Designation: D7382 – 08

Standard Test Methods for Determination of Maximum Dry Unit Weight and Water Content Range for Effective Compaction of Granular Soils Using a Vibrating Hammer[1]

This standard is issued under the fixed designation D7382; 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.

1. Scope*

1.1 These test methods cover the determination of the maximum dry unit weight and water content range for effective compaction of granular soils. A vibrating hammer is used to impart a surcharge and compactive effort to the soil specimen.

1.2 These test methods apply to soils with up to 35 %, by dry mass, passing a No. 200 (75-µm) sieve if the portion passing the No. 40 (425-µm) sieve is nonplastic.

1.3 These test methods apply to soils with up to 15 %, by dry mass, passing a No. 200 (75-µm) sieve if the portion passing the No. 40 (425-µm) sieve exhibits plastic behavior.

1.4 These test methods apply to soils in which 100 %, by dry mass, passes the 2-in. (50-mm) sieve.

1.5 These test methods apply only to soils (materials) that have 30 % or less, by dry mass of their particles retained on the ¾-in. (19.0-mm) sieve.

NOTE 1—For relationships between unit weights and water contents of soils with 30 % or less, by dry mass, of material retained on the ¾-in. (19.0-mm) sieve to unit weights and water contents of the fraction passing the ¾-in. (19.0-mm) sieve, see Practice D4718.

1.6 These test methods will typically produce a higher maximum dry density/unit weight for the soils specified in 1.2 and 1.3 than that obtained by impact compaction in which a well-defined moisture-density relationship is not apparent. However, for some soils containing more than 15 % fines, the use of impact compaction (Test Methods D698 or D1557) may be useful in evaluating what is an appropriate maximum index density/unit weight.

1.7 Two alternative test methods are provided, with the variation being in mold size. The method used shall be as indicated in the specification for the material being tested. If no method is specified, the choice should be based on the maximum particle size of the material.

1.7.1 *Method A:*

1.7.1.1 *Mold*—6-in. (152.4-mm) diameter.

1.7.1.2 *Material*—Passing ¾-in. (19.0-mm) sieve and consistent with the requirements of 1.2 and 1.3.

1.7.1.3 *Layers*—Three.

1.7.1.4 *Time of Compaction per layer*—60 ± 5 s.

1.7.2 *Method B:*

1.7.2.1 *Mold*—11-in. (279.4-mm) diameter.

1.7.2.2 *Material*—Passing 2-in. (50-mm) sieve and consistent with the requirements of 1.2 and 1.3.

1.7.2.3 *Layers*—Three.

1.7.2.4 *Time of Compaction per layer*—52 ± 5 s at each of 8 locations.

NOTE 2—Method A (with the correction procedure of Practice D4718, if appropriate), has been shown (reference thesis or paper) to provide consistent results with Method B. Therefore, for ease of operations, it is highly recommended to use Method A, unless Method B is required due to soil gradations not meeting Practice D4718.

NOTE 3—Results have been found to vary slightly when a material is tested at the same compaction effort in different size molds.

1.7.3 Either method, A or B, can be performed with the material in an oven-dried or wet/saturated state, whichever provides the maximum dry unit weight.

1.8 If the test specimen contains more than 5 % by mass of oversize fraction (coarse fraction) and the material will not be included in the test, corrections must be made to the unit weight and water content of the test specimen or to the appropriate field in-place density test specimen using Practice D4718.

1.9 This test method causes a minimal amount of degradation (particle breakdown) of the soil. When degradation occurs, typically there is an increase in the maximum unit weight obtained, and comparable test results may not be obtained when different size molds are used to test a given soil. For soils where degradation is suspected, a sieve analysis of the specimen should be performed before and after the compaction test to determine the amount of degradation.

1.10 *Units*—The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system may not be exact equivalents;

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

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

therefore, each system shall be used independently of the other. Combining values from the two systems may result in non-conformance with the standard.

1.11 The vibrating hammer test method may be performed in the field or in the laboratory.

1.12 *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]

C127 Test Method for Density, Relative Density (Specific Gravity), and Absorption of Coarse Aggregate

C136 Test Method for Sieve Analysis of Fine and Coarse Aggregates

C778 Specification for Sand

D422 Test Method for Particle-Size Analysis of Soils

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))

D854 Test Methods for Specific Gravity of Soil Solids by Water Pycnometer

D1140 Test Methods for Determining the Amount of Material Finer than 75-μm (No. 200) Sieve in Soils by Washing

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

D2216 Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass

D2487 Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)

D2488 Practice for Description and Identification of Soils (Visual-Manual Procedure)

D3282 Practice for Classification of Soils and Soil-Aggregate Mixtures for Highway Construction Purposes

D3740 Practice for Minimum Requirements for Agencies Engaged in Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction

D4220 Practices for Preserving and Transporting Soil Samples

D4253 Test Methods for Maximum Index Density and Unit Weight of Soils Using a Vibratory Table

D4254 Test Methods for Minimum Index Density and Unit Weight of Soils and Calculation of Relative Density

D4318 Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils

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

D6026 Practice for Using Significant Digits in Geotechnical Data

E11 Specification for Woven Wire Test Sieve Cloth and Test Sieves

E145 Specification for Gravity-Convection and Forced-Ventilation Ovens

IEEE/ASTM SI 10 Standard for Use of the International System of Units (SI): the Modern Metric System

2.2 *American Association of State Highway and Transportation Officials Standards:*[3]

M092-05-UL Standard Specification for Wire-Cloth Sieves for Testing Purposes

M145-91-UL Standard Specification for Classification of Soils and Soil-Aggregate Mixtures for Highway Construction Purposes

M231-95-UL Standard Specification for Weighing Devices Used in the Testing of Materials

3. Terminology

3.1 *Definitions:*

3.1.1 For definitions of terms used in this test method, refer to Terminology D653.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *granular soil, n*—any soil with less than 35 %, by dry mass, passing the No. 200 (75-μm) sieve.

3.2.2 *nonplastic, adj*—description for a soil sample when any one of the liquid limit, plastic limit, or plasticity index can not be determined.

3.2.3 *plastic, adj*—description for a soil sample when the liquid limit, plastic limit, and plasticity index can all be determined.

3.2.4 *water content range for effective compaction, n*—the range of water contents, expressed as a percentage, bounded by 80 % of w_{ZAV} and w_{ZAV}.

3.2.5 *zero air voids water content, w_{ZAV} , n*—the water content, expressed as a percentage, that corresponds to saturation at the maximum dry unit weight.

3.2.6 *oversize fraction (coarse fraction), P_c (%), n*—the portion of total sample not used in performing the compaction test; it is the portion of total sample retained the ¾-in. (19.0-mm) sieve.

3.2.7 *test fraction (finer fraction), P_f (%), n*—the portion of total sample used in performing the compaction test; it is the portion of total sample passing the ¾-in. (19.0-mm) sieve.

4. Summary of Test Method

4.1 The maximum dry unit weight and water content range for effective compaction of a given free-draining soil is determined using either an oven-dried or wet/saturated soil. Soil is placed in three layers into a mold of given dimensions.

[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.

[3] Available from American Association of State Highway and Transportation Officials (AASHTO), 444 N. Capitol St., NW, Suite 249, Washington, DC 20001, http://www.transportation.org.

Each layer is compacted for a given amount of time by a vibrating hammer that applies vibration and surcharge to the soil. The dry unit weight is calculated by dividing the oven-dried weight of the densified soil by the volume of the mold containing the soil. The water content range for effective compaction is determined from the maximum dry unit weight and the specific gravity of solids.

5. Significance and Use

5.1 For many cohesionless, free-draining soils, the maximum dry unit weight is one of the key components in evaluating the state of compactness of a given soil mass that is either naturally occurring or is constructed (fill).

5.2 Soil placed as an engineered fill is compacted to a dense state to obtain satisfactory engineering properties such as shear strength, compressibility, permeability, or combinations thereof. Also, foundation soils are often compacted to improve their engineering properties. Laboratory compaction tests provide the basis for determining the percent compaction and water content needed at the time of compaction to achieve the required engineering properties, and for controlling construction to assure that the required unit weights and water contents are achieved.

5.3 It is generally recognized that percent compaction is a good indicator of the state of compactness of a given soil mass. However, the engineering properties, such as strength, compressibility, and permeability of a given soil, compacted by various methods to a given state of compactness can vary considerably. Therefore, considerable engineering judgment must be used in relating the engineering properties of soil to the state of compactness.

5.4 Experience indicates that the construction control aspects discussed in 5.2 are extremely difficult to implement or yield erroneous results when dealing with certain soils. 5.4.1, 5.4.2, and 5.4.3 describe typical problem soils, the problems encountered when dealing with such soils, and possible solutions to these problems.

5.4.1 *Degradation*—Soils containing particles that degrade during compaction are a problem, especially when more degradation occurs during laboratory compaction than field compaction, as is typical. Degradation typically occurs during the compaction of a granular-residual soil or aggregate. When degradation occurs, the maximum dry unit weight increases[4] so that the laboratory maximum value is not representative of field conditions. Often, in these cases, the maximum dry unit weight is impossible to achieve in the field.

5.4.1.1 One method to design and control the compaction of such soils is to use a test fill to determine the required degree of compaction and the method to obtain that compaction, followed by the use of a method specification to control the compaction. Components of a method specification typically contain the type and size of compaction equipment to be used, the lift thickness, and the number of passes.

NOTE 4—Success in executing the compaction control of an earthwork project, especially when a method specification is used, is highly dependent upon the quality and experience of the "contractor" and "inspector."

5.4.2 *Gap Graded*—Gap-graded soils (soils containing many large particles with limited small particles) are a problem because the compacted soil will have larger voids than usual. To handle these large voids, standard test methods (laboratory or field) typically have to be modified using engineering judgment.

5.4.3 *Gravelly Soils Possessing Low Angularity and High Percentage of Fines*—Gravelly soils possessing low angularity and a high percentage of fines can lead to poor results for dry unit weight when using the wet/saturated method. However, when water contents at the time of compaction are near saturation with no free water, the dry unit weight achieved may result in a higher value than that from the dry method. Ultimately, during densification, the material may reach a saturated state. Therefore, for these soils, a water content of 1 or 2 % less than the w_{zav} for the density achieved by using the dry method is recommended. This is more of a concern for testing in the 11-in. mold than in the 6-in. mold.

5.5 An absolute maximum dry unit weight is not necessarily obtained by these test methods.

NOTE 5—The quality of the result produced by this standard is dependent on the competence of the personnel performing it, and the suitability of the equipment and facilities used. Agencies that meet the criteria of Practice D3740 are generally considered capable of competent and objective testing/sampling/inspection, and the like. Users of this standard are cautioned that compliance with Practice D3740 does not in itself assure reliable results. Reliable results depend on many factors; Practice D3740 provides a means of evaluating some of those factors.

6. Apparatus

6.1 *Vibrating Hammer*—The vibrating hammer used for this test should be one that is commercially available and provides reliable performance. The vibration hammer shall operate at a frequency of 3200 to 3500 beats per minute and the manufacturer's rated impact energy shall be in the range of 7 to 9 ft-lbf (9.5 to 12 m-N) and weigh 12 to 20 lbf (53 to 89 N), not including the weight of the tamper.

NOTE 6—It has been found that a Bosch model 11248EVS will provide the above specified characteristics. Other vibrating hammers also may provide satisfactory compaction and may be used if they meet the calibration required in Annex A2. Some characteristics of candidate hammers are shown in Table 1. Subcommittee D18.03 is open to identifying other makes and models that would meet these requirements.

TABLE 1 Characteristics of Candidate Vibratory Hammers

	Bosch 11248EVS	Bosch 11318EVS	Milwaukee 5327-21	Milwaukee 5336-22
Volts	120	120	120	120
Amps	11	11	11	13
Beats/min	1700-3300	1300-3300	3400	1300-3450
Hertz	28-55	22-55	57	22-58
Impact Energy (ft·lb)	7.4 (10 m·N)	8.8 (12 m·N)	7.9 (11 m·N)	8.6 (12 m·N)
Length (in.)	18 (46 cm)	17.75 (45 cm)	17.5 (44 cm)	18.5 (47 cm)
Weight (lb)	14.4 (64 N)	12.5 (56 N)	12.9 (57 N)	15 (67 N)

[4] Johnson, A. W., and Sallberg, J. R., Factors Influencing Compaction Test Results, Highway Research Board, Bulletin 318, Publication 967, National Academy of Sciences-National Research Council, Washington, DC, 1962, p. 73.

6.2 *Mold Assembly*—The molds shall be cylindrical in shape, made of rigid metal and be within the capacity and dimensions indicated in 6.2.1 or 6.2.2 and Figs. 1 and 2. See also Table 2. The walls of the mold may be solid, split, or tapered. The "split" type may consist of two half-round sections, or a section of pipe split along one element, which can be securely locked together to form a cylinder meeting the requirements of this section. The "tapered" type shall have an internal diameter taper that is uniform and not more than 0.200 in. per ft (16.7 mm per m) of mold height. Each mold shall have a base plate and an extension collar assembly, both made of rigid metal and constructed so they can be securely attached and easily detached from the mold. The extension collar assembly shall have a height extending above the top of the mold of at least 2.0 in. (50.8 mm) which may include an upper section that flares out to form a funnel provided there is at least a 0.75 in. (19.0-mm) straight cylindrical section beneath it. The extension collar shall align with the inside of the mold. The bottom of the base plate and bottom of the centrally recessed area that accepts the cylindrical mold shall be planar.

6.2.1 *Mold, 6 in.*—A mold having a 6.000 ± 0.026-in. (152.4 ± 0.7-mm) average inside diameter, a height of 4.584 ± 0.018 in. (116.4 ± 0.5 mm), and a volume of 0.075 ± 0.0009 ft^3 (2124 ± 25 cm^3). A mold assembly having the minimum required features is shown in Fig. 1.

6.2.2 *Mold, 11 in.*—A mold having a 11.000 ± 0.044-in. (279.4 ± 1.1-mm) average inside diameter, a height of 9.092 ± 0.018 in. (230.9 ± 0.5 mm), and a volume of 0.500 ± 0.005 ft^3 (14 200 ± 142 cm^3). A mold assembly having the minimum required features is shown in Fig. 2.

6.3 *Hammer Frame*—The hammer frame shall consist of a metal clamp assembly to firmly hold the vibrating hammer that moves on guide rods that allow for free vertical movement of the vibrating hammer and clamp assembly. The guide rods are fastened to a metal base in a manner to keep them vertical and parallel to each other. The frame shall be designed to securely hold the vibrating hammer and clamp assembly in an elevated position during insertion and removal of molds. Guides may be placed on the base of the frame to allow for proper alignment of molds underneath the tamper. The mass of the clamp assembly, vibrating hammer (6.1), and tamper (Fig. 3) shall be such to impart a surcharge of 2.5 to 5.0 psi (17 to 34 kPa) from the base of the tamper. The metal base dimensions in Fig. 4 provide sufficient mass and stiffness to support the compaction molds. This plate may be mounted on heavy duty casters or on a rigid table. A suitable design is shown in Figs. 4 and 5. See also Table 3.

6.4 *Sample Extruder (optional)*—A jack, frame, or other device adapted for the purpose of extruding compacted specimens from the mold.

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

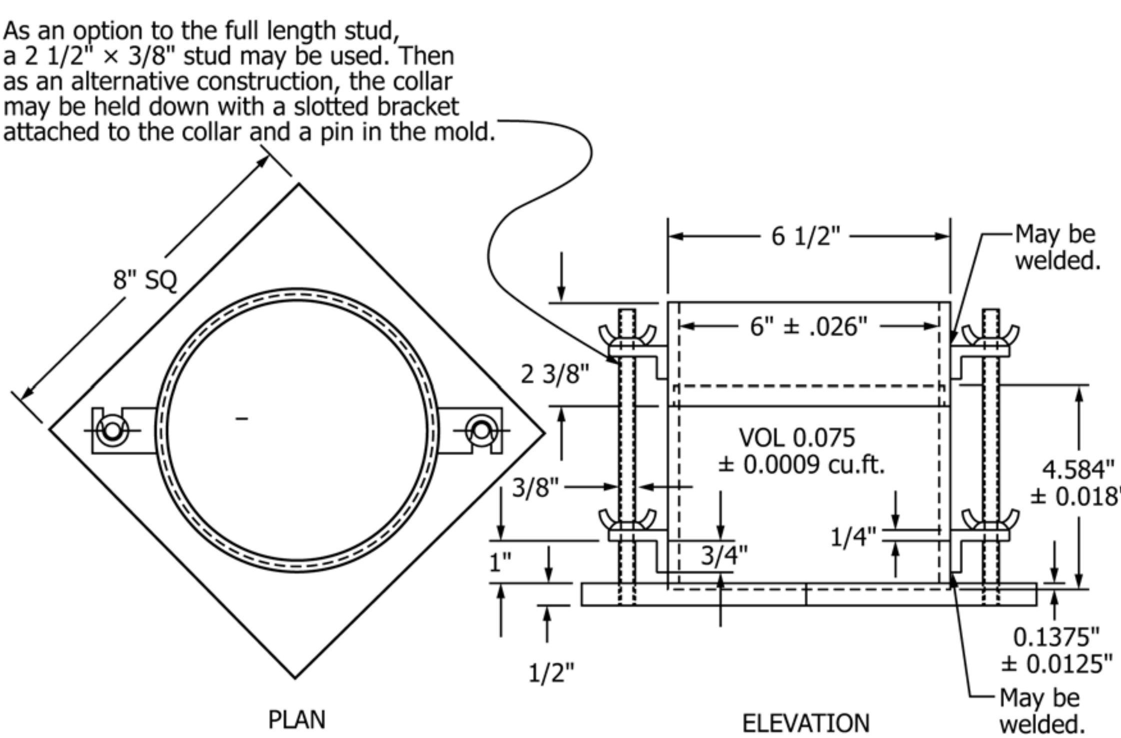
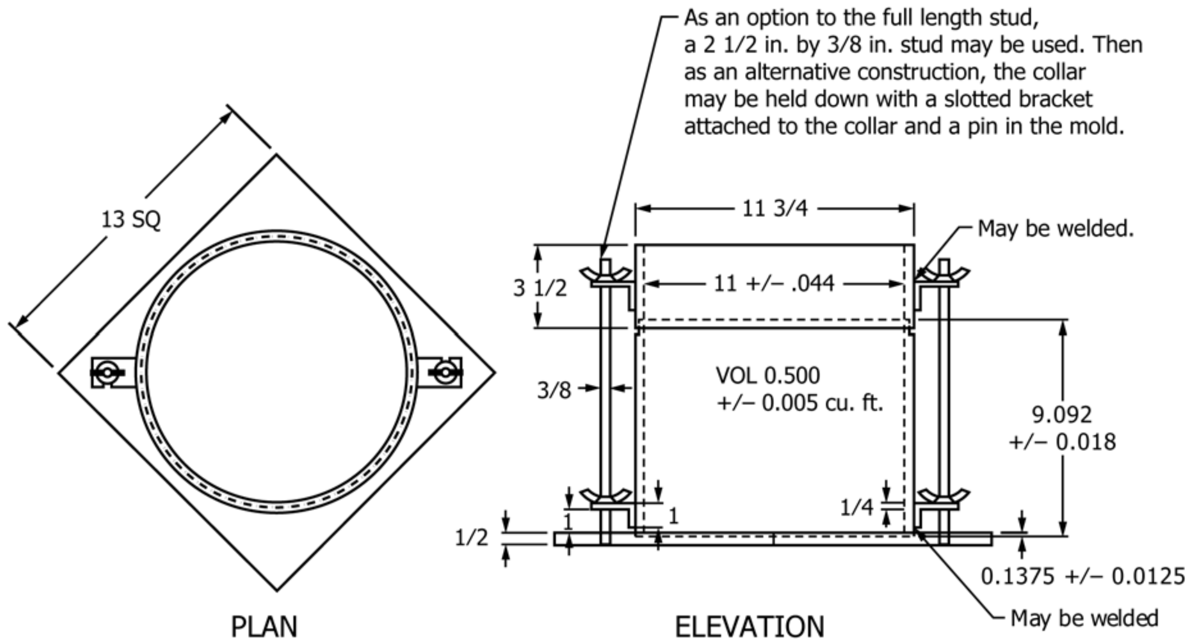


FIG. 1 6.0-in. Cylindrical Mold (see Table 2 for SI equivalent dimensions)



NOTE 1—All dimensions are in inches.

FIG. 2 11.0-in. Cylindrical Mold (see Table 2 for SI equivalent dimensions)

TABLE 2 SI Equivalents for Figs. 1-3

in.	mm	in.	mm	ft³	cm³
0.005	0.13	2⅜	60.33	0.0009	25
0.0125	0.32	3½	88.90	0.005	142
0.018	0.46	4.584	116.43	0.075	2124
0.026	0.66	5.750	146.05	0.500	14 200
0.044	1.12	6	152.40		
0.1375	3.49	6½	165.10		
¼	6.35	8	203.20		
⅜ and 0.375	9.53	9.092	230.94		
½	12.70	11	279.40		
¾	19.05	11¾	298.45		
1	25.40	13	330.20		

6.5.1 For 6-in. (152.4-mm) molds, use a balance of at least 30-lbm (15-kg) capacity and meeting the requirements of AASHTO M231-95-UL for Class G5 or Guide D4753 for Class GP 5 (readability of 1 g).

6.5.2 For 11-in. (279.4-mm) molds, use a balance having a minimum capacity of 125 lbm (60 kg) and meeting the requirements of AASHTO M231-95-UL for Class G100 (readability of 20 g) or Guide D4753 for Class GP 100 (readability of 50 g).

6.6 *Drying Oven*—Thermostatically controlled, preferably of a forced-draft type, meeting the requirements of Specification E145 and capable of maintaining a uniform temperature of 230 ± 9°F (110 ± 5°C) throughout the drying chamber.

6.7 *Straightedge*—A stiff metal straightedge of any convenient length, but not less than 4 in. (101.6 mm) longer than the diameter of the mold used. The total length of the straightedge shall be machined straight to a tolerance of ±0.005 in. (±0.1 mm). The scraping edge shall be beveled if it is thicker than ⅛ in. (3 mm).

6.8 *Sieves*—3-in. (75-mm), 1½-in. (37.5-mm), ¾-in. (19-mm), ⅜-in. (9.5-mm), No. 4 (4.75-mm), and No. 200 (75-µm) sieves conforming to the requirements of AASHTO M092-05-UL or Specification E11.

6.9 Other equipment such as mixing pans, a large metal scoop, a hair-bristled dusting brush, and a timing device indicating minutes and seconds.

NOTE 7—Modifications may be made to the vibrating hammer such as a mechanical device using pneumatic or electrical power to lift the vibrating hammer up and down as long as the device does not impede the free movement of the hammer during compaction. In addition, a timing device to directly control the vibrating hammer may be used; however, a power relay is usually needed to provide the power required to supply to the hammer.

7. Hazards

7.1 **Warning—**Use of vibrating hammers in certain acoustic environments may produce noise levels above those considered acceptable. Suitable hearing-protection devices shall be used in areas where such conditions are known to exist or where acoustic monitoring surveys have not been conducted. In addition, testing personnel should also adhere to any additional personal safety requirements in accordance with individual laboratory policies.

8. Sampling and Test Specimens

8.1 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.

8.2 Do not reuse soil that has been previously compacted in the laboratory.

8.3 The required dry specimen mass is approximately 15 lbm (7 kg) for Method A and 100 lbm (45 kg) for Method B. Therefore, the field sample should have a moist mass of at least 20 lbm (9 kg) for Method A and 125 lbm (57 kg) for Method B.

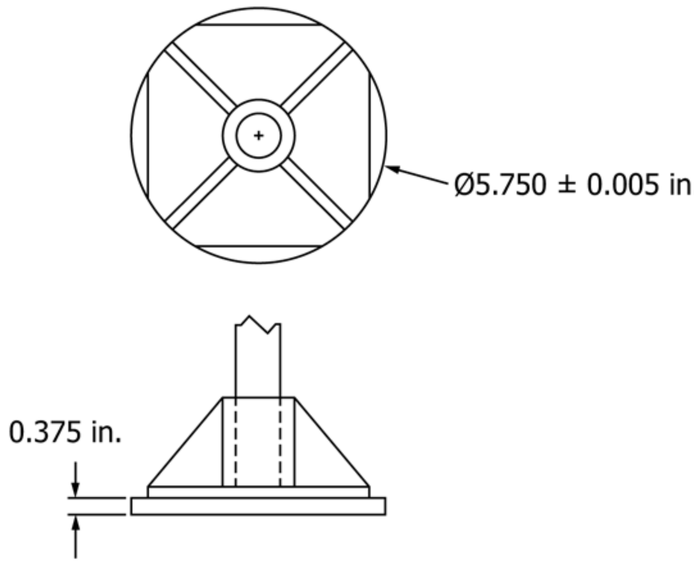
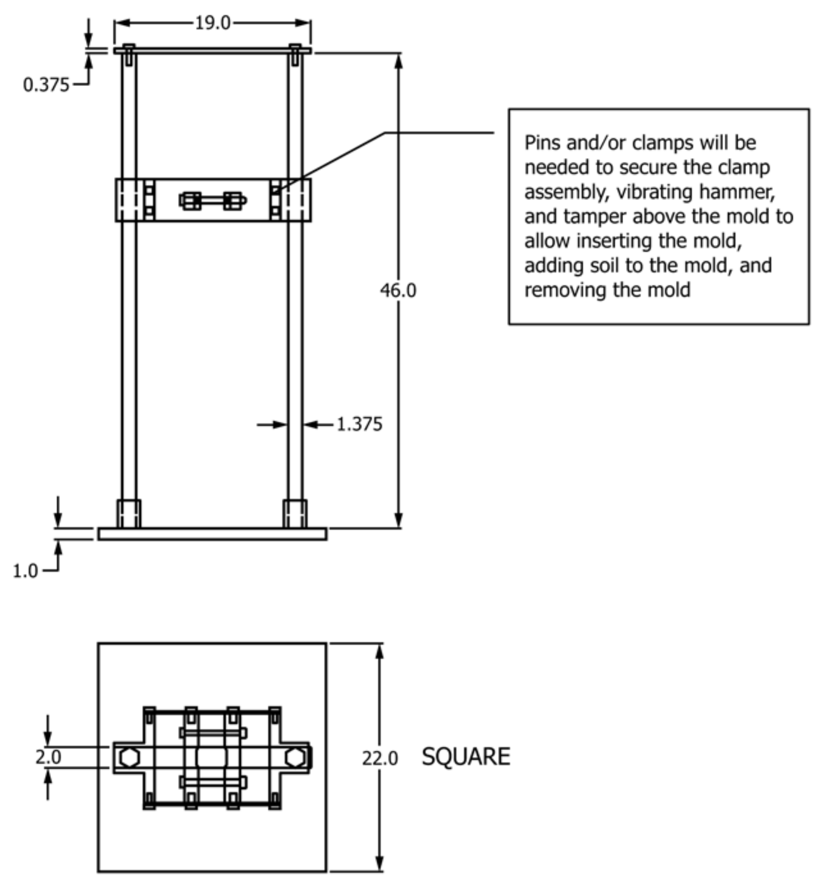


FIG. 3 6-in. Tamper (see Table 2 for SI equivalent dimensions)

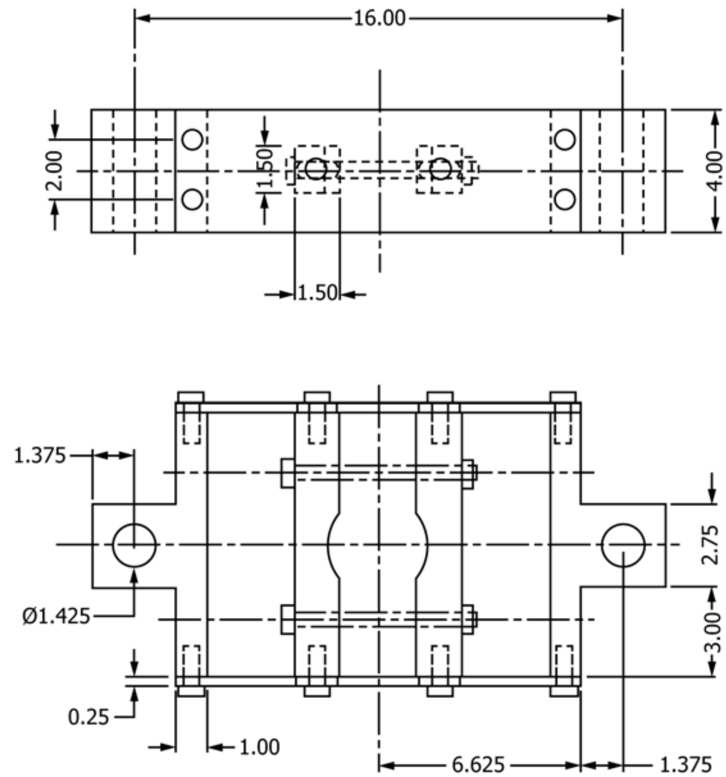


NOTE 1—All dimensions are in inches.

FIG. 4 Hammer Frame

8.4 Select a representative specimen of soil that meets the requirements of 8.3, using a splitter, riffle, or other method such as quartering.

8.5 If the dry method is being performed, dry the specimen in the drying oven, maintained at 230 ± 9°F (110 ± 5°C), to a constant mass. It is often desirable to obtain the water content



NOTE 1—All dimensions are in inches.

FIG. 5 Hammer Clamp Assembly

TABLE 3 SI Equivalents for Figs. 4 and 5

in.	mm
0.250	6.35
0.375	9.53
1.000	25.40
1.375	19.05
1.425	34.93
1.500	38.10
2.000	50.80
2.750	69.85
3.000	76.20
4.000	101.60
6.625	168.28
16.000	406.40
19.000	482.60
22.000	558.80
46.000	1168.40

of the field sample. If this is the case, determine the water content in accordance with Test Method D2216.

8.5.1 After drying, thoroughly break up the weakly cemented aggregations, avoiding the reduction of the natural size of the particles.

9. Preparation of Apparatus

9.1 Select the proper compaction mold in accordance with the Method (A or B) being used. Determine and record the mass of the mold and base plate. Assemble the mold, base plate, and extension collar. Check the alignment of the inner wall of the mold and mold extension collar.

9.2 Check that the vibrating hammer and the hammer frame are in good working condition and that parts are not loose or worn. Make any necessary service adjustments or repairs. If service adjustments or repairs are made to the vibrating hammer, the hammer must be recalibrated.

9.3 Insert the tamper foot into the chuck of the vibrating hammer and ensure a good connection.

9.4 If the vibrating hammer has variable settings, ensure that it is set to hammer mode (not rotating hammer mode) and is set at the highest operating frequency. The frequency must be within that specified in 6.1.

10. Calibration

10.1 Perform calibrations before initial use, after repairs or other occurrences that might affect the test results, at intervals not exceeding 500 test specimens, or annually, whichever occurs first, for the following apparatus:

10.1.1 *Balance*—Evaluate in accordance with AASHTO M231-95-UL or Guide D4753.

10.1.2 *Molds*—Determine the volume as described in Annex A1.

10.2 *Vibrating Hammer*—Verify that appropriate energy is applied to the soil as described in Annex A2.

11. Procedure

11.1 Mix the specimen to provide an even distribution of particle sizes and water content (for the wet/saturated method) with as little segregation as possible. The wet/saturated method may be conducted on either oven-dried soil to which sufficient water is added or, if preferred, on wet soil from the field. If water is added to dry soil, allow a minimum soaking period of about ½ h. The amount of water added should be sufficient enough that free water does not accumulate in the mixing pan, and the specimen will become basically saturated during the densification process.

NOTE 8—The wet method may require sealing of mold base of the mold to the base plate to reduce draining of water from specimen.

NOTE 9—The following equation can be used to estimate the amount of water required to be added to an oven-dried soil or, initially, try about 1000 mL for every 4.5 kg of dry soil.

$$M_w = M_s \cdot \left(\frac{\rho_w}{\rho_d} - \frac{1}{G_s} \right)$$

where:

M_w = mass of water in grams,
ρ_d = estimated dry density after initial placement in mold in Mg/m^3. This typically ranges between 1.6 and 1.9 Mg/m^3,
M_s = mass of test specimen in grams,
ρ_w = density of water, 1 Mg/m^3, and
G_s = specific gravity of soil solids.

11.2 Place sufficient soil into the mold such that it will occupy one third of the mold volume after compaction and spread the soil to a layer of uniform thickness. Position the mold on the base of the hammer frame and lower the vibrating hammer and clamp assembly so that the tamper is in uniform contact with the surface of the soil layer and does not bind against the mold wall. Vibrate the soil layer. For the wet/saturated method, after initial compaction of the soil layer, ensure that free water exists above the top of layer, but not an excessive amount. If additional water is needed, add a sufficient amount by squeezing from a sponge, pouring from a small container, or by other means.

11.2.1 For Method A, vibrate the soil layer for 60 ± 5 s.

11.2.2 For Method B, vibrate each soil layer in 8 locations in the sequence shown in Fig. 6 with vibration for 52 ± 5 s at each location.

11.3 Raise the vibrating hammer and clamp assembly and secure it in its elevated position. Scarify the surface of the compacted soil to ensure a good bond between soil layers.

11.4 Repeat 11.2 and 11.3 for the second and third soil layers, except that the surface of the third layer shall not be scarified.

11.5 Following compaction of the third layer, remove the collar from the mold. Verify that the surface of the compacted soil is above the top of the mold, but is not higher than 0.375 in. (10 mm) above the top of the mold. The specimen shall be discarded if the surface of the third layer extends more than 0.375 in. (10 mm) above the top of the mold or if any point on the surface is below the top of the mold.

11.6 Carefully trim the compacted specimen even with the top of the mold by means of the straightedge scraped across the top of the mold.

11.6.1 If large soil particles do not allow for a plane surface to be achieved at the top of the mold, fill in any holes in the top surface with unused or trimmed soil from the specimen, press in with the fingers, and again scrape the straightedge across the top of the mold.

11.6.2 Alternative to 11.6.1, an accurate specimen volume may be obtained by using the fingers to equate the volume of voids below the surface of the mold with the volume of compacted particles that protrude above the surface of the mold.

11.6.3 Use of a straightedge and/or the fingers may result in disturbance to the top of the specimen when large particles exist near the surface. It may be desirable to manually use a tamper or other object to return the surface material to a compacted state so that its relative position to the top of the mold can be properly observed.

11.7 For the oven-dried method, determine and record the mass of the specimen, mold, and base plate. For the wet/saturated method, if a determination of the specimen water content is desired, determine and record the mass of the soil, mold and base plate. Carefully remove the entire wet specimen from the mold, placing it in a pan of known mass for oven drying. Wash all particles clinging to the inside of the mold and base plate into the pan. Dry the specimen in a drying oven, maintained at 110 ± 5°C to a constant mass (Test Method

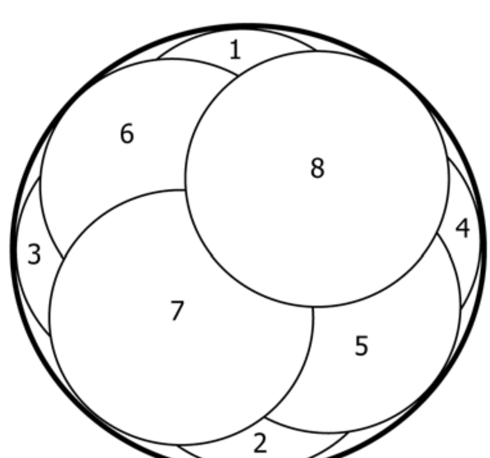


FIG. 6 Sequence of 6-in. Tamper Positions in 11-in. Mold

D2216). Determine and record its oven-dried mass, using a balance meeting the requirements of 6.6.

11.8 Steps 11.1 through 11.7 should be repeated on new specimens until the results of the tests for either the dry method or the wet/saturated method agree within 2 % of the values for each method.

12. Calculation

12.1 Calculate the dry density of the soil as follows:

$$\rho_d = \frac{M_s}{V} \quad (1)$$

where:

ρ_d = dry density of compacted specimen, lbm/ft^3 (kg/m^3),
M_s = mass of the tested-dry soil (either from dry or wet/saturated method), lbm (kg), and
V = volume of compaction mold, ft^3 (m^3) (see Annex A1).

12.2 Calculate the dry unit weight of the soil as follows:

$$\gamma_d \text{ in lbf/ft}^3 = \rho_d \text{ in lbm/ft}^3 \quad (2)$$

or

$$\gamma_d \text{ in kN/m}^3 = 9.807\ \rho_d \text{ in kg/m}^3 \quad (3)$$

12.2.1 If more than 5 % by weight of oversize material was removed from the sample, calculate the corrected dry unit weight of the total material using Practice D4718.

12.2.2 The maximum dry unit weight is the larger of the two values obtained from the dry method and the wet/saturated method. When replicate tests are performed, average values for the dry method and average values for the wet/saturated method may be used in this determination.

12.3 Calculate w_{ZAV} (see 3.2.5) as follows:

$$w_{ZAV} = \left(\frac{\gamma_w}{(\gamma_d)_{max}} - \frac{1}{G_s}\right) \cdot 100\,\% \quad (4)$$

where:

γ_w = unit weight of water, 62.32 lbf/ft^3 (9.789 kN/m^3) at 68°F (20°C), and
G_s = specific gravity of soil solids.

NOTE 10—Specific gravity of soil solids may be estimated for the test specimen on the basis of test data from other samples of the same soil classification and source. Otherwise, a specific gravity test (Test Method D854) is necessary.

12.4 Determine the water content range for effective compaction. The maximum value of this range is w_{ZAV} and the minimum value is 80 % of w_{ZAV}.

12.4.1 As an alternative to 12.3 and 12.4, the water content range for effective compaction may be determined from Table 4.

13. Report

13.1 The report shall include the following information:

13.1.1 Origin of material used in the test (project, location, depth).

13.1.2 Description of appearance of test specimen, based on AASHTO M145-91-UL, Practice D3282, or Practice D2488 (Practice D2487 may be used as an alternative).

13.1.3 Specific gravity and method of determination.

13.1.4 If the percent fines are greater than 15 %, method used to show that they were nonplastic.

13.1.5 Soil sieve data when applicable for determination of Method (A or B) used.

13.1.6 Method used (A or B and dry or wet/saturated).

13.1.7 Maximum dry unit weight, to the nearest 0.1 lbf/ft^3 (0.01 kN/m^3).

13.1.8 Water content range for effective compaction, to the nearest 0.1 %.

13.1.9 Oversize correction data, if used, including the oversize fraction (coarse fraction, P_c in percent).

13.1.10 Any abnormalities, such as loss of material, segregation, or degradation.

14. Precision and Bias

14.1 *Precision*—The repeatability standard deviation has been determined to be within 3.3 lbf/ft^3 (0.52 kN/m^3) for test results obtained under laboratory conditions with the same test method in the same laboratory by the same operator with the same equipment in the shortest practical period of time using test specimens taken at random from a single quantity of source material. The reproducibility standard deviation of this test method is being determined and will be available after project implementation studies have been completed.

14.2 *Bias*—There are no accepted reference values for this test method, therefore, bias cannot be determined.

TABLE 4 Water Content Range for Effective Compaction, Based on $(\gamma_d)_{max}$ and G_s

$(\gamma_d)_{max}$		Water Content Range for Effective Compaction					
		G_s = 2.65		G_s = 2.70		G_s = 2.75	
(lbf/ft^3)	(kN/m^3)	Min (%)	Max (%)	Min (%)	Max (%)	Min (%)	Max (%)
100	15.7	19.7	24.7	20.3	25.4	20.8	26.0
105	16.5	17.4	21.7	17.9	22.4	18.5	23.1
110	17.3	15.2	19.0	15.8	19.7	16.3	20.4
115	18.1	13.2	16.5	13.8	17.2	14.3	17.9
120	18.9	11.4	14.3	12.0	15.0	12.5	15.6
125	19.6	9.7	12.2	10.3	12.9	10.8	13.6
130	20.4	8.2	10.3	8.8	11.0	9.3	11.6
135	21.2	6.8	8.5	7.3	9.2	7.9	9.9
140	22.0	5.5	6.8	6.0	7.5	6.6	8.2
145	22.8	4.2	5.3	4.8	6.0	5.3	6.7
150	23.6	3.1	3.9	3.7	4.6	4.2	5.2

15. Keywords

15.1 density; granular soil; soil compaction; unit weight; vibrating hammer; water content

ANNEXES

(Mandatory Information)

A1. VOLUME OF COMPACTION MOLD

A1.1 Scope

A1.1.1 This annex describes the procedure for determining the volume of a compaction mold.

A1.1.2 The volume is determined by a water-filled method and checked by a linear-measurement method.

A1.2 Apparatus

A1.2.1 In addition to the apparatus listed in Section 6 the following items are required:

A1.2.1.1 *Vernier or Dial Caliper,* having a measuring range of at least 0 to 12 in. (0 to 300 mm) and readable to at least 0.001 in. (0.02 mm).

A1.2.1.2 *Inside Micrometer,* having a measuring range of at least 2 to 12 in. (50 to 300 mm) and readable to at least 0.001 in. (0.02 mm).

A1.2.1.3 *Plastic or Glass Plates*—A plastic or glass plate approximately 13 in. square by ¼ in. thick (330 by 330 by 6 mm).

A1.2.1.4 *Thermometric Device*—A thermometric device with a range covering 64 to 80°F (18 to 26°C), with a readability of 0.1°C (0.2°F),

A1.2.1.5 *Stopcock Grease,* or similar sealant.

A1.2.1.6 *Miscellaneous Equipment*—Bulb syringe, towels, etc.

A1.3 Precautions

A1.3.1 Perform this method in an area isolated from drafts or extreme temperature fluctuations.

A1.4 Procedure

A1.4.1 *Water-Filling Method:*

A1.4.1.1 Lightly grease the bottom of the compaction mold. Place the greased mold onto the base plate and secure with the locking studs. Lightly grease the top of the mold. Be careful not to get grease on the inside of the mold.

A1.4.1.2 Determine the mass of the greased mold, base plate, and the plastic or glass plate to be used on top of the mold to the nearest 0.01 lbm (1 g) and record.

A1.4.1.3 Place the mold and the base plate on a firm, level surface and fill the mold with water to slightly above its rim.

A1.4.1.4 Slide the plastic or glass plate over the top surface of the mold so that the mold remains completely filled with water and air bubbles are not entrapped. Add or remove water as necessary with a bulb syringe.

A1.4.1.5 Completely dry any excess water from the outside of the mold and plates.

A1.4.1.6 Determine the mass of the mold, plates, and water and record to the nearest 0.01 lbm (1 g).

A1.4.1.7 Determine the temperature of the water in the mold to the nearest 0.2°F (0.1°C) and record. Determine from Table A1.1 (by interpolation if needed) the absolute density of water and record.

A1.4.1.8 Calculate the mass of water in the mold by subtracting the mass determined in A1.4.1.2 from the mass determined in A1.4.1.6.

A1.4.1.9 Calculate the volume of water by dividing the mass of water by the density of water and record to the nearest 0.0001 ft ^{3} (1 cm^3).

A1.4.2 *Linear Measurement Method :*

A1.4.2.1 Using either the vernier caliper or the inside micrometer, measure the diameter of the mold six times at the top of the mold and six times at the bottom of the mold, spacing each of the six top and bottom measurements equally around the circumference of the mold. Record the values to the nearest 0.001 in. (0.02 mm).

A1.4.2.2 Using the vernier caliper, measure the inside height of the mold by making three measurements equally spaced around the circumference of the mold. Record values to the nearest 0.001 in. (0.02 mm).

A1.4.2.3 Calculate the average top diameter, average bottom diameter, and average height.

A1.4.2.4 Calculate the volume of the mold and record to the nearest 0.0001 ft^3 (1 cm^3) as follows:

$$V = \frac{(\pi)(h)(d_1 + d_b)^2}{(16)(1728)} \quad (\text{inch} - \text{pound}) \qquad (A1.1)$$

TABLE A1.1 Density of Water[A,B]

Temperature, °F (°C)	Density of Water, lbm/ft^3 (kg/m^3)
64.4 (18.0)	62.32 (998.59)
66.2 (19.0)	62.31 (998.41)
68.0 (20.0)	62.30 (998.21)
69.8 (21.0)	62.28 (998.00)
71.6 (22.0)	62.27 (997.78)
73.4 (23.0)	62.26 (997.55)
75.2 (24.0)	62.24 (997.31)
77.0 (25.0)	62.23 (997.06)
78.8 (26.0)	62.21 (996.80)

[A] Values other than shown may be obtained.
[B] *CRC Handbook of Chemistry and Physics*, 86th Edition, 2005-2006.

$$V = \frac{(\pi)(h)(d_1 + d_b)^2}{(16)(1000)} \quad \text{(SI)} \qquad (A1.2)$$

where:

V	=	volume of mold, ft^3 (cm^3),
h	=	average height, in. (mm),
d_t	=	average top diameter, in. (mm),
d_b	=	average bottom diameter, in. (mm),
1/1728	=	constant to convert in.^{3} to ft ^{3}, and
1/1000	=	constant to convert mm^3 to cm^3.

A1.5 Comparison of Results

A1.5.1 The volume obtained by either method should be within the volume tolerance requirements of 6.2.1 and 6.2.2.

A1.5.2 The difference between the two methods should not exceed 0.5 % of the nominal volume of the mold.

A1.5.3 Repeat the determination of volume if criteria in both A1.5.1 and A1.5.2 are not met.

A1.5.4 Failure to obtain satisfactory agreement between the two methods, even after several trials, is an indication that the mold is badly deformed and shall be replaced.

A1.5.5 Use the volume of the mold determined using the water-filling method as the assigned volume value for calculating the dry density (see 12.1).

A2. ENERGY OF VIBRATING HAMMER

A2.1 Scope

A2.1.1 This annex describes the procedure for determining if a vibrating hammer has sufficient energy to conform to this standard.

A2.1.2 A sample of standard sand is compacted following the standard procedure; the energy of the vibrating hammer is sufficient if a specified dry unit weight is achieved.

A2.2 Apparatus

A2.2.1 The apparatus used is identical to that found in Section 6.

A2.3 Precautions

A2.3.1 The precautions found in Section 7 apply to this annex.

A2.4 Procedure

A2.4.1 The standard sand tested shall conform to the requirements for 20-30 Sand, as found in Specification C778.

A2.4.2 Prepare the sand sample as described in Section 8.

A2.4.3 Prepare the apparatus as described in Section 9.

A2.4.4 Compact the standard sand following the procedures of Method A in Section 11.

A2.5 Calculation

A2.5.1 Determine the dry unit weight obtained as described in Section 12.

A2.6 Acceptance

A2.6.1 The energy of the vibrating hammer is sufficient if the calculated dry unit weight meets or exceeds 110.0 lbf/ft^3 (17.29 kN/m^3).

SUMMARY OF CHANGES

Committee D18 has identified the location of selected changes to this standard since the last issue (D7382 – 07) that may impact the use of this standard. (Approved Nov. 1, 2008.)

(1) Revised Section 6.3.