d = in-place dry unit weight, kN/m^3, and
ρ_d = in-place dry density, Mg/m^3.

NOTE 3—It may be desirable to express the in-place density as a percentage of some other density or unit weight, for example, the laboratory maximum dry density or unit weight as determined in accordance with Test Methods D698. This relationship can be determined by dividing the in-place dry density or unit weight by the maximum dry density or unit weight, respectively, and multiplying by 100.

10. Report

10.1 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 and Practice D6026.

10.2 Record, as a minimum, the following general information (data):
10.2.1 Test location,
10.2.2 Test location elevation,

10.3 Record as a minimum the following specimen data:
10.3.1 Test hole volume, m^3,
10.3.2 In-place wet density, Mg/m^3,
10.3.3 In-place dry unit weight, kN/m^3 (ρ_d (kg/m^3) × 9.807), expressed to the nearest 0.1 kN/m^3.
10.3.4 In-place water content of the soil expressed as a percentage of dry mass, and the test method used.
10.3.5 Water (moisture) content of the soil expressed as a percentage of dry mass,
10.3.6 Test apparatus identity and operating pressure used,
10.3.7 Comments on test, as applicable, and
10.3.8 Visual description of the soil.
10.3.9 If the in-place dry density or unit weight is expressed as a percentage of another value, include the following:
10.3.9.1 Identity of the reference method used,
10.3.9.2 The comparative maximum dry density or unit weight and the optimum water (moisture) content used, and
10.3.9.3 Correction for oversized particles and details, if applicable.
10.3.9.4 The comparative percentage of the in-place materials to the comparison value.
10.3.9.5 If the in-place density, unit weight, or water content are to be used for acceptance, include the acceptance criteria applicable to the test.

11. Precision and Bias

11.1 *Precision*—Test data on precision are not presented due to the nature of this test method. It is either not feasible or too costly at this time to have ten or more agencies participate in an in situ testing program at a given site.

11.1.1 Laboratory studies have determined the precision of the apparatus to determine the volume of cast holes of known volumes under laboratory conditions. One study with smaller volume holes indicated that volumes measured were from 0.24 to 5.31 % lower than the volumes determined by water calibration, with the accuracies affected by hole volume, shape, smoothness, and operator technique. A second study found that with larger volumes (10 to 30 L) that the error was +0 to 0.6 % with an average error of 0.31 %.

11.1.2 While no formal round-robin testing has been completed, it is estimated by the Subcommittee D18.08 from experience that the results of two properly conducted tests performed by a skilled operator on the same material at a given time and location should not differ by more than approximately 1 lb/ft^3 (1.6 kg/m^3). Tests performed by unskilled operators on the same material would be expected to yield substantially greater differences.

11.1.3 Subcommittee D18.08 is seeking pertinent data from users of this test method on precision.

11.2 *Bias*—There is no accepted reference value for this test method, therefore, bias cannot be determined.

12. Keywords

12.1 acceptance tests; balloon test; compaction tests; degree of compaction; densitometer test; density tests; field control tests; inplace density; inplace dry density; in situ density; relative density; soil tests; unit weight

ANNEX

(Mandatory Information)

A1. CALIBRATION OF RUBBER BALLOON APPARATUS

A1.1 Scope

A1.1.1 This annex describes the procedure for determining the accuracy of the rubber balloon apparatus volume indicators.

A1.1.2 Calibration of the apparatus is required for new devices or whenever damage, repair, or other activities occur, which could affect the accuracy of the volume indicator.

A1.2 Apparatus

A1.2.1 The following equipment is required in addition to that required for the test:

A1.2.1.1 *Thermometer,* accurate to 0.5°C (1°F).

A1.2.1.2 *Glass Plate,* 6 mm (¼ in.) or thicker, of sufficient size to cover the calibration molds.

A1.2.1.3 *Calibration Molds*—Containers of different known volumes that dimensionally simulate test holes that will be used in the field (see Note A1.1). The apparatus and procedures shall be such that these containers will be measured to within 1 % of the actual volumes. Calibration molds of different volumes should be used so that the calibration of the volume indicator covers the range of anticipated field test volumes.

A1.3 Calibration Procedure

A1.3.1 Verify the procedure to be used and the accuracy of the volume indicator by using the apparatus to measure containers or molds of known volume that dimensionally simulate test holes that will be used in the field (see Note A1.1). The apparatus and procedures shall be such that these containers will be measured to within 1 % of the actual volumes (see Note A1.1). Containers of different volumes shall be used so that the calibration of the volume indicator covers the range of anticipated test volumes.

NOTE A1.1—The 100 and 150 mm (4 and 6-in.) molds described in Test Methods D698 and Test Methods D1557, or any other molds prepared to simulate actual test hole diameters and volumes may be used. When several sets of balloon apparatus are used, or long-term use is anticipated, it may be desirable to cast duplicates of actual test holes. This can be accomplished by forming plaster of paris negatives in actual test holes over a range of volumes, and using these as forms for concrete castings. They should be cast against a flat plane surface, and after the removal of the negative, sealed water-tight.

A1.3.2 *Volume Determination*—Determine the mass of water, in grams, required to fill the containers or hole molds. Using a glass plate and a thin film of grease, if needed for sealing, determine the mass of the container or mold and glass plate to the nearest gram. Fill the container or mold with water, carefully sliding the glass plate over the opening in such a manner as to ensure that no air bubbles are entrapped and that the mold is filled completely with water. Remove excess water and determine the mass of the glass plate, water, and mold or container to the nearest gram. Determine the temperature of the water. Calculate the volume of the mold or container in accordance with A1.3.4. Repeat this procedure for each container or mold until three consecutive volumes having a maximum variation of 2.8×10^{-6} m^3 (0.0001 ft^3) are obtained. Record the average of the three trials as the mold or container volume, V_t. Repeat the procedure for each of the containers or molds to be used.

A1.3.3 *Calibration Check Tests*—Place the rubber balloon apparatus and base plate on a smooth horizontal surface. Applying an operating pressure, take an initial reading on the volume indicator (see Note A1.2). Transfer the apparatus to one of the previously calibrated molds or containers with a horizontally leveled bearing surface. Apply the operating pressure as necessary until there is no change indicated on the volume indicator. Depending on the type of apparatus, the operating pressure may be as high as 34.5 kpa (5 psi), and it may be necessary to apply a downward load (surcharge) to the apparatus to keep it from rising (see Note A1.3). Record the readings, pressures, and surcharge loads used. The difference between the initial and final readings is the indicated volume. Determine the volumes of the other molds or containers. A satisfactory calibration check of an apparatus has been achieved when the difference between the indicated and calibrated volume of the container or mold is 1 %, or less, for all volumes measured. Select the optimum operating pressure and record it for use with the apparatus during field testing operations.

NOTE A1.2—Before any measurements are taken, it may be necessary to distend the rubber balloon and by kneading, remove the air bubbles adhering to the inside of the membrane. If the calibration castings or molds are airtight, it may be necessary to provide an air escape to prevent erroneous results caused by the trapping of air by the membrane. One means of providing air escape is to place small diameter strings over the edge of and down the inside, slightly beyond bottom center of the mold or casting. This will allow trapped air to escape during the measurement of the calibrated mold or container.

NOTE A1.3—It is recommended that the operating pressure of the apparatus be kept as low as possible while maintaining the 1 % volume accuracy. The use of higher pressures than necessary may require the use of an additional load or surcharge weight to prevent uplift of the apparatus. The combined pressure and surcharge loads may result in pressing the unsupported soil surrounding the test hole, causing it to deform.

A1.3.4 Calculate the volume of the calibration containers or molds as follows:

$$V = (M_2 - M_1) \times V_w$$

where:

V = volume of the container or mold, mL,
M_2 = mass of mold or container, glass, and water, g,
M_1 = mass of mold or container and glass, g, and
V_w = volume per unit mass of water based on temperature taken from, mL/g.

NOTE A1.4—Multiply millilitres by 3.5315×10^{-5} for ft^3 if needed for equipment usage.

TABLE A1.1 Volume of Water per Gram Based on Temperature[A]

Temperature		Volume of Water,
°C	°F	mL/g
12	53.6	1.00048
14	57.2	1.00073
16	60.8	1.00103
18	64.4	1.00138
20	68.0	1.00177
22	71.6	1.00221
24	75.2	1.00268
26	78.8	1.00320
28	82.4	1.00375
30	86.0	1.00435
32	89.6	1.00497

[A] Values other than shown may be obtained by referring to *Handbook of Chemistry and Physics*, Chemical Rubber Publishing Co., Cleveland, OH.

SUMMARY OF CHANGES

In accordance with Committee D18 policy, this section identifies the location of changes to this standard since the last edition (2008) that may impact the use of this standard. (July 1, 2015)

(1) Modified Note 1 to the current D18 standard style
(2) Modified Section 10 to the current D18 standard style.
(3) Removed Note 2 regarding conversion between m^3 and ft^3.
(4) Corrected an error in Equation 3.