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

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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 1½ in. (37.5 mm), (*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 1½ in. (37.5 mm), Test Methods D 4914 or D 5030 should be used.

1.5 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 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, 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 *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:*

D 653 Terminology Relating to Soil, Rock, and Contained Fluids[2]

D 698 Test Methods for Moisture-Density Relations of Soils and Soil-Aggregate Mixtures, Using 5.5-lb (2.49-kg) Rammer and 12-in. (305-mm) Drop[2]

D 1557 Test Methods for Moisture-Density Relations of Soils and Soil-Aggregate Mixtures Using 10-lb (4.54-kg) Rammer and 18-in. (457-mm) Drop[2]

D 2216 Method for Laboratory Determination of Water (Moisture) Content of Soil, Rock, and Soil-Aggregate Mixtures[2]

D 3740 Practice for the Evaluation of Agencies Engaged in Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction[2]

D 4643 Test Method for Determination of Water (Moisture) Content of Soils by the Microwave Oven Method[2]

D 4718 Practice for the Correction of Unit Weight and Water Content for Soils Containing Oversize Particles[2]

D 4753 Specification for Evaluating, Selecting, and Specifying Balances and Scales for Use in Testing Soil, Rock, and Related Construction Materials[2]

D 4914 Test Method for Density of Soil and Rock in Place by the Sand Replacement Method in a Test Pit[2]

D 4944 Test Method for Field Determination of Water (Moisture) Content of Soil by the Calcium Carbide Gas Pressure Tester[2]

D 4959 Test Method for Determination of Water (Moisture) Content of Soils by the Direct Heating Method[2]

D 5030 Test Method for Density and Unit Weight of Soil and Rock in Place by the Water Replacement Method in a Test Pit[2]

3. Summary of Test Method

3.1 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

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

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.

4. Significance and Use

4.1 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.

4.2 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.

4.3 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—Notwithstanding the statements on precision and bias contained in this test method, the precision of this test method 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 D 3740 are generally considered capable of competent and objective testing. Users of this test method are cautioned that compliance with Practice D 3740 does not in itself ensure reliable testing. Reliable testing depends on many factors; Practice D 3740 provides a means of evaluating some of those factors.

5. Apparatus

5.1 *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

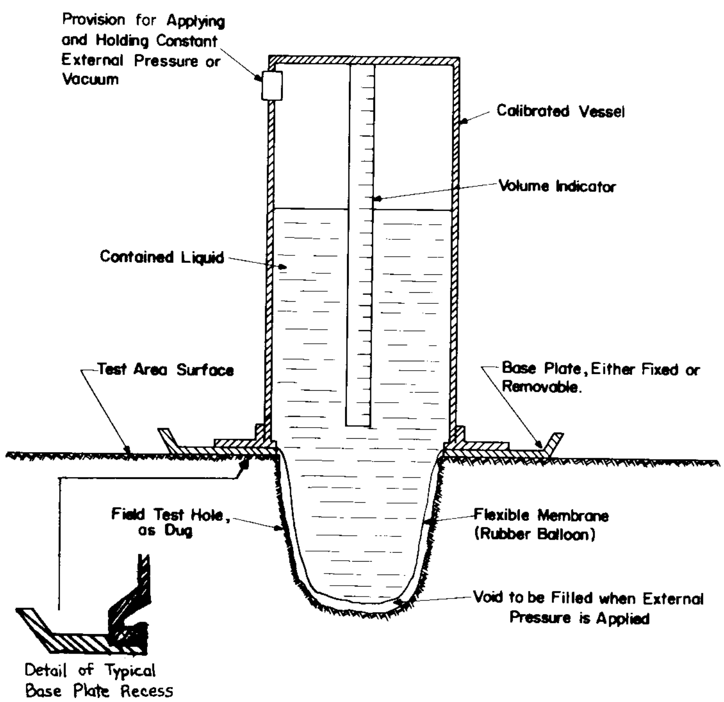

FIG. 1 Schematic Drawing of Calibrated Vessel Indicating Principle (Not to Scale)

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 gage 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.

5.1.1 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 1|n$ in. (37.5 mm) are prevalent in the material being tested.

5.2 *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).

5.3 *Balances or Scales*—A balance or scale having a minimum capacity of 20 kg meeting the requirements of Specification D 4753 for a balance of 5.0 g readability. Balances or scales required for moisture determination or oversize correction are contained in those standards.

5.4 *Drying Apparatus*—Equipment or ovens, or both, for the determination of moisture content in accordance with Test Methods D 2216, D 4643, D 4959, or D 4944.

5.5 *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.

6. Calibration

6.1 Prior to 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.

6.2 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.

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

Maximum Particle Size in.	(mm)	Minimum Test Hole Volumes cm ^{3}	ft ^{3}
1 / 2	(12.5)	1420	0.05
1	(25.0)	2120	0.075
1 1 / 2	(37.5)	2840	0.1

7. Procedure

7.1 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.

7.2 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.

7.3 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, and isolated large particles are encountered, the test can be moved to a new location or the changing to another test method, such as Test Method D 4914 or D 5030. When particles larger than 1½ in. (37.5 mm) 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.

7.4 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.

7.5 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 D 2216, D 4643, D 4959, or D 4944. If oversize particles are present in the, perform field corrections in accordance with Test Method D 4718.

8. Calculation

8.1 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—$m^3 = ft^3(0.02832)$.

NOTE 3—Calculations shown are for using units in grams and cubic metres. Other units are permissible provided the appropriate conversion factors are used to maintain consistency of units throughout the calculations.

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

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

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 %.

8.3 Calculate the in-place dry unit weight, δ_d, as follows:

$$\delta_d = \rho_d (9.807) \text{ in } kN/m^3 \tag{3}$$

$$\delta_d = \rho_d (62.43) \text{ in } lbf/ft^3$$

where:
δ_d = in-place dry unit weight, and
ρ_d = in-place dry density, mg/m^3.

NOTE 4—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 D 698. 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.

9. Report

9.1 Report, as a minimum, the following information:

9.1.1 Test location,

9.1.2 Test location elevation,

9.1.3 Test hole volume, m^3,

9.1.4 In-place wet density, mg/m^3,

9.1.5 In-place dry unit weight, kN/m^3 ($\rho_d \times 9.807$), or lb/ft^3 ($\rho_d \times 62.43$), expressed to the nearest .1 kN/m^3 or 1.0 for lb/ft^3.

9.1.6 In-place water content of the soil expressed as a percentage of dry mass, and the test method used.

9.1.7 Water (moisture) content of the soil expressed as a percentage of dry mass,

9.1.8 Test apparatus identity and operating pressure used,

9.1.9 Comments on test, as applicable, and

9.1.10 Visual description of the soil.

9.1.11 If the in-place dry density or unit weight is expressed as a percentage of another value, include the following:

9.1.11.1 Identity of the reference method used,

9.1.11.2 The comparative maximum dry density or unit weight and the optimum water (moisture) content used, and

9.1.11.3 Correction for oversized particles and details, if applicable.

9.1.11.4 The comparative percentage of the in-place materials to the comparison value.

9.1.11.5 If the in-place density, unit weight, or water content are to be used for acceptance, include the acceptance criteria applicable to the test.

10. Precision and Bias

10.1 The precision of this test method is operator dependent and a function of the care exercised in performing the steps of the procedure, giving particular attention to careful control and systematic repetition of the procedure used. No standard soils exist for determination of the overall precision of this test method under field conditions.

10.2 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 %.

10.3 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.

10.4 There are no absolute values of in-place density for soils against which this test method can be compared. Therefore this Standard Test Method has no determinable bias since the values obtained can only be defined in terms of the test method.

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

11. Keywords

11.1 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 1°F (0.5°C).

A1.2.1.2 *Glass Plate*, ¼ in. (6 mm) 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 4 and 6-in. (102 and 152-mm) molds described in Test Methods D 698 and Test Methods D 1557, 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 portland cement 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 0.0001 ft^3 (2.8× 10^{-6} m^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 5 psi (34.5 kpa), 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 dressing 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 of water based on temperature taken from Table A1.1, 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, mL/g
°C	°F	
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.

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