دانشگاه خوارزمی

دانشکده فنی و مهندسی

آزمایش های مکانیک خاک

(براساس استاندارد ASTM)

تهیه وتنظیم:

گروه مهندسی عمران

- این مجموعه در بر گیرنده آزمایش های پایه و تخصصی مهندسی خاک و پی بر اساس استانداردASTM می‌باشد

استاندارد آزمایش دانه بندی ASTM-D422-07

استاندارد آزمایش هیدرومتری ASTM-D421-07

استاندارد طبقه بندی خاک ASTM-D2487-11

استانداردآزمایش حدود اتربرگ ASTM-D4318-10

استاندارد آزمایش دانسیته برجا ASTM-D1556-07

استاندارد آزمایش ظرفیت باربری کالیفرنیا (CBR) ASTM-D1883-14

استانداردآزمایش تک محوری محدود نشده ASTM-D2166-13

استاندارد آزمایش تراکم ASTM-D698-12

استاندارد آزمایش تحکیم ASTM-D2435-11

استاندارد آزمایش برش مستقیم ASTM-D3080-11

استاندارد آزمایش برش سه محوری ASTM-D2850-03

استاندارد آزمایش هم ارز ماسه ASTM-D2419-14

استاندارد آزمایش تعیین چگالی ویژه توسط آب ASTM-D854-14

استاندارد آزمایش تعیین چگالی ویژه توسط گاز ASTM-D5550-14

استاندارد آزمایش بارگذاری صفحه (PLT) – بارگذاری تکراری ASTM-D1195-09

استاندارد آزمایش بارگذاری صفحه (PLT) – بارگذاری غیرتکراری ASTM-D1196-12

استاندارد آزمایش چگالی ماکزیمم γ_{max} ASTM-D4253-14

استاندارد آزمایش چگالی منیمم γ_{min} ASTM-D4254-14

استاندارد آزمایش چگالی ماکزیمم خشک–$\gamma_{d(max)}$ ASTM-D7382-08

استاندارد آزمایش دانه بندی

ASTM-D422-07

Designation: D422 – 63 (Reapproved 2007)$^{\varepsilon 1}$

Standard Test Method for Particle-Size Analysis of Soils[1]

This standard is issued under the fixed designation D422; 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.

ε^1 NOTE—Editorial changes made throughout in February 2014.

1. Scope

1.1 This test method covers the quantitative determination of the distribution of particle sizes in soils. The distribution of particle sizes larger than 75 µm (retained on the No. 200 sieve) is determined by sieving, while the distribution of particle sizes smaller than 75 µm is determined by a sedimentation process, using a hydrometer to secure the necessary data (Note 1 and Note 2).

NOTE 1—Separation may be made on the No. 4 (4.75-mm), No. 40 (425-µm), or No. 200 (75-µm) sieve instead of the No. 10. For whatever sieve used, the size shall be indicated in the report.

NOTE 2—Two types of dispersion devices are provided: (*1*) a high-speed mechanical stirrer, and (*2*) air dispersion. Extensive investigations indicate that air-dispersion devices produce a more positive dispersion of plastic soils below the 20-µm size and appreciably less degradation on all sizes when used with sandy soils. Because of the definite advantages favoring air dispersion, its use is recommended. The results from the two types of devices differ in magnitude, depending upon soil type, leading to marked differences in particle size distribution, especially for sizes finer than 20 µm.

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D421 Practice for Dry Preparation of Soil Samples for Particle-Size Analysis and Determination of Soil Constants

E11 Specification for Woven Wire Test Sieve Cloth and Test Sieves

E100 Specification for ASTM Hydrometers

2.2 *ASTM Adjuncts:*

Air-Jet Dispersion Cup for Grain-Size Analysis of Soil[3]

3. Apparatus

3.1 *Balances*—A balance sensitive to 0.01 g for weighing the material passing a No. 10 (2.00-mm) sieve, and a balance sensitive to 0.1 % of the mass of the sample to be weighed for weighing the material retained on a No. 10 sieve.

3.2 *Stirring Apparatus*—Either apparatus A or B may be used.

3.2.1 Apparatus A shall consist of a mechanically operated stirring device in which a suitably mounted electric motor turns a vertical shaft at a speed of not less than 10 000 rpm without load. The shaft shall be equipped with a replaceable stirring paddle made of metal, plastic, or hard rubber, as shown in Fig. 1. The shaft shall be of such length that the stirring paddle will operate not less than ¾ in. (19.0 mm) nor more than 1½ in. (38.1 mm) above the bottom of the dispersion cup. A special dispersion cup conforming to either of the designs shown in Fig. 2 shall be provided to hold the sample while it is being dispersed.

3.2.2 Apparatus B shall consist of an air-jet dispersion cup (see drawing [3]) (Note 3) conforming to the general details shown in Fig. 3 (Note 4 and Note 5).

NOTE 3—The amount of air required by an air-jet dispersion cup is of the order of 2 ft^3/min; some small air compressors are not capable of supplying sufficient air to operate a cup.

NOTE 4—Another air-type dispersion device, known as a dispersion tube, developed by Chu and Davidson at Iowa State College, has been shown to give results equivalent to those secured by the air-jet dispersion cups. When it is used, soaking of the sample can be done in the sedimentation cylinder, thus eliminating the need for transferring the slurry. When the air-dispersion tube is used, it shall be so indicated in the report.

NOTE 5—Water may condense in air lines when not in use. This water must be removed, either by using a water trap on the air line, or by blowing the water out of the line before using any of the air for dispersion purposes.

3.3 *Hydrometer*—An ASTM hydrometer, graduated to read in either specific gravity of the suspension or grams per litre of suspension, and conforming to the requirements for hydrometers 151H or 152H in Specifications E100. Dimensions of both hydrometers are the same, the scale being the only item of difference.

3.4 *Sedimentation Cylinder*—A glass cylinder essentially 18 in. (457 mm) in height and 2½ in. (63.5 mm) in diameter, and

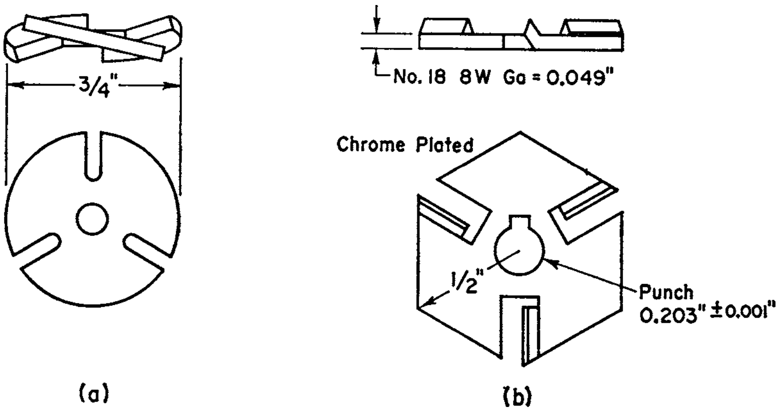
---

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

Current edition approved Oct. 15, 2007. Published October 2007. Originally approved in 1935. Last previous edition approved in 2002 as D422 – 63 (2002)$^{\varepsilon 1}$. DOI: 10.1520/D0422-63R07E01.

[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.

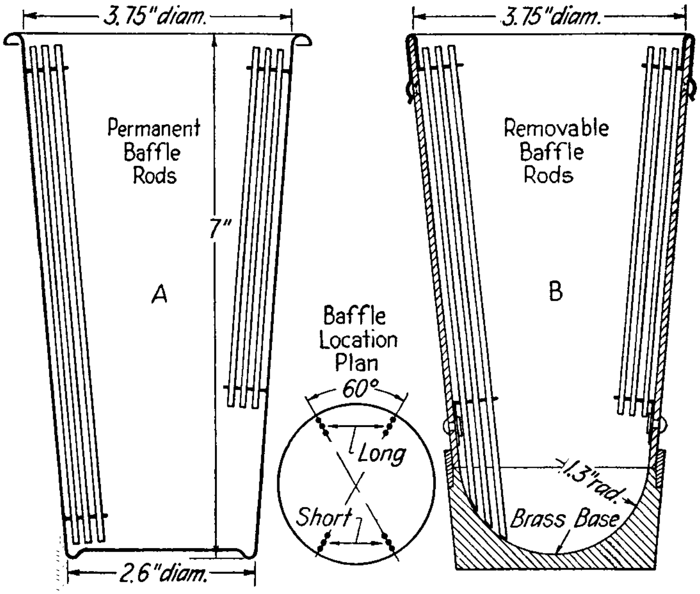
[3] Available from ASTM International Headquarters. Order Adjunct No. ADJD0422.



Metric Equivalents

in.	0.001	0.049	0.203	½	¾
mm	0.03	1.24	5.16	12.7	19.0

FIG. 1 Detail of Stirring Paddles



Metric Equivalents

in.	1.3	2.6	3.75
mm	33	66	95.2

FIG. 2 Dispersion Cups of Apparatus

marked for a volume of 1000 mL. The inside diameter shall be such that the 1000-mL mark is 36 ± 2 cm from the bottom on the inside.

3.5 *Thermometer*—A thermometer accurate to 1°F (0.5°C).

3.6 *Sieves*—A series of sieves, of square-mesh woven-wire cloth, conforming to the requirements of Specification E11. A full set of sieves includes the following (Note 6):

3-in. (75-mm)
2-in. (50-mm)
1½-in. (37.5-mm)
1-in. (25.0-mm)
¾-in. (19.0-mm)
⅜-in. (9.5-mm)
No. 4 (4.75-mm)
No. 10 (2.00-mm)
No. 20 (850-μm)
No. 40 (425-μm)
No. 60 (250-μm)
No. 140 (106-μm)
No. 200 (75-μm)

NOTE 6—A set of sieves giving uniform spacing of points for the graph, as required in Section 17, may be used if desired. This set consists of the following sieves:

3-in. (75-mm)
1½-in. (37.5-mm)
¾-in. (19.0-mm)
⅜-in. (9.5-mm)
No. 4 (4.75-mm)
No. 8 (2.36-mm)
No. 16 (1.18-mm)
No. 30 (600-μm)
No. 50 (300-μm)
No. 100 (150-μm)
No. 200 (75-μm)

3.7 *Water Bath or Constant-Temperature Room*—A water bath or constant-temperature room for maintaining the soil suspension at a constant temperature during the hydrometer analysis. A satisfactory water tank is an insulated tank that maintains the temperature of the suspension at a convenient constant temperature at or near 68°F (20°C). Such a device is illustrated in Fig. 4. In cases where the work is performed in a room at an automatically controlled constant temperature, the water bath is not necessary.

3.8 *Beaker*—A beaker of 250-mL capacity.

3.9 *Timing Device*—A watch or clock with a second hand.

4. Dispersing Agent

4.1 A solution of sodium hexametaphosphate (sometimes called sodium metaphosphate) shall be used in distilled or demineralized water, at the rate of 40 g of sodium hexametaphosphate/litre of solution (Note 7).

NOTE 7—Solutions of this salt, if acidic, slowly revert or hydrolyze back to the orthophosphate form with a resultant decrease in dispersive action. Solutions should be prepared frequently (at least once a month) or adjusted to pH of 8 or 9 by means of sodium carbonate. Bottles containing solutions should have the date of preparation marked on them.

4.2 All water used shall be either distilled or demineralized water. The water for a hydrometer test shall be brought to the temperature that is expected to prevail during the hydrometer test. For example, if the sedimentation cylinder is to be placed in the water bath, the distilled or demineralized water to be used shall be brought to the temperature of the controlled water bath; or, if the sedimentation cylinder is used in a room with controlled temperature, the water for the test shall be at the

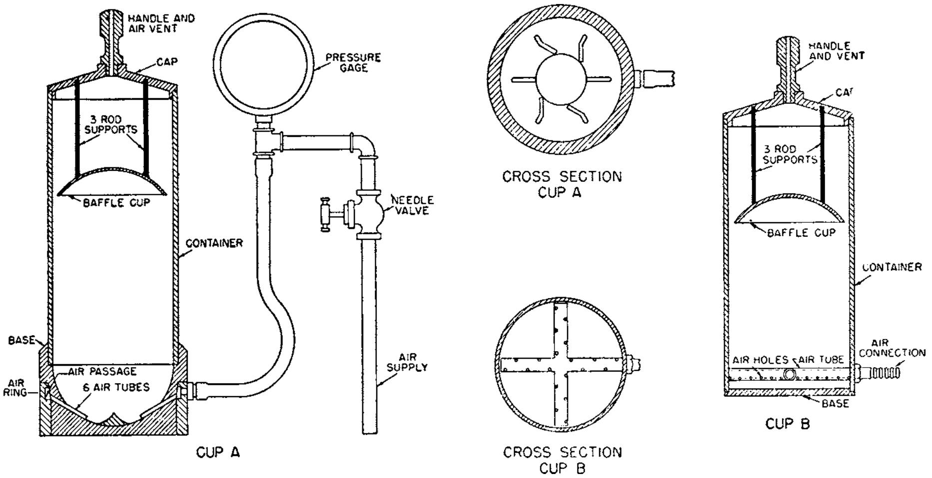
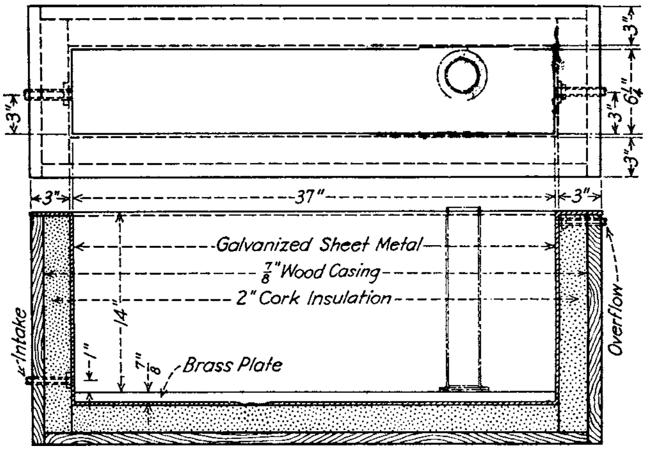


FIG. 3 Air-Jet Dispersion Cups of Apparatus B



Metric Equivalents

in.	⅞	1	3	6¼	14	37
mm	22.2	25.4	76.2	158.2	356	940

FIG. 4 Insulated Water Bath

temperature of the room. The basic temperature for the hydrometer test is 68°F (20°C). Small variations of temperature do not introduce differences that are of practical significance and do not prevent the use of corrections derived as prescribed.

5. Test Sample

5.1 Prepare the test sample for mechanical analysis as outlined in Practice D421. During the preparation procedure the sample is divided into two portions. One portion contains only particles retained on the No. 10 (2.00-mm) sieve while the other portion contains only particles passing the No. 10 sieve. The mass of air-dried soil selected for purpose of tests, as prescribed in Practice D421, shall be sufficient to yield quantities for mechanical analysis as follows:

5.1.1 The size of the portion retained on the No. 10 sieve shall depend on the maximum size of particle, according to the following schedule:

Nominal Diameter of Largest Particles, in. (mm)	Approximate Minimum Mass of Portion, g
⅜ (9.5)	500
¾ (19.0)	1000
1 (25.4)	2000
1½ (38.1)	3000
2 (50.8)	4000
3 (76.2)	5000

5.1.2 The size of the portion passing the No. 10 sieve shall be approximately 115 g for sandy soils and approximately 65 g for silt and clay soils.

5.2 Provision is made in Section 5 of Practice D421 for weighing of the air-dry soil selected for purpose of tests, the separation of the soil on the No. 10 sieve by dry-sieving and washing, and the weighing of the washed and dried fraction retained on the No. 10 sieve. From these two masses the percentages retained and passing the No. 10 sieve can be calculated in accordance with 12.1.

NOTE 8—A check on the mass values and the thoroughness of pulverization of the clods may be secured by weighing the portion passing the No. 10 sieve and adding this value to the mass of the washed and oven-dried portion retained on the No. 10 sieve.

SIEVE ANALYSIS OF PORTION RETAINED ON NO. 10 (2.00-mm) SIEVE

6. Procedure

6.1 Separate the portion retained on the No. 10 (2.00-mm) sieve into a series of fractions using the 3-in. (75-mm), 2-in. (50-mm), 1½-in. (37.5-mm), 1-in. (25.0-mm), ¾-in. (19.0-mm), ⅜-in. (9.5-mm), No. 4 (4.75-mm), and No. 10 sieves, or as many as may be needed depending on the sample, or upon the specifications for the material under test.

6.2 Conduct the sieving operation by means of a lateral and vertical motion of the sieve, accompanied by a jarring action in order to keep the sample moving continuously over the surface of the sieve. In no case turn or manipulate fragments in the sample through the sieve by hand. Continue sieving until not more than 1 mass % of the residue on a sieve passes that sieve during 1 min of sieving. When mechanical sieving is used, test the thoroughness of sieving by using the hand method of sieving as described above.

6.3 Determine the mass of each fraction on a balance conforming to the requirements of 3.1. At the end of weighing, the sum of the masses retained on all the sieves used should equal closely the original mass of the quantity sieved.

HYDROMETER AND SIEVE ANALYSIS OF PORTION PASSING THE NO. 10 (2.00-mm) SIEVE

7. Determination of Composite Correction for Hydrometer Reading

7.1 Equations for percentages of soil remaining in suspension, as given in 14.3, are based on the use of distilled or demineralized water. A dispersing agent is used in the water, however, and the specific gravity of the resulting liquid is appreciably greater than that of distilled or demineralized water.

7.1.1 Both soil hydrometers are calibrated at 68°F (20°C), and variations in temperature from this standard temperature produce inaccuracies in the actual hydrometer readings. The amount of the inaccuracy increases as the variation from the standard temperature increases.

7.1.2 Hydrometers are graduated by the manufacturer to be read at the bottom of the meniscus formed by the liquid on the stem. Since it is not possible to secure readings of soil suspensions at the bottom of the meniscus, readings must be taken at the top and a correction applied.

7.1.3 The net amount of the corrections for the three items enumerated is designated as the composite correction, and may be determined experimentally.

7.2 For convenience, a graph or table of composite corrections for a series of 1° temperature differences for the range of expected test temperatures may be prepared and used as needed. Measurement of the composite corrections may be made at two temperatures spanning the range of expected test temperatures, and corrections for the intermediate temperatures calculated assuming a straight-line relationship between the two observed values.

7.3 Prepare 1000 mL of liquid composed of distilled or demineralized water and dispersing agent in the same proportion as will prevail in the sedimentation (hydrometer) test. Place the liquid in a sedimentation cylinder and the cylinder in the constant-temperature water bath, set for one of the two temperatures to be used. When the temperature of the liquid becomes constant, insert the hydrometer, and, after a short interval to permit the hydrometer to come to the temperature of the liquid, read the hydrometer at the top of the meniscus formed on the stem. For hydrometer 151H the composite correction is the difference between this reading and one; for hydrometer 152H it is the difference between the reading and zero. Bring the liquid and the hydrometer to the other temperature to be used, and secure the composite correction as before.

8. Hygroscopic Moisture

8.1 When the sample is weighed for the hydrometer test, weigh out an auxiliary portion of from 10 to 15 g in a small metal or glass container, dry the sample to a constant mass in an oven at 230 ± 9°F (110 ± 5°C), and weigh again. Record the masses.

9. Dispersion of Soil Sample

9.1 When the soil is mostly of the clay and silt sizes, weigh out a sample of air-dry soil of approximately 50 g. When the soil is mostly sand the sample should be approximately 100 g.

9.2 Place the sample in the 250-mL beaker and cover with 125 mL of sodium hexametaphosphate solution (40 g/L). Stir until the soil is thoroughly wetted. Allow to soak for at least 16 h.

9.3 At the end of the soaking period, disperse the sample further, using either stirring apparatus A or B. If stirring apparatus A is used, transfer the soil-water slurry from the beaker into the special dispersion cup shown in Fig. 2, washing any residue from the beaker into the cup with distilled or demineralized water (Note 9). Add distilled or demineralized water, if necessary, so that the cup is more than half full. Stir for a period of 1 min.

NOTE 9—A large size syringe is a convenient device for handling the water in the washing operation. Other devices include the wash-water bottle and a hose with nozzle connected to a pressurized distilled water tank.

9.4 If stirring apparatus B (Fig. 3) is used, remove the cover cap and connect the cup to a compressed air supply by means of a rubber hose. A air gage must be on the line between the cup and the control valve. Open the control valve so that the gage indicates 1 psi (7 kPa) pressure (Note 10). Transfer the soil-water slurry from the beaker to the air-jet dispersion cup by washing with distilled or demineralized water. Add distilled or demineralized water, if necessary, so that the total volume in the cup is 250 mL, but no more.

NOTE 10—The initial air pressure of 1 psi is required to prevent the soil-water mixture from entering the air-jet chamber when the mixture is transferred to the dispersion cup.

9.5 Place the cover cap on the cup and open the air control valve until the gage pressure is 20 psi (140 kPa). Disperse the soil according to the following schedule:

Plasticity Index	Dispersion Period, min
Under 5	5
6 to 20	10
Over 20	15

Soils containing large percentages of mica need be dispersed for only 1 min. After the dispersion period, reduce the gage pressure to 1 psi preparatory to transfer of soil-water slurry to the sedimentation cylinder.

10. Hydrometer Test

10.1 Immediately after dispersion, transfer the soil-water slurry to the glass sedimentation cylinder, and add distilled or demineralized water until the total volume is 1000 mL.

10.2 Using the palm of the hand over the open end of the cylinder (or a rubber stopper in the open end), turn the cylinder upside down and back for a period of 1 min to complete the agitation of the slurry (Note 11). At the end of 1 min set the cylinder in a convenient location and take hydrometer readings at the following intervals of time (measured from the beginning of sedimentation), or as many as may be needed, depending on the sample or the specification for the material under test: 2, 5, 15, 30, 60, 250, and 1440 min. If the controlled water bath is used, the sedimentation cylinder should be placed in the bath between the 2- and 5-min readings.

NOTE 11—The number of turns during this minute should be approximately 60, counting the turn upside down and back as two turns. Any soil remaining in the bottom of the cylinder during the first few turns should be loosened by vigorous shaking of the cylinder while it is in the inverted position.

10.3 When it is desired to take a hydrometer reading, carefully insert the hydrometer about 20 to 25 s before the reading is due to approximately the depth it will have when the reading is taken. As soon as the reading is taken, carefully remove the hydrometer and place it with a spinning motion in a graduate of clean distilled or demineralized water.

NOTE 12—It is important to remove the hydrometer immediately after each reading. Readings shall be taken at the top of the meniscus formed by the suspension around the stem, since it is not possible to secure readings at the bottom of the meniscus.

10.4 After each reading, take the temperature of the suspension by inserting the thermometer into the suspension.

11. Sieve Analysis

11.1 After taking the final hydrometer reading, transfer the suspension to a No. 200 (75-µm) sieve and wash with tap water until the wash water is clear. Transfer the material on the No. 200 sieve to a suitable container, dry in an oven at 230 ± 9°F (110 ± 5°C) and make a sieve analysis of the portion retained, using as many sieves as desired, or required for the material, or upon the specification of the material under test.

CALCULATIONS AND REPORT

12. Sieve Analysis Values for the Portion Coarser than the No. 10 (2.00-mm) Sieve

12.1 Calculate the percentage passing the No. 10 sieve by dividing the mass passing the No. 10 sieve by the mass of soil originally split on the No. 10 sieve, and multiplying the result by 100. To obtain the mass passing the No. 10 sieve, subtract the mass retained on the No. 10 sieve from the original mass.

12.2 To secure the total mass of soil passing the No. 4 (4.75-mm) sieve, add to the mass of the material passing the No. 10 sieve the mass of the fraction passing the No. 4 sieve and retained on the No. 10 sieve. To secure the total mass of soil passing the ⅜-in. (9.5-mm) sieve, add to the total mass of soil passing the No. 4 sieve, the mass of the fraction passing the ⅜-in. sieve and retained on the No. 4 sieve. For the remaining sieves, continue the calculations in the same manner.

12.3 To determine the total percentage passing for each sieve, divide the total mass passing (see 12.2) by the total mass of sample and multiply the result by 100.

13. Hygroscopic Moisture Correction Factor

13.1 The hydroscopic moisture correction factor is the ratio between the mass of the oven-dried sample and the air-dry mass before drying. It is a number less than one, except when there is no hygroscopic moisture.

14. Percentages of Soil in Suspension

14.1 Calculate the oven-dry mass of soil used in the hydrometer analysis by multiplying the air-dry mass by the hygroscopic moisture correction factor.

14.2 Calculate the mass of a total sample represented by the mass of soil used in the hydrometer test, by dividing the oven-dry mass used by the percentage passing the No. 10 (2.00-mm) sieve, and multiplying the result by 100. This value is the weight W in the equation for percentage remaining in suspension.

14.3 The percentage of soil remaining in suspension at the level at which the hydrometer is measuring the density of the suspension may be calculated as follows (Note 13): For hydrometer 151H:

$$P = \left[(100\,000/W) \times G/(G - G_1)\right](R - G_1) \tag{1}$$

NOTE 13—The bracketed portion of the equation for hydrometer 151H is constant for a series of readings and may be calculated first and then multiplied by the portion in the parentheses.

For hydrometer 152H:

TABLE 1 Values of Correction Factor, α, for Different Specific Gravities of Soil Particles[A]

Specific Gravity	Correction Factor[A]
2.95	0.94
2.90	0.95
2.85	0.96
2.80	0.97
2.75	0.98
2.70	0.99
2.65	1.00
2.60	1.01
2.55	1.02
2.50	1.03
2.45	1.05

[A] For use in equation for percentage of soil remaining in suspension when using Hydrometer 152H.

$$P = (Ra/W) \times 100 \tag{2}$$

where:

a = correction faction to be applied to the reading of hydrometer 152H. (Values shown on the scale are computed using a specific gravity of 2.65. Correction factors are given in Table 1),

P = percentage of soil remaining in suspension at the level at which the hydrometer measures the density of the suspension,

R = hydrometer reading with composite correction applied (Section 7),

W = oven-dry mass of soil in a total test sample represented by mass of soil dispersed (see 14.2), g,

G = specific gravity of the soil particles, and

G_1 = specific gravity of the liquid in which soil particles are suspended. Use numerical value of one in both instances in the equation. In the first instance any possible variation produces no significant effect, and in the second instance, the composite correction for R is based on a value of one for G_1.

15. Diameter of Soil Particles

15.1 The diameter of a particle corresponding to the percentage indicated by a given hydrometer reading shall be calculated according to Stokes' law (Note 14), on the basis that a particle of this diameter was at the surface of the suspension at the beginning of sedimentation and had settled to the level at which the hydrometer is measuring the density of the suspension. According to Stokes' law (see Table 2):

$$D = \sqrt{[30n/980(G - G_1)] \times L/T} \tag{3}$$

where:

D = diameter of particle, mm,

n = coefficient of viscosity of the suspending medium (in this case water) in poises (varies with changes in temperature of the suspending medium),

L = distance from the surface of the suspension to the level at which the density of the suspension is being measured, cm. (For a given hydrometer and sedimentation cylinder, values vary according to the hydrometer readings. This distance is known as effective depth (see Table 2)),

T = interval of time from beginning of sedimentation to the taking of the reading, min,

G = specific gravity of soil particles, and

G_1 = specific gravity (relative density) of suspending medium (value may be used as 1.000 for all practical purposes).

NOTE 14—Since Stokes' law considers the terminal velocity of a single sphere falling in an infinity of liquid, the sizes calculated represent the diameter of spheres that would fall at the same rate as the soil particles.

15.2 For convenience in calculations the above equation may be written as follows (see Table 3):

$$D = K\sqrt{L/T} \tag{5}$$

where:

K = constant depending on the temperature of the suspension and the specific gravity of the soil particles. Values of K for a range of temperatures and specific gravities are given in Table 3. The value of K does not change for a series of readings constituting a test, while values of L and T do vary.

15.3 Values of D may be computed with sufficient accuracy, using an ordinary 10-in. slide rule.

NOTE 15—The value of L is divided by T using the *A*- and *B*-scales, the square root being indicated on the *D*-scale. Without ascertaining the value of the square root it may be multiplied by K, using either the *C*- or *CI*-scale.

16. Sieve Analysis Values for Portion Finer than No. 10 (2.00-mm) Sieve

16.1 Calculation of percentages passing the various sieves used in sieving the portion of the sample from the hydrometer test involves several steps. The first step is to calculate the mass of the fraction that would have been retained on the No. 10 sieve had it not been removed. This mass is equal to the total percentage retained on the No. 10 sieve (100 minus total percentage passing) times the mass of the total sample represented by the mass of soil used (as calculated in 14.2), and the result divided by 100.

TABLE 2 Values of Effective Depth Based on Hydrometer and Sedimentation Cylinder of Specified Sizes[A]

Hydrometer 151H		Hydrometer 152H			
Actual Hydrometer Reading	Effective Depth, *L*, cm	Actual Hydrometer Reading	Effective Depth, *L*, cm	Actual Hydrometer Reading	Effective Depth, *L*, cm
1.000	16.3	0	16.3	31	11.2
1.001	16.0	1	16.1	32	11.1
1.002	15.8	2	16.0	33	10.9
1.003	15.5	3	15.8	34	10.7
1.004	15.2	4	15.6	35	10.6
1.005	15.0	5	15.5		
1.006	14.7	6	15.3	36	10.4
1.007	14.4	7	15.2	37	10.2
1.008	14.2	8	15.0	38	10.1
1.009	13.9	9	14.8	39	9.9
1.010	13.7	10	14.7	40	9.7
1.011	13.4	11	14.5	41	9.6
1.012	13.1	12	14.3	42	9.4
1.013	12.9	13	14.2	43	9.2
1.014	12.6	14	14.0	44	9.1
1.015	12.3	15	13.8	45	8.9
1.016	12.1	16	13.7	46	8.8
1.017	11.8	17	13.5	47	8.6
1.018	11.5	18	13.3	48	8.4
1.019	11.3	19	13.2	49	8.3
1.020	11.0	20	13.0	50	8.1
1.021	10.7	21	12.9	51	7.9
1.022	10.5	22	12.7	52	7.8
1.023	10.2	23	12.5	53	7.6
1.024	10.0	24	12.4	54	7.4
1.025	9.7	25	12.2	55	7.3
1.026	9.4	26	12.0	56	7.1
1.027	9.2	27	11.9	57	7.0
1.028	8.9	28	11.7	58	6.8
1.029	8.6	29	11.5	59	6.6
1.030	8.4	30	11.4	60	6.5
1.031	8.1				
1.032	7.8				
1.033	7.6				
1.034	7.3				
1.035	7.0				
1.036	6.8				
1.037	6.5				
1.038	6.2				

[A] Values of effective depth are calculated from the equation:

$$L = L_1 + 1/2\,[L_2 - (V_B/A)] \qquad (4)$$

where:

L = effective depth, cm,

L_1 = distance along the stem of the hydrometer from the top of the bulb to the mark for a hydrometer reading, cm,

L_2 = overall length of the hydrometer bulb, cm,

V_B = volume of hydrometer bulb, cm^3, and

A = cross-sectional area of sedimentation cylinder, cm^2

Values used in calculating the values in Table 2 are as follows:
For both hydrometers, 151H and 152H:

L_2 = 14.0 cm

V_B = 67.0 cm^3

A = 27.8 cm^2

For hydrometer 151H:

L_1 = 10.5 cm for a reading of 1.000
= 2.3 cm for a reading of 1.031

For hydrometer 152H:

L_1 = 10.5 cm for a reading of 0 g/litre
= 2.3 cm for a reading of 50 g/litre

16.2 Calculate next the total mass passing the No. 200 sieve. Add together the fractional masses retained on all the sieves, including the No. 10 sieve, and subtract this sum from the mass of the total sample (as calculated in 14.2).

16.3 Calculate next the total masses passing each of the other sieves, in a manner similar to that given in 12.2.

16.4 Calculate last the total percentages passing by dividing the total mass passing (as calculated in 16.3) by the total mass of sample (as calculated in 14.2), and multiply the result by 100.

17. Graph

17.1 When the hydrometer analysis is performed, a graph of the test results shall be made, plotting the diameters of the particles on a logarithmic scale as the abscissa and the percentages smaller than the corresponding diameters to an arithmetic scale as the ordinate. When the hydrometer analysis is not made on a portion of the soil, the preparation of the graph is optional, since values may be secured directly from tabulated data.

18. Report

18.1 The report shall include the following:

18.1.1 Maximum size of particles,

18.1.2 Percentage passing (or retained on) each sieve, which may be tabulated or presented by plotting on a graph (Note 16),

18.1.3 Description of sand and gravel particles:

18.1.3.1 Shape—rounded or angular,

18.1.3.2 Hardness—hard and durable, soft, or weathered and friable,

18.1.4 Specific gravity, if unusually high or low,

18.1.5 Any difficulty in dispersing the fraction passing the No. 10 (2.00-mm) sieve, indicating any change in type and amount of dispersing agent, and

18.1.6 The dispersion device used and the length of the dispersion period.

NOTE 16—This tabulation of graph represents the gradation of the sample tested. If particles larger than those contained in the sample were removed before testing, the report shall so state giving the amount and maximum size.

18.2 For materials tested for compliance with definite specifications, the fractions called for in such specifications shall be reported. The fractions smaller than the No. 10 sieve shall be read from the graph.

18.3 For materials for which compliance with definite specifications is not indicated and when the soil is composed almost entirely of particles passing the No. 4 (4.75-mm) sieve, the results read from the graph may be reported as follows:

(*1*) Gravel, passing 3-in. and retained on No. 4 sieve . . . %
(*2*) Sand, passing No. 4 sieve and retained on No. 200 sieve . . . %
    (*a*) Coarse sand, passing No. 4 sieve and retained on No. 10 sieve . . . %
    (*b*) Medium sand, passing No. 10 sieve and retained on No. 40 sieve . . . %
    (*c*) Fine sand, passing No. 40 sieve and retained on No. 200 sieve . . . %
(*3*) Silt size, 0.074 to 0.005 mm . . . %
(*4*) Clay size, smaller than 0.005 mm . . . %
    Colloids, smaller than 0.001 mm . . . %

18.4 For materials for which compliance with definite specifications is not indicated and when the soil contains material retained on the No. 4 sieve sufficient to require a sieve analysis on that portion, the results may be reported as follows (Note 17):

TABLE 3 Values of K for Use in Equation for Computing Diameter of Particle in Hydrometer Analysis

Temperature, °C	Specific Gravity of Soil Particles								
	2.45	2.50	2.55	2.60	2.65	2.70	2.75	2.80	2.85
16	0.01530	0.01505	0.01481	0.01457	0.01435	0.01414	0.01394	0.01374	0.01356
17	0.01511	0.01486	0.01462	0.01439	0.01417	0.01396	0.01376	0.01356	0.01338
18	0.01492	0.01467	0.01443	0.01421	0.01399	0.01378	0.01359	0.01339	0.01321
19	0.01474	0.01449	0.01425	0.01403	0.01382	0.01361	0.01342	0.1323	0.01305
20	0.01456	0.01431	0.01408	0.01386	0.01365	0.01344	0.01325	0.01307	0.01289
21	0.01438	0.01414	0.01391	0.01369	0.01348	0.01328	0.01309	0.01291	0.01273
22	0.01421	0.01397	0.01374	0.01353	0.01332	0.01312	0.01294	0.01276	0.01258
23	0.01404	0.01381	0.01358	0.01337	0.01317	0.01297	0.01279	0.01261	0.01243
24	0.01388	0.01365	0.01342	0.01321	0.01301	0.01282	0.01264	0.01246	0.01229
25	0.01372	0.01349	0.01327	0.01306	0.01286	0.01267	0.01249	0.01232	0.01215
26	0.01357	0.01334	0.01312	0.01291	0.01272	0.01253	0.01235	0.01218	0.01201
27	0.01342	0.01319	0.01297	0.01277	0.01258	0.01239	0.01221	0.01204	0.01188
28	0.01327	0.01304	0.01283	0.01264	0.01244	0.01255	0.01208	0.01191	0.01175
29	0.01312	0.01290	0.01269	0.01249	0.01230	0.01212	0.01195	0.01178	0.01162
30	0.01298	0.01276	0.01256	0.01236	0.01217	0.01199	0.01182	0.01165	0.01149

SIEVE ANALYSIS

Sieve Size	Percentage Passing
3-in.	. . . .
2-in.	. . . .
1½-in.	. . . .
1-in.	. . . .
¾-in.	. . . .
⅜-in.	. . . .
No. 4 (4.75-mm)	. . . .
No. 10 (2.00-mm)	. . . .
No. 40 (425-µm)	. . . .
No. 200 (75-µm)	. . . .

HYDROMETER ANALYSIS

0.074 mm	. . . .
0.005 mm	. . . .
0.001 mm	. . . .

NOTE 17—No. 8 (2.36-mm) and No. 50 (300-µm) sieves may be substituted for No. 10 and No. 40 sieves.

19. Keywords

19.1 grain-size; hydrometer analysis; hygroscopic moisture; particle-size; sieve analysis

استاندارد آزمایش هیدرومتری

ASTM-D421-07

Designation: D421 – 85 (Reapproved 2007)

Standard Practice for
Dry Preparation of Soil Samples for Particle-Size Analysis and Determination of Soil Constants[1]

This standard is issued under the fixed designation D421; 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 Department of Defense.

1. Scope

1.1 This practice covers the dry preparation of soil samples as received from the field for particle-size analysis and the determination of the soil constants.

1.2 *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]

D2217 Practice for Wet Preparation of Soil Samples for Particle-Size Analysis and Determination of Soil Constants

E11 Specification for Woven Wire Test Sieve Cloth and Test Sieves

3. Significance and Use

3.1 This practice can be used to prepare samples for particle-size and plasticity tests where it is desired to determine test values on air-dried samples, or where it is known that air drying does not have an effect on test results relative to samples prepared in accordance with Practice D2217.

4. Apparatus

4.1 *Balance,* sensitive to 0.1 g.

4.2 *Mortar and Rubber-Covered Pestle* , suitable for breaking up the aggregations of soil particles.

4.3 *Sieves*—A series of sieves, of square mesh woven wire cloth, conforming to Specification E11. The sieves required are as follows:

No. 4 (4.75-mm)
No. 10 (2.00-mm)
No. 40 (425-μm)

4.4 *Sampler*—A riffle sampler or sample splitter, for quartering the samples.

5. Sampling

5.1 Expose the soil sample as received from the field to the air at room temperature until dried thoroughly. Break up the aggregations thoroughly in the mortar with a rubber-covered pestle. Select a representative sample of the amount required to perform the desired tests by the method of quartering or by the use of a sampler. The amounts of material required to perform the individual tests are as follows:

5.1.1 *Particle-Size Analysis*—For the particle-size analysis, material passing a No. 10 (2.00-mm) sieve is required in amounts equal to 115 g of sandy soils and 65 g of either silt or clay soils.

5.1.2 *Tests for Soil Constants*—For the tests for soil constants, material passing the No. 40 (425-μm) sieve is required in total amount of 220 g, allocated as follows:

Test	Grams
Liquid limit	100
Plastic limit	15
Centrifuge moisture equivalent	10
Volumetric shrinkage	30
Check tests	65

6. Preparation of Test Sample

6.1 Select that portion of the air-dried sample selected for purpose of tests and record the mass as the mass of the total test sample uncorrected for hygroscopic moisture. Separate the test sample by sieving with a No. 10 (2.00-mm) sieve. Grind that fraction retained on the No. 10 sieve in a mortar with a rubber-covered pestle until the aggregations of soil particles are broken up into the separate grains. Then separate the ground soil into two fractions by sieving with a No. 10 sieve.

6.2 Wash that fraction retained after the second sieving free of all fine material, dry, and weigh. Record this mass as the

---

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

Current edition approved Sept. 1, 2007. Published September 2007. Originally approved in 1935. Last previous edition approved in 2002 as D421 – 85 (2002). DOI: 10.1520/D0421-85R07.

[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.

mass of coarse material. Sieve the coarse material, after being washed and dried, on the No. 4 (4.75-mm) sieve and record the mass retained on the No. 4 sieve.

7. Test Sample for Particle-Size Analysis

7.1 Thoroughly mix together the fractions passing the No. 10 (2.00-mm) sieve in both sieving operations, and by the method of quartering or the use of a sampler, select a portion weighing approximately 115 g for sandy soils and approximately 65 g for silt and clay soil for particle-size analysis.

8. Test Sample for Soil Constants

8.1 Separate the remaining portion of the material passing the No. 10 (2.00-mm) sieve into two parts by means of a No. 40 (425-µm) sieve. Discard the fraction retained on the No. 40 sieve. Use the fraction passing the No. 40 sieve for the determination of the soil constants.

9. Keywords

9.1 dry preparation; particle-size analysis; soil

استاندارد طبقه بندی خاک

ASTM-D2487-11

Designation: D2487 – 11

Standard Practice for
Classification of Soils for Engineering Purposes (Unified Soil Classification System)[1]

This standard is issued under the fixed designation D2487; 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 Department of Defense.

1. Scope*

1.1 This practice describes a system for classifying mineral and organo-mineral soils for engineering purposes based on laboratory determination of particle-size characteristics, liquid limit, and plasticity index and shall be used when precise classification is required.

NOTE 1—Use of this standard will result in a single classification group symbol and group name except when a soil contains 5 to 12 % fines or when the plot of the liquid limit and plasticity index values falls into the crosshatched area of the plasticity chart. In these two cases, a dual symbol is used, for example, GP-GM, CL-ML. When the laboratory test results indicate that the soil is close to another soil classification group, the borderline condition can be indicated with two symbols separated by a slash. The first symbol should be the one based on this standard, for example, CL/CH, GM/SM, SC/CL. Borderline symbols are particularly useful when the liquid limit value of clayey soils is close to 50. These soils can have expansive characteristics and the use of a borderline symbol (CL/CH, CH/CL) will alert the user of the assigned classifications of expansive potential.

1.2 The group symbol portion of this system is based on laboratory tests performed on the portion of a soil sample passing the 3-in. (75-mm) sieve (see Specification E11).

1.3 As a classification system, this standard is limited to naturally occurring soils.

NOTE 2—The group names and symbols used in this test method may be used as a descriptive system applied to such materials as shale, claystone, shells, crushed rock, etc. See Appendix X2.

1.4 This standard is for qualitative application only.

NOTE 3—When quantitative information is required for detailed designs of important structures, this test method must be supplemented by laboratory tests or other quantitative data to determine performance characteristics under expected field conditions.

1.5 This standard is the ASTM version of the Unified Soil Classification System. The basis for the classification scheme is the Airfield Classification System developed by A. Casagrande in the early 1940s.[2] It became known as the Unified Soil Classification System when several U.S. Government Agencies adopted a modified version of the Airfield System in 1952.

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.*

1.7 *This practice offers a set of instructions for performing one or more specific operations. This document cannot replace education or experience and should be used in conjunction with professional judgment. Not all aspects of this practice may be applicable in all circumstances. This ASTM standard is not intended to represent or replace the standard of care by which the adequacy of a given professional service must be judged, nor should this document be applied without consideration of a project's many unique aspects. The word "Standard" in the title of this document means only that the document has been approved through the ASTM consensus process.*

2. Referenced Documents

2.1 *ASTM Standards:*[3]

C117 Test Method for Materials Finer than 75-µm (No. 200) Sieve in Mineral Aggregates by Washing
C136 Test Method for Sieve Analysis of Fine and Coarse Aggregates
C702 Practice for Reducing Samples of Aggregate to Testing Size
D420 Guide to Site Characterization for Engineering Design and Construction Purposes
D422 Test Method for Particle-Size Analysis of Soils
D653 Terminology Relating to Soil, Rock, and Contained Fluids
D1140 Test Methods for Amount of Material in Soils Finer

---

[1] This practice is under the jurisdiction of ASTM Committee D18 on Soil and Rock and is the direct responsibility of Subcommittee D18.07 on Identification and Classification of Soils.

Current edition approved May 1, 2011. Published June 2011. Originally approved in 1966. Last previous edition approved in 2010 as D2487–10. DOI: 10.1520/D2487-11.

[2] Casagrande, A., "Classification and Identification of Soils," *Transactions,* ASCE, 1948 , p. 901.

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

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

than No. 200 (75-µm) Sieve

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

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

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

D4083 Practice for Description of Frozen Soils (Visual-Manual Procedure)

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

D4427 Classification of Peat Samples by Laboratory Testing

D6913 Test Methods for Particle-Size Distribution (Gradation) of Soils Using Sieve Analysis

E11 Specification for Woven Wire Test Sieve Cloth and Test Sieves

3. Terminology

3.1 *Definitions*—Except as listed below, all definitions are in accordance with Terminology D653.

NOTE 4—For particles retained on a 3-in. (75-mm) U.S. standard sieve, the following definitions are suggested:

Cobbles—particles of rock that will pass a 12-in. (300-mm) square opening and be retained on a 3-in. (75-mm) U.S. standard sieve, and

Boulders—particles of rock that will not pass a 12-in. (300-mm) square opening.

3.1.1 *clay*—soil passing a No. 200 (75-µm) U.S. standard sieve that can be made to exhibit plasticity (putty-like properties) within a range of water contents and that exhibits considerable strength when air dry. For classification, a clay is a fine-grained soil, or the fine-grained portion of a soil, with a plasticity index equal to or greater than 4, and the plot of plasticity index versus liquid limit falls on or above the "A" line.

3.1.2 *gravel*—particles of rock that will pass a 3-in. (75-mm) sieve and be retained on a No. 4 (4.75-mm) U.S. standard sieve with the following subdivisions:

Coarse—passes 3-in. (75-mm) sieve and retained on ¾-in. (19-mm) sieve, and

Fine—passes ¾-in. (19-mm) sieve and retained on No. 4 (4.75-mm) sieve.

3.1.3 *organic clay*—a clay with sufficient organic content to influence the soil properties. For classification, an organic clay is a soil that would be classified as a clay except that its liquid limit value after oven drying is less than 75 % of its liquid limit value before oven drying.

3.1.4 *organic silt*—a silt with sufficient organic content to influence the soil properties. For classification, an organic silt is a soil that would be classified as a silt except that its liquid limit value after oven drying is less than 75 % of its liquid limit value before oven drying.

3.1.5 *peat*—a soil composed of vegetable tissue in various stages of decomposition usually with an organic odor, a dark-brown to black color, a spongy consistency, and a texture ranging from fibrous to amorphous.

3.1.6 *sand*—particles of rock that will pass a No. 4 (4.75-mm) sieve and be retained on a No. 200 (75-µm) U.S. standard sieve with the following subdivisions:

Coarse—passes No. 4 (4.75-mm) sieve and retained on No. 10 (2.00-mm) sieve,

Medium—passes No. 10 (2.00-mm) sieve and retained on No. 40 (425-µm) sieve, and

Fine—passes No. 40 (425-µm) sieve and retained on No. 200 (75-µm) sieve.

3.1.7 *silt*—soil passing a No. 200 (75-µm) U.S. standard sieve that is nonplastic or very slightly plastic and that exhibits little or no strength when air dry. For classification, a silt is a fine-grained soil, or the fine-grained portion of a soil, with a plasticity index less than 4 or if the plot of plasticity index versus liquid limit falls below the "A" line.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *coefficient of curvature, Cc*—the ratio $(D_{30})^2/(D_{10} \times D_{60})$, where D_{60}, D_{30}, and D_{10} are the particle sizes corresponding to 60, 30, and 10 % finer on the cumulative particle-size distribution curve, respectively.

3.2.2 *coefficient of uniformity, Cu*—the ratio D_{60}/D_{10}, where D_{60} and D_{10} are the particle diameters corresponding to 60 and 10 % finer on the cumulative particle-size distribution curve, respectively.

4. Summary

4.1 As illustrated in Table 1, this classification system identifies three major soil divisions: coarse-grained soils, fine-grained soils, and highly organic soils. These three divisions are further subdivided into a total of 15 basic soil groups.

4.2 Based on the results of visual observations and prescribed laboratory tests, a soil is catalogued according to the basic soil groups, assigned a group symbol(s) and name, and thereby classified. The flow charts, Fig. 1 for fine-grained soils, and Fig. 3 for coarse-grained soils, can be used to assign the appropriate group symbol(s) and name.

5. Significance and Use

5.1 This standard classifies soils from any geographic location into categories representing the results of prescribed laboratory tests to determine the particle-size characteristics, the liquid limit, and the plasticity index.

5.2 The assigning of a group name and symbol(s) along with the descriptive information required in Practice D2488 can be used to describe a soil to aid in the evaluation of its significant properties for engineering use.

5.3 The various groupings of this classification system have been devised to correlate in a general way with the engineering behavior of soils. This standard provides a useful first step in any field or laboratory investigation for geotechnical engineering purposes.

5.4 This standard may also be used as an aid in training personnel in the use of Practice D2488.

5.5 This standard may be used in combination with Practice D4083 when working with frozen soils.

NOTE 5—Notwithstanding the statements on precision and bias contained in this standard: The precision of this test method 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

TABLE 1 Soil Classification Chart

Criteria for Assigning Group Symbols and Group Names Using Laboratory Tests[A]				Soil Classification	
				Group Symbol	Group Name[B]
COARSE-GRAINED SOILS More than 50 % retained on No. 200 sieve	Gravels (More than 50 % of coarse fraction retained on No. 4 sieve)	Clean Gravels (Less than 5 % fines[C])	$Cu \geq 4$ and $1 \leq Cc \leq 3$[D]	GW	Well-graded gravel[E]
			$Cu < 4$ and/or $[Cc < 1$ or $Cc > 3]$[D]	GP	Poorly graded gravel[E]
		Gravels with Fines (More than 12 % fines[C])	Fines classify as ML or MH	GM	Silty gravel[E,F,G]
			Fines classify as CL or CH	GC	Clayey gravel[E,F,G]
	Sands (50 % or more of coarse fraction passes No. 4 sieve)	Clean Sands (Less than 5 % fines[H])	$Cu \geq 6$ and $1 \leq Cc \leq 3$[D]	SW	Well-graded sand[I]
			$Cu < 6$ and/or $[Cc < 1$ or $Cc > 3]$[D]	SP	Poorly graded sand[I]
		Sands with Fines (More than 12 % fines[H])	Fines classify as ML or MH	SM	Silty sand[F,G,I]
			Fines classify as CL or CH	SC	Clayey sand[F,G,I]
FINE-GRAINED SOILS 50 % or more passes the No. 200 sieve	Silts and Clays Liquid limit less than 50	inorganic	PI > 7 and plots on or above "A" line[J]	CL	Lean clay[K,L,M]
			PI < 4 or plots below "A" line[J]	ML	Silt[K,L,M]
		organic	$\frac{\text{Liquid limit -- oven dried}}{\text{Liquid limit -- not dried}} < 0.75$	OL	Organic clay[K,L,M,N] Organic silt[K,L,M,O]
	Silts and Clays Liquid limit 50 or more	inorganic	PI plots on or above "A" line	CH	Fat clay[K,L,M]
			PI plots below "A" line	MH	Elastic silt[K,L,M]
		organic	$\frac{\text{Liquid limit -- oven dried}}{\text{Liquid limit -- not dried}} < 0.75$	OH	Organic clay[K,L,M,P] Organic silt[K,L,M,Q]
HIGHLY ORGANIC SOILS	Primarily organic matter, dark in color, and organic odor			PT	Peat

[A] Based on the material passing the 3-in. (75-mm) sieve.

[B] If field sample contained cobbles or boulders, or both, add "with cobbles or boulders, or both" to group name.

[C] Gravels with 5 to 12 % fines require dual symbols:
GW-GM well-graded gravel with silt
GW-GC well-graded gravel with clay
GP-GM poorly graded gravel with silt
GP-GC poorly graded gravel with clay

[D] $Cu = D_{60}/D_{10} \qquad Cc = \frac{(D_{30})^2}{D_{10} \times D_{60}}$

[E] If soil contains ≥15 % sand, add "with sand" to group name.

[F] If fines classify as CL-ML, use dual symbol GC-GM, or SC-SM.

[G] If fines are organic, add "with organic fines" to group name.

[H] Sands with 5 to 12 % fines require dual symbols:
SW-SM well-graded sand with silt
SW-SC well-graded sand with clay
SP-SM poorly graded sand with silt
SP-SC poorly graded sand with clay

[I] If soil contains ≥15 % gravel, add "with gravel" to group name.

[J] If Atterberg limits plot in hatched area, soil is a CL-ML, silty clay.

[K] If soil contains 15 to <30 % plus No. 200, add "with sand" or "with gravel," whichever is predominant.

[L] If soil contains ≥30 % plus No. 200, predominantly sand, add "sand " to group name.

[M] If soil contains ≥30 % plus No. 200, predominantly gravel, add "gravelly" to group name.

[N] PI ≥ 4 and plots on or above "A" line.

[O] PI < 4 or plots below "A" line.

[P] PI plots on or above "A" line.

[Q] PI plots below "A" line.

D3740 are generally considered capable of competent and objective testing. Users of this test method are cautioned that compliance with Practice D3740 does not in itself assure reliable testing. Reliable testing depends on several factors; Practice D3740 provides a means for evaluating some of those factors.

6. Apparatus

6.1 In addition to the apparatus that may be required for obtaining and preparing the samples and conducting the prescribed laboratory tests, a plasticity chart, similar to Fig. 4, and a cumulative particle-size distribution curve, similar to Fig. 5, are required.

NOTE 6—The "U" line shown on Fig. 4 has been empirically determined to be the approximate "upper limit" for natural soils. It is a good check against erroneous data, and any test results that plot above or to the left of it should be verified.

7. Sampling

7.1 Samples shall be obtained and identified in accordance with a method or methods, recommended in Guide D420 or by other accepted procedures.

7.2 Test Methods D6913 provides guidance on selecting size of specimen. Two test methods are provided in this standard. The methods differ in the significant digits recorded

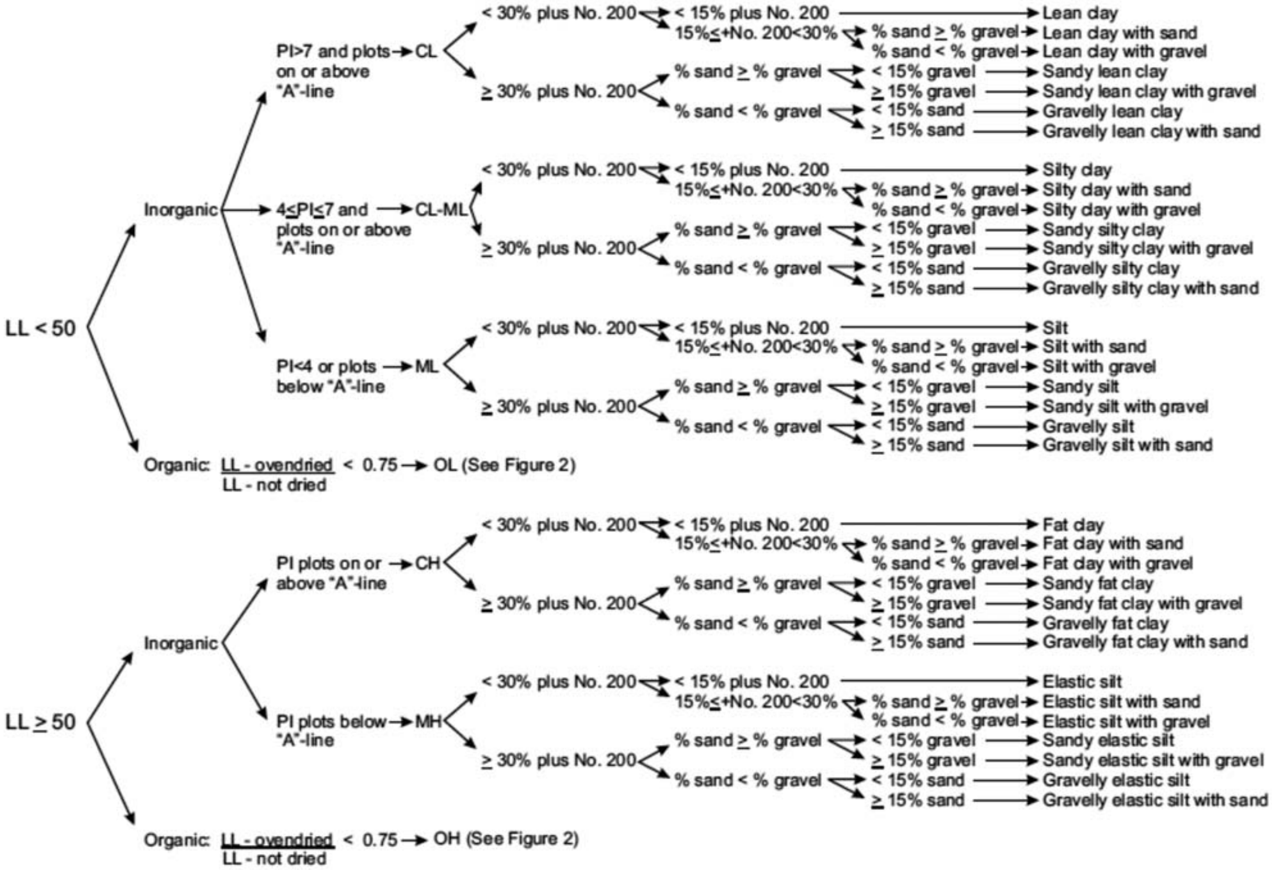


FIG. 1 Flow Chart for Classifying Fine-Grained Soil (50 % or More Passes No. 200 Sieve)

and the size of the specimen (mass) required. The method to be used may be specified by the requesting authority; otherwise Method A shall be performed. Whenever possible, the field samples should have weights two to four times larger than shown.

7.3 If the field sample or test specimen is smaller than the minimum recommended amount, the report shall include an appropriate remark.

8. Classification of Peat

8.1 A sample composed primarily of vegetable tissue in various stages of decomposition and has a fibrous to amorphous texture, a dark-brown to black color, and an organic odor should be designated as a highly organic soil and shall be classified as peat, PT, and not subjected to the classification procedures described hereafter.

8.2 If desired, classification of type of peat can be performed in accordance with Classification D4427.

9. Preparation for Classification

9.1 Before a soil can be classified according to this standard, generally the particle-size distribution of the minus 3-in. (75-mm) material and the plasticity characteristics of the minus No. 40 (425-μm) sieve material must be determined. See 9.8 for the specific required tests.

9.2 The preparation of the soil specimen(s) and the testing for particle-size distribution and liquid limit and plasticity index shall be in accordance with accepted standard procedures. Two procedures for preparation of the soil specimens for testing for soil classification purposes are given in Appendixes X3 and X4. Appendix X3 describes the wet preparation method and is the preferred method for cohesive soils that have never dried out and for organic soils.

9.3 When reporting soil classifications determined by this standard, the preparation and test procedures used shall be reported or referenced.

9.4 Although the test procedure used in determining the particle-size distribution or other considerations may require a hydrometer analysis of the material, a hydrometer analysis is not necessary for soil classification.

9.5 The percentage (by dry weight) of any plus 3-in. (75-mm) material must be determined and reported as auxiliary information.

9.6 The maximum particle size shall be determined (measured or estimated) and reported as auxiliary information.

9.7 When the cumulative particle-size distribution is required, a set of sieves shall be used which include the following sizes (with the largest size commensurate with the maximum particle size) with other sieve sizes as needed or required to define the particle-size distribution:

3-in. (75-mm)
¾-in. (19.0-mm)
No. 4 (4.75-mm)
No. 10 (2.00-mm)
No. 40 (425-μm)

No. 200 (75-µm)

9.8 The tests required to be performed in preparation for classification are as follows:

9.8.1 For soils estimated to contain less than 5 % fines, a plot of the cumulative particle-size distribution curve of the fraction coarser than the No. 200 (75-µm) sieve is required. A semi-log plot of percent passing versus partical-size or sieve size/sieve number is plotted as shown in Fig. 5.

9.8.2 For soils estimated to contain 5 to 15 % fines, a cumulative particle-size distribution curve, as described in 9.8.1, is required, and the liquid limit and plasticity index are required.

9.8.2.1 If sufficient material is not available to determine the liquid limit and plasticity index, the fines should be estimated to be either silty or clayey using the procedures described in Practice D2488 and so noted in the report.

9.8.3 For soils estimated to contain 15 % or more fines, a determination of the percent fines, percent sand, and percent gravel is required, and the liquid limit and plasticity index are required. For soils estimated to contain 90 % fines or more, the percent fines, percent sand, and percent gravel may be estimated using the procedures described in Practice D2488 and so noted in the report.

10. Preliminary Classification Procedure

10.1 Class the soil as fine-grained if 50 % or more by dry weight of the test specimen passes the No. 200 (75-µm) sieve and follow Section 3.1.2.

10.2 Class the soil as coarse-grained if more than 50 % by dry weight of the test specimen is retained on the No. 200 (75-µm) sieve and follow Section 12.

11. Procedure for Classification of Fine-Grained Soils (50 % or more by dry weight passing the No. 200 (75-µm) sieve)

11.1 The soil is an inorganic clay if the position of the plasticity index versus liquid limit plot, Fig. 4, falls on or above the "A" line, the plasticity index is greater than 4, and the presence of organic matter does not influence the liquid limit as determined in 11.3.2.

NOTE 7—The plasticity index and liquid limit are determined on the minus No. 40 (425 µm) sieve material.

11.1.1 Classify the soil as a *lean clay,* CL, if the liquid limit is less than 50. See area identified as CL on Fig. 4.

11.1.2 Classify the soil as a *fat clay,* CH, if the liquid limit is 50 or greater. See area identified as CH on Fig. 4.

NOTE 8—In cases where the liquid limit exceeds 110 or the plasticity index exceeds 60, the plasticity chart may be expanded by maintaining the same scale on both axes and extending the "A" line at the indicated slope.

11.1.3 Classify the soil as a *silty clay,* CL-ML, if the position of the plasticity index versus liquid limit plot falls on or above the "A" line and the plasticity index is in the range of 4 to 7. See area identified as CL-ML on Fig. 4.

11.2 The soil is an inorganic silt if the position of the plasticity index versus liquid limit plot, Fig. 4, falls below the "A" line or the plasticity index is less than 4, and presence of organic matter does not influence the liquid limit as determined in 11.3.2.

11.2.1 Classify the soil as a *silt,* ML, if the liquid limit is less than 50. See area identified as ML on Fig. 4.

11.2.2 Classify the soil as an *elastic silt,* MH, if the liquid limit is 50 or greater. See area identified as MH on Fig. 4.

11.3 The soil is an organic silt or clay if organic matter is present in sufficient amounts to influence the liquid limit as determined in 11.3.2.

11.3.1 If the soil has a dark color and an organic odor when moist and warm, a second liquid limit test shall be performed on a test specimen which has been oven dried at 110 ± 5°C to a constant weight, typically over night.

11.3.2 The soil is an organic silt or organic clay if the liquid limit after oven drying is less than 75 % of the liquid limit of the original specimen determined before oven drying.

11.3.3 Classify the soil as an *organic silt* or *organic clay,* OL, if the liquid limit (not oven dried) is less than 50 %. Classify the soil as an *organic silt,* OL, if the plasticity index is less than 4, or the position of the plasticity index versus liquid limit plot falls below the "A" line. Classify the soil as an *organic clay,* OL, if the plasticity index is 4 or greater and the position of the plasticity index versus liquid limit plot falls on or above the "A" line. See area identified as OL (or CL-ML) on Fig. 4.

11.3.4 Classify the soil as an *organic clay* or *organic silt,* OH, if the liquid limit (not oven dried) is 50 or greater. Classify the soil as an *organic silt,* OH, if the position of the plasticity index versus liquid limit plot falls below the "A" line. Classify

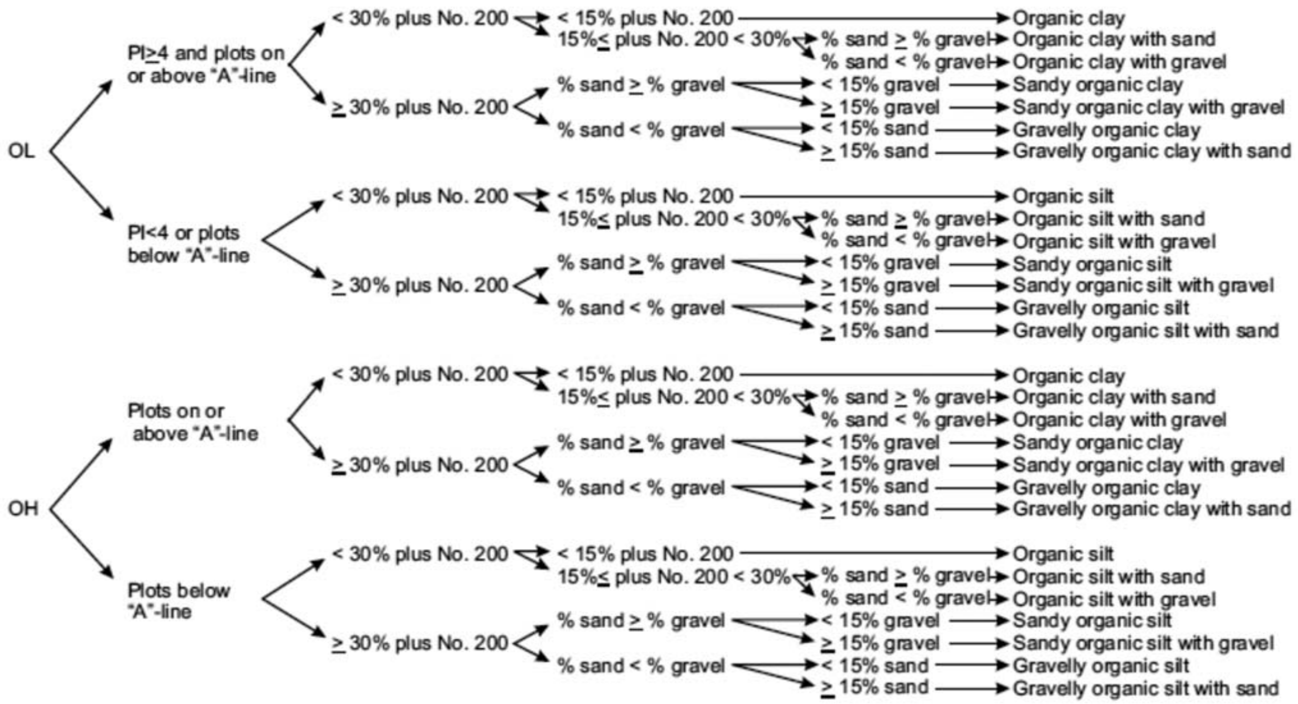


FIG. 2 Flow Chart for Classifying Organic Fine-Grained Soil (50 % or More Passes No. 200 Sieve)

the soil as an *organic clay,* OH, if the position of the plasticity index versus liquid-limit plot falls on or above the "A" line. See area identified as OH on Fig. 4.

11.4 If less than 30 % but 15 % or more of the test specimen is retained on the No. 200 (75-µm) sieve, the words" with sand" or "with gravel" (whichever is predominant) shall be added to the group name. For example, lean clay with sand, CL; silt with gravel, ML. If the percent of sand is equal to the percent of gravel, use "with sand."

11.5 If 30 % or more of the test specimen is retained on the No. 200 (75-µm) sieve, the words "sandy" or" gravelly" shall be added to the group name. Add the word "sandy" if 30 % or more of the test specimen is retained on the No. 200 (75-µm) sieve and the coarse-grained portion is predominantly sand. Add the word "gravelly" if 30 % or more of the test specimen is retained on the No. 200 (75-µm) sieve and the coarse-grained portion is predominantly gravel. For example, sandy lean clay, CL; gravelly fat clay, CH; sandy silt, ML. If the percent of sand is equal to the percent of gravel, use "sandy."

12. Procedure for Classification of Coarse-Grained Soils (more than 50 % retained on the No. 200 (75-µm) sieve)

12.1 Class the soil as gravel if more than 50 % of the coarse fraction [plus No. 200 (75-µm) sieve] is retained on the No. 4 (4.75-mm) sieve.

12.2 Class the soil as sand if 50 % or more of the coarse fraction [plus No. 200 (75-µm) sieve] passes the No. 4 (4.75-mm) sieve.

12.3 If 12 % or less of the test specimen passes the No. 200 (75-µm) sieve, plot the cumulative particle-size distribution, Fig. 5, and compute the coefficient of uniformity, *Cu*, and coefficient of curvature, *Cc*, as given in Eqs 1 and 2.

$$Cu = D_{60}/D_{10} \tag{1}$$

$$Cc = (D_{30})^2/(D_{10} \times D_{60}) \tag{2}$$

where:

D_{10}, D_{30}, and D_{60} = the particle-size diameters corresponding to 10, 30, and 60 %, respectively, passing on the cumulative particle-size distribution curve, Fig. 5.

NOTE 9—It may be necessary to extrapolate the curve to obtain the D_{10} diameter.

12.3.1 If less than 5 % of the test specimen passes the No. 200 (75-µm) sieve, classify the soil as a *well-graded gravel,* GW, or *well-graded sand,* SW, if Cu is greater than or equal to 4.0 for gravel or greater than 6.0 for sand, and Cc is at least 1.0 but not more than 3.0.

12.3.2 If less than 5 % of the test specimen passes the No. 200 (75-µm) sieve, classify the soil as *poorly graded gravel,* GP, or *poorly graded sand,* SP, if either the *Cu* or the *Cc* criteria for well-graded soils are not satisfied.

12.4 If more than 12 % of the test specimen passes the No. 200 (75-µm) sieve, the soil shall be considered a coarse-grained soil with fines. The fines are determined to be either clayey or silty based on the plasticity index versus liquid limit plot on Fig. 4. (See 9.8.2.1 if insufficient material available for testing) (see Note 7).

12.4.1 Classify the soil as a *clayey gravel,* GC, or *clayey sand,* SC, if the fines are clayey, that is, the position of the plasticity index versus liquid limit plot, Fig. 4, falls on or above the "A" line and the plasticity index is greater than 7.

12.4.2 Classify the soil as a *silty gravel,* GM, or *silty sand,* SM, if the fines are silty, that is, the position of the plasticity index versus liquid limit plot, Fig. 4, falls below the "A" line or the plasticity index is less than 4.

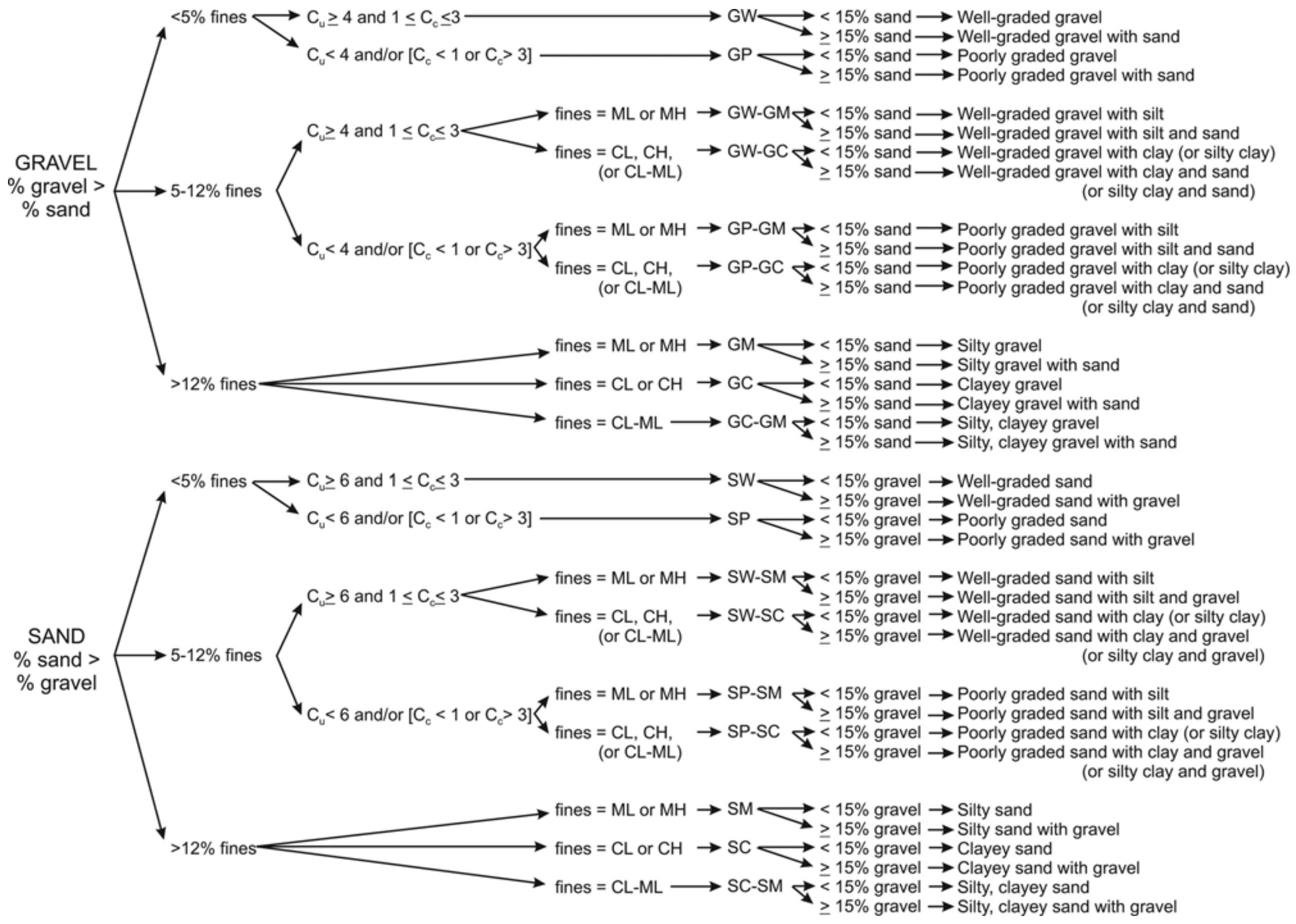


FIG. 3 Flow Chart for Classifying Coarse-Grained Soils (More Than 50 % Retained on No. 200 Sieve)

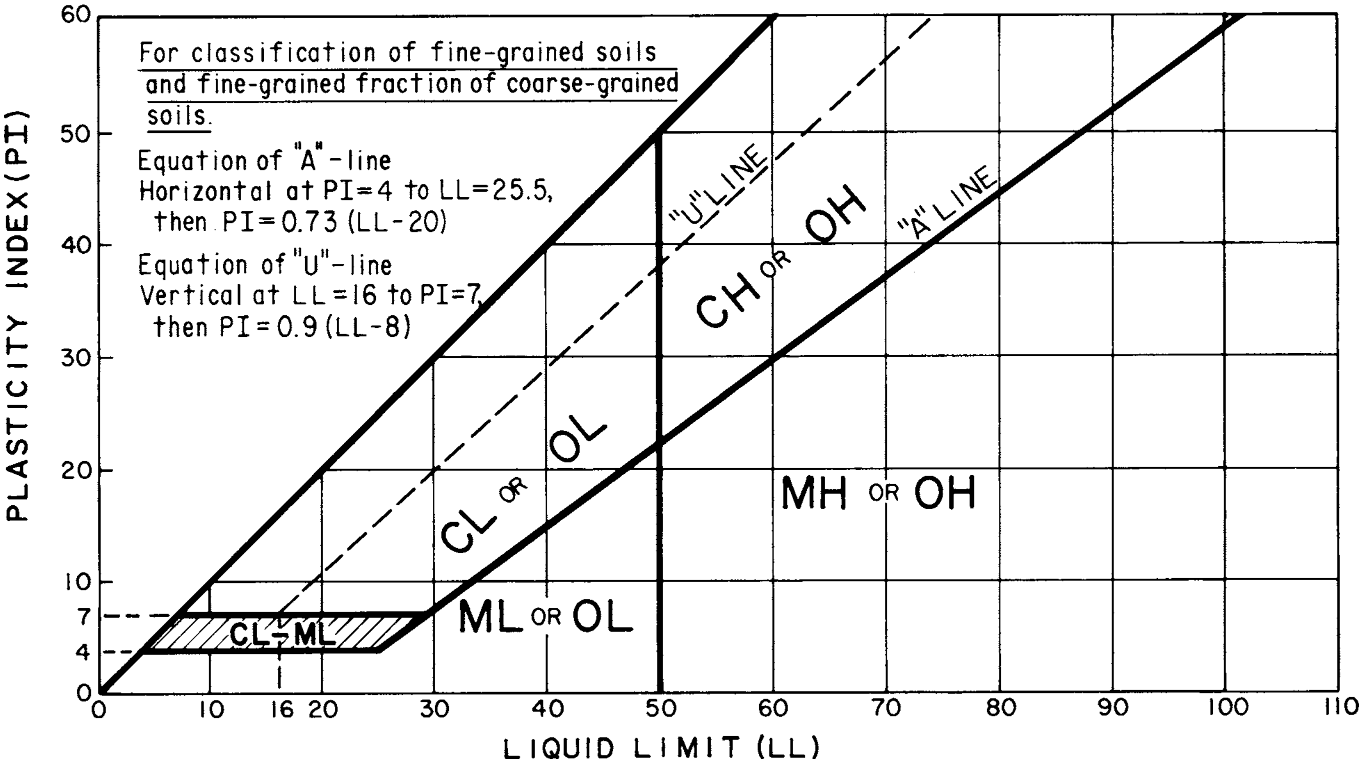
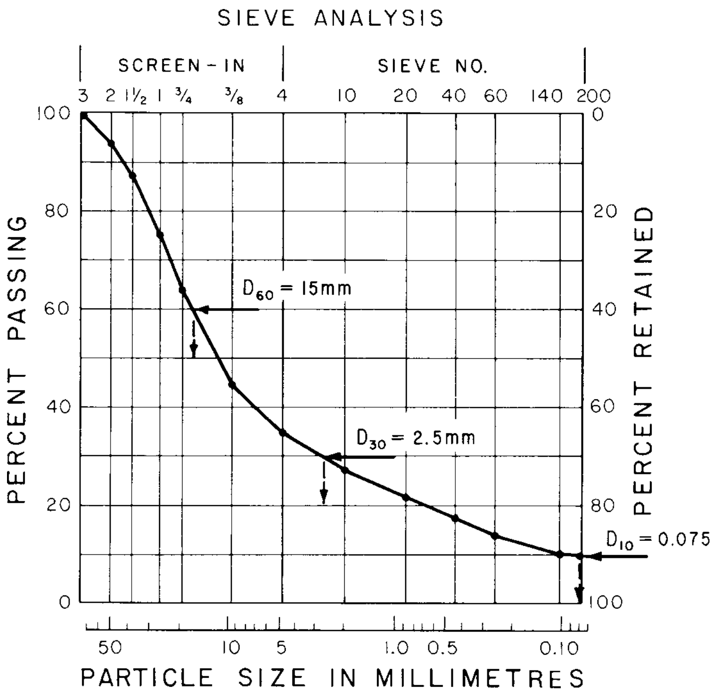


FIG. 4 Plasticity Chart



$$Cu = \frac{D_{60}}{D_{10}} = \frac{15}{0.075} = 200 \qquad Cc = \frac{(D_{30})^2}{D_{10} \times D_{60}} = \frac{(2.5)^2}{0.075 \times 15} = 5.6$$

FIG. 5 Cumulative Particle-Size Plot

12.4.3 If the fines plot as a silty clay, CL-ML, classify the soil as a *silty*, *clayey gravel*, GC-GM, if it is a gravel or a *silty*, *clayey sand*, SC-SM, if it is a sand.

12.5 If 5 to 12 % of the test specimen passes the No. 200 (75-µm) sieve, give the soil a dual classification using two group symbols.

12.5.1 The first group symbol shall correspond to that for a gravel or sand having less than 5 % fines (GW, GP, SW, SP), and the second symbol shall correspond to a gravel or sand having more than 12 % fines (GC, GM, SC, SM).

12.5.2 The group name shall correspond to the first group symbol plus "with clay" or "with silt" to indicate the plasticity characteristics of the fines. For example, well-graded gravel with clay, GW-GC; poorly graded sand with silt, SP-SM (See 9.8.2.1 if insufficient material available for testing).

NOTE 10—If the fines plot as a *silty clay,* CL-ML, the second group symbol should be either GC or SC. For example, a poorly graded sand with 10 % fines, a liquid limit of 20, and a plasticity index of 6 would be classified as a poorly graded sand with silty clay, SP-SC.

12.6 If the specimen is predominantly sand or gravel but contains 15 % or more of the other coarse-grained constituent, the words "with gravel" or "with sand" shall be added to the group name. For example, poorly graded gravel with sand, clayey sand with gravel.

12.7 If the field sample contained any cobbles or boulders or both, the words "with cobbles," or "with cobbles and boulders" shall be added to the group name. For example, silty gravel with cobbles, GM.

13. Report

13.1 The report should include the group name, group symbol, and the results of the laboratory tests. The particle-size distribution shall be given in terms of percent of gravel, sand, and fines. The plot of the cumulative particle-size distribution curve shall be reported if used in classifying the soil. Report appropriate descriptive information according to the procedures in Practice D2488. A local or commercial name or geologic interpretation for the material may be added at the end of the descriptive information if identified as such. The test procedures used shall be referenced.

NOTE 11—*Example: Clayey Gravel with Sand and Cobbles* (GC)—46 % fine to coarse, hard, subrounded gravel; 30 % fine to coarse, hard, subrounded sand; 24 % clayey fines, LL = 38, PI = 19; weak reaction with HCl; original field sample had 4 % hard, subrounded cobbles; maximum dimension 150 mm.

In-Place Conditions—firm, homogeneous, dry, brown,
Geologic Interpretation—alluvial fan.

NOTE 12—Other examples of soil descriptions are given in Appendix X1.

14. Precision and Bias

14.1 Criteria for acceptability depends on the precision and bias of Test Methods D422, D1140 and D4318.

15. Keywords

15.1 Atterberg limits; classification; clay; gradation; gravel; laboratory classification; organic soils; sand; silt; soil classification; soil tests

APPENDIXES

(Nonmandatory Information)

X1. EXAMPLES OF DESCRIPTIONS USING SOIL CLASSIFICATION

X1.1 The following examples show how the information required in 13.1 can be reported. The appropriate descriptive information from Practice D2488 is included for illustrative purposes. The additional descriptive terms that would accompany the soil classification should be based on the intended use of the classification and the individual circumstances.

X1.1.1 *Well-Graded Gravel with Sand (GW)*—73 % fine to coarse, hard, subangular gravel; 23 % fine to coarse, hard, subangular sand; 4 % fines; Cc = 2.7, Cu = 12.4.

X1.1.2 *Silty Sand with Gravel (SM)*—61 % predominantly fine sand; 23 % silty fines, LL = 33, PI = 6; 16 % fine, hard, subrounded gravel; no reaction with HCl; (field sample smaller than recommended). *In-Place Conditions*—Firm, stratified and contains lenses of silt 1 to 2 in. thick, moist, brown to gray; in-place density = 106 lb/ft^3 and in-place moisture = 9 %.

X1.1.3 *Organic Clay (OL)*—100 % fines, LL (not dried) = 32, LL (oven dried) = 21, PI (not dried) = 10; wet, dark brown, organic odor, weak reaction with HCl.

X1.1.4 *Silty Sand with Organic Fines (SM)*—74 % fine to coarse, hard, subangular reddish sand; 26 % organic and silty dark-brown fines, LL (not dried) = 37, LL (oven dried) = 26, PI (not dried) = 6, wet, weak reaction with HCl.

X1.1.5 *Poorly Graded Gravel with Silt, Sand, Cobbles and Boulders (GP-GM)*—78 % fine to coarse, hard, subrounded to subangular gravel; 16 % fine to coarse, hard, subrounded to subangular sand; 6 % silty (estimated) fines; moist, brown; no reaction with HCl; original field sample had 7 % hard, subrounded cobbles and 2 % hard, subrounded boulders with a maximum dimension of 18 in.

X2. USING SOIL CLASSIFICATION AS A DESCRIPTIVE SYSTEM FOR SHALE, CLAYSTONE, SHELLS, SLAG, CRUSHED ROCK, ETC.

X2.1 The group names and symbols used in this standard may be used as a descriptive system applied to materials that exist in situ as shale, claystone, sandstone, siltstone, mudstone, etc., but convert to soils after field or laboratory processing (crushing, slaking, etc.).

X2.2 Materials such as shells, crushed rock, slag, etc., should be identified as such. However, the procedures used in this standard for describing the particle size and plasticity characteristics may be used in the description of the material. If desired, a classification in accordance with this standard may be assigned to aid in describing the material.

X2.3 If a classification is used, the group symbol(s) and group names should be placed in quotation marks or noted with some type of distinguishing symbol. See examples.

X2.4 Examples of how soil classifications could be incorporated into a description system for materials that are not naturally occurring soils are as follows:

X2.4.1 *Shale Chunks*—Retrieved as 2- to 4-in. pieces of shale from power auger hole, dry, brown, no reaction with HCl. After laboratory processing by slaking in water for 24 h, material classified as "Sandy Lean Clay (CL)"—61 % clayey fines, LL = 37, PI = 16; 33 % fine to medium sand; 6 % gravel-size pieces of shale.

X2.4.2 *Crushed Sandstone*—Product of commercial crushing operation; "Poorly Graded Sand with Silt (SP-SM)"—91 % fine to medium sand; 9 % silty (estimated) fines; dry, reddish-brown, strong reaction with HCl.

X2.4.3 *Broken Shells*—65 % gravel-size broken shells; 31 % sand and sand-size shell pieces; 4 % fines; Cc = 2.4, Cu = 1.9; would be classified as "Poorly Graded Gravel with Sand (GP)".

X2.4.4 *Crushed Rock*—Processed gravel and cobbles from Pit No. 7; "Poorly Graded Gravel (GP)"—89 % fine, hard, angular gravel-size particles; 11 % coarse, hard, angular sand-size particles, dry, tan; no reaction with HCl; Cc = 2.4, Cu = 0.9.

X3. PREPARATION AND TESTING FOR CLASSIFICATION PURPOSES BY THE WET METHOD

X3.1 This appendix describes the steps in preparing a soil sample for testing for purposes of soil classification using a wet-preparation procedure.

X3.2 Samples prepared in accordance with this procedure should contain as much of their natural water content as possible and every effort should be made during obtaining, preparing, and transportating the samples to maintain the natural moisture.

X3.3 The procedures to be followed in this standard assume that the field sample contains fines, sand, gravel, and plus 3-in. (75-mm) particles and the cumulative particle-size distribution plus the liquid limit and plasticity index values are required (see 9.8). Some of the following steps may be omitted when they are not applicable to the soil being tested.

X3.4 If the soil contains plus No. 200 (75-µm) particles that would degrade during dry sieving, use a test procedure for determining the particle-size characteristics that prevents this degradation.

X3.5 Since this classification system is limited to the portion of a sample passing the 3-in. (75-mm) sieve, the plus 3-in. (75-mm) material shall be removed prior to the determination of the particle-size characteristics and the liquid limit and plasticity index.

X3.6 The portion of the field sample finer than the 3-in. (75-mm) sieve shall be obtained as follows:

X3.6.1 Separate the field sample into two fractions on a 3-in. (75-mm) sieve, being careful to maintain the natural water content in the minus 3-in. (75-mm) fraction. Any particles adhering to the plus 3-in. (75-mm) particles shall be brushed or wiped off and placed in the fraction passing the 3-in. (75-mm) sieve.

X3.6.2 Determine the air-dry or oven-dry weight of the fraction retained on the 3-in. (75-mm) sieve. Determine the total (wet) weight of the fraction passing the 3-in. (75-mm) sieve.

X3.6.3 Thoroughly mix the fraction passing the 3-in. (75-mm) sieve. Determine the water content, in accordance with Test Method D2216, of a representative specimen with a minimum dry weight as required in 7.2. Save the water-content specimen for determination of the particle-size analysis in accordance with X3.8.

X3.6.4 Compute the dry weight of the fraction passing the 3-in. (75-mm) sieve based on the water content and total (wet) weight. Compute the total dry weight of the sample and calculate the percentage of material retained on the 3-in. (75-mm) sieve.

X3.7 Determine the liquid limit and plasticity index as follows:

X3.7.1 If the soil disaggregates readily, mix on a clean, hard surface and select a representative sample by quartering in accordance with Practice C702.

X3.7.1.1 If the soil contains coarse-grained particles coated with and bound together by tough clayey material, take extreme care in obtaining a representative portion of the No. 40 (425-µm) fraction. Typically, a larger portion than normal has to be selected, such as the minimum weights required in 7.2.

X3.7.1.2 To obtain a representative specimen of a basically cohesive soil, it may be advantageous to pass the soil through a ¾-in. (19-mm) sieve or other convenient size so the material can be more easily mixed and then quartered or split to obtain the representative specimen.

X3.7.2 Process the representative specimen in accordance with the Wet Preparation Method in Test Method D4318.

X3.7.3 Perform the liquid-limit test in accordance with Test Method D4318, except the soil shall not be air dried prior to the test.

X3.7.4 Perform the plastic-limit test in accordance with Test Method D4318, except the soil shall not be air dried prior to the test, and calculate the plasticity index.

X3.8 Determine the particle-size distribution as follows:

X3.8.1 If the water content of the fraction passing the 3-in. (75-mm) sieve was required (X3.6.3), use the water-content specimen for determining the particle-size distribution. Otherwise, select a representative specimen in accordance with Practice C702 with a minimum dry weight as required in 7.2.

X3.8.2 If the cumulative particle-size distribution including a hydrometer analysis is required, determine the particle-size distribution in accordance with Test Method D422. See 9.7 for the set of required sieves.

X3.8.3 If the cumulative particle-size distribution without a hydrometer analysis is required, determine the particle-size distribution in accordance with Test Method C136. See 9.7 for the set of required sieves. The specimen should be soaked until all clayey aggregations have softened and then washed in accordance with Test Method C117 prior to performing the particle-size distribution.

X3.8.4 If the cumulative particle-size distribution is not required, determine the percent fines, percent sand, and percent gravel in the specimen in accordance with Test Method C117, being sure to soak the specimen long enough to soften all clayey aggregations, followed by Test Method C136 using a nest of sieves which shall include a No. 4 (4.75-mm) sieve and a No. 200 (75-µm) sieve.

X3.8.5 Calculate the percent fines, percent sand, and percent gravel in the minus 3-in. (75-mm) fraction for classification purposes.

X4. AIR-DRIED METHOD OF PREPARATION OF SOILS FOR TESTING FOR CLASSIFICATION PURPOSES

X4.1 This appendix describes the steps in preparing a soil sample for testing for purposes of soil classification when air-drying the soil before testing is specified or desired or when the natural moisture content is near that of an air-dried state.

X4.2 If the soil contains organic matter or mineral colloids that are irreversibly affected by air drying, the wet-preparation method as described in Appendix X3 should be used.

X4.3 Since this classification system is limited to the portion of a sample passing the 3-in. (75-mm) sieve, the plus 3-in. (75-mm) material shall be removed prior to the determination of the particle-size characteristics and the liquid limit and plasticity index.

X4.4 The portion of the field sample finer than the 3-in. (75-mm) sieve shall be obtained as follows:

X4.4.1 Air dry and weigh the field sample.

X4.4.2 Separate the field sample into two fractions on a 3-in. (75-mm) sieve.

X4.4.3 Weigh the two fractions and compute the percentage of the plus 3-in. (75-mm) material in the field sample.

X4.5 Determine the particle-size distribution and liquid limit and plasticity index as follows (see 9.8 for when these tests are required):

X4.5.1 Thoroughly mix the fraction passing the 3-in. (75-mm) sieve.

X4.5.2 If the cumulative particle-size distribution including a hydrometer analysis is required, determine the particle-size distribution in accordance with Test Method D422. See 9.7 for the set of sieves that is required.

X4.5.3 If the cumulative particle-size distribution without a hydrometer analysis is required, determine the particle-size distribution in accordance with Test Method D1140 followed by Test Method C136. See 9.7 for the set of sieves that is required.

X4.5.4 If the cumulative particle-size distribution is not required, determine the percent fines, percent sand, and percent gravel in the specimen in accordance with Test Method D1140 followed by Test Method C136 using a nest of sieves which shall include a No. 4 (4.75-mm) sieve and a No. 200 (75-µm) sieve.

X4.5.5 If required, determine the liquid limit and the plasticity index of the test specimen in accordance with Test Method D4318.

X5. ABBREVIATED SOIL CLASSIFICATION SYMBOLS

X5.1 In some cases, because of lack of space, an abbreviated system may be useful to indicate the soil classification symbol and name. Examples of such cases would be graphical logs, databases, tables, etc.

X5.2 This abbreviated system is not a substitute for the full name and descriptive information but can be used in supplementary presentations when the complete description is referenced.

X5.3 The abbreviated system should consist of the soil classification symbol based on this standard with appropriate lower case letter prefixes and suffixes as:

Prefix	Suffix
s = sandy	s = with sand
g = gravelly	g = with gravel
	c = cobbles
	b = boulders

X5.4 The soil classification symbol is to be enclosed in parentheses. Some examples would be:

Group Symbol and Full Name	Abbreviated
CL, Sandy lean clay	s(CL)
SP-Sm, Poorly graded sand with silt and gravel	(SP-SM)g
GP, poorly graded gravel with sand, cobbles, and boulders	(GP)scb
ML, gravelly silt with sand and cobbles	g(ML)sc

SUMMARY OF CHANGES

Committee D18 has identified the location of selected changes to this practice since the last issue, D2487–10, that may impact the use of this practice. (Approved May 1, 2011)

(*1*) Deleted reference to Practice D2217 in 11.3.2 and X3.7.2.

استانداردآزمایش حدود اتربرگ

ASTM-D4318-10

Designation: D4318 – 10$^{\varepsilon 1}$

Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils[1]

This standard is issued under the fixed designation D4318; 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.

ε^1 NOTE—Editorial corrections made throughout in January 2014.

1. Scope*

1.1 These test methods cover the determination of the liquid limit, plastic limit, and the plasticity index of soils as defined in Section 3 on Terminology.

1.2 Two methods for preparing test specimens are provided as follows: *Wet preparation method,* as described in 10.1. *Dry preparation method,* as described in 10.2. The method to be used shall be specified by the requesting authority. If no method is specified, use the wet preparation method.

1.2.1 The liquid and plastic limits of many soils that have been allowed to dry before testing may be considerably different from values obtained on non-dried samples. If the liquid and plastic limits of soils are used to correlate or estimate the engineering behavior of soils in their natural moist state, samples should not be permitted to dry before testing unless data on dried samples are specifically desired.

1.3 Two methods for determining the liquid limit are provided as follows: *Method A,* Multipoint test as described in Sections 11 and 12. *Method B,* One-point test as described in Sections 13 and 14. The method to be used shall be specified by the requesting authority. If no method is specified, use Method A.

1.3.1 The multipoint liquid limit method is generally more precise than the one-point method. It is recommended that the multipoint method be used in cases where test results may be subject to dispute, or where greater precision is required.

1.3.2 Because the one-point method requires the operator to judge when the test specimen is approximately at its liquid limit, it is particularly not recommended for use by inexperienced operators.

1.3.3 The correlation on which the calculations of the one-point method are based may not be valid for certain soils, such as organic soils or soils from a marine environment. It is strongly recommended that the liquid limit of these soils be determined by the multipoint method.

1.4 The plastic limit test is performed on material prepared for the liquid limit test.

1.5 The liquid limit and plastic limit of soils (along with the shrinkage limit) are often collectively referred to as the Atterberg limits. These limits distinguished the boundaries of the several consistency states of plastic soils.

1.6 The composition and concentration of soluble salts in a soil affect the values of the liquid and plastic limits as well as the water content values of soils (see Test Method D4542). Special consideration should therefore be given to soils from a marine environment or other sources where high soluble salt concentrations may be present. The degree to which the salts present in these soils are diluted or concentrated must be given careful consideration.

1.7 The methods described herein are performed only on that portion of a soil that passes the 425-μm (No. 40) sieve. Therefore, the relative contribution of this portion of the soil to the properties of the sample as a whole must be considered when using these tests to evaluate properties of a soil.

1.8 The values stated in SI units are to be regarded as the standard, except as noted below. The values given in parentheses are for information only.

1.8.1 The standard units for the resilience tester covered in Annex A1 are inch-pound, not SI. The SI values given are for information only.

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

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

1.9.2 The procedures used to specify how data are collected/recorded or calculated, in this standard are regarded as the industry standard. In addition, they are representative of the significant digits that generally should be retained. The procedures do not consider material variation, purpose for obtaining

---

[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.

Current edition approved Jan. 15, 2010. Published March 2010. Originally approved in 1983. Last previous edition approved in 2005 as D4318 – 05. DOI: 10.1520/D4318-10E01.

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

the data, special purpose studies, or any considerations for the user's objectives; and it is common practice to increase or reduce significant digits of reported data to be commensurate with these considerations. It is beyond the scope of this standard to consider significant digits used in analysis methods for engineering design.

1.10 *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]

C702 Practice for Reducing Samples of Aggregate to Testing Size

D75 Practice for Sampling Aggregates

D420 Guide to Site Characterization for Engineering Design and Construction Purposes (Withdrawn 2011)[3]

D653 Terminology Relating to Soil, Rock, and Contained Fluids

D1241 Specification for Materials for Soil-Aggregate Subbase, Base, and Surface Courses

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)

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

D4542 Test Method for Pore Water Extraction and Determination of the Soluble Salt Content of Soils by Refractometer

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

E177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods

E691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method

3. Terminology

3.1 *Definitions:*

3.1.1 For common definitions of terms in this standard, refer to Terminology D653.

3.1.2 *Atterberg Limits*—Originally, six "limits of consistency" of fine-grained soils were defined by Albert Atterberg: the upper limit of viscous flow, the liquid limit, the sticky limit, the cohesion limit, the plastic limit, and the shrinkage limit. In current engineering usage, the term usually refers only to the liquid limit, plastic limit, and in some references, the shrinkage limit.

3.1.3 *consistency*—the relative ease with which a soil can be deformed.

3.1.4 *liquid limit (LL, w_L)*—the water content, in percent, of a soil at the arbitrarily defined boundary between the semi-liquid and plastic states.

3.1.4.1 *Discussion*—The undrained shear strength of soil at the liquid limit is considered to be approximately 2 kPa (0.28 psi).

3.1.5 *plastic limit (PL, w_p)*—the water content, in percent, of a soil at the boundary between the plastic and semi-solid states.

3.1.6 *plastic soil*—a soil which has a range of water content over which it exhibits plasticity and which will retain its shape on drying.

3.1.7 *plasticity index (PI)*—the range of water content over which a soil behaves plastically. Numerically, it is the difference between the liquid limit and the plastic limit.

3.1.8 *liquidity index*—the ratio, expressed as a percentage of (*1*) the water content of a soil minus its plastic limit, to (*2*) its plasticity index.

3.1.9 *activity number (A)*—the ratio of (*1*) the plasticity index of a soil to (*2*) the percent by mass of particles having an equivalent diameter smaller than 2 µm.

4. Summary of Test Method

4.1 The specimen is processed to remove any material retained on a 425-µm (No. 40) sieve. The liquid limit is determined by performing trials in which a portion of the specimen is spread in a brass cup, divided in two by a grooving tool, and then allowed to flow together from the shocks caused by repeatedly dropping the cup in a standard mechanical device. The multipoint liquid limit, Method A, requires three or more trials over a range of water contents to be performed and the data from the trials plotted or calculated to make a relationship from which the liquid limit is determined. The one-point liquid limit, Method B, uses the data from two trials at one water content multiplied by a correction factor to determine the liquid limit.

4.2 The plastic limit is determined by alternately pressing together and rolling into a 3.2-mm (⅛-in.) diameter thread a small portion of plastic soil until its water content is reduced to a point at which the thread crumbles and can no longer be pressed together and re-rolled. The water content of the soil at this point is reported as the plastic limit.

4.3 The plasticity index is calculated as the difference between the liquid limit and the plastic limit.

5. Significance and Use

5.1 These test methods are used as an integral part of several engineering classification systems to characterize the fine-grained fractions of soils (see Practices D2487 and D3282) and

---

[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] The last approved version of this historical standard is referenced on www.astm.org.

to specify the fine-grained fraction of construction materials (see Specification D1241). The liquid limit, plastic limit, and plasticity index of soils are also used extensively, either individually or together, with other soil properties to correlate with engineering behavior such as compressibility, hydraulic conductivity (permeability), compactibility, shrink-swell, and shear strength.

5.2 The liquid and plastic limits of a soil and its water content can be used to express its relative consistency or liquidity index. In addition, the plasticity index and the percentage finer than 2-μm particle size can be used to determine its activity number.

5.3 These methods are sometimes used to evaluate the weathering characteristics of clay-shale materials. When subjected to repeated wetting and drying cycles, the liquid limits of these materials tend to increase. The amount of increase is considered to be a measure of a shale's susceptibility to weathering.

5.4 The liquid limit of a soil containing substantial amounts of organic matter decreases dramatically when the soil is oven-dried before testing. Comparison of the liquid limit of a sample before and after oven-drying can therefore be used as a qualitative measure of organic matter content of a soil (see Practice D2487.

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

6. Apparatus

6.1 *Liquid Limit Device*—A mechanical device consisting of a brass cup suspended from a carriage designed to control its drop onto the surface of a block of resilient material that serves as the base of the device. Fig. 1 shows the essential features and critical dimensions of the device. The device may be operated by either a hand crank or electric motor.

6.1.1 *Base*—A block of material having a resilience rebound of at least 77 % but no more than 90 %. Conduct resilience tests on the finished base with the feet attached. Details for measuring the resilience of the base are given in Annex A1.

6.1.2 *Rubber Feet,* supporting the base, designed to provide dynamic isolation of the base from the work surface.

6.1.3 *Cup,* brass, with a mass, including cup hanger, of 185 to 215 g.

6.1.4 *Cam*—Designed to raise the cup smoothly and continuously to its maximum height, over a distance of at least 180° of cam rotation, without developing an upward or downward velocity of the cup when the cam follower leaves the cam. (The preferred cam motion is a uniformly accelerated lift curve.)

NOTE 2—The cam and follower design in Fig. 1 is for uniformly accelerated (parabolic) motion after contact and assures that the cup has no velocity at drop off. Other cam designs also provide this feature and may be used. However, if the cam-follower lift pattern is not known, zero velocity at drop off can be assured by carefully filing or machining the cam and follower so that the cup height remains constant over the last 20 to 45° of cam rotation.

6.1.5 *Carriage,* constructed in a way that allows convenient but secure adjustment of the height-of-drop of the cup to 10

DIMENSIONS

LETTER	A Δ	B Δ	C Δ	E Δ	F	G	H	J Δ	K Δ	L Δ	M Δ
MM	54 ± 0.5	2 ± 0.1	27 ± 0.5	56 ± 2.0	32	10	16	60 ± 1.0	50 ± 2.0	150 ± 2.0	125 ± 2.0

LETTER	N	P	R	T	U Δ	V	W	Z
MM	24	28	24	45	47 ± 1.0	3.8	13	6.5

Δ ESSENTIAL DIMENSIONS

CAM ANGLE DEGREES	CAM RADIUS
0	0.742 R
30	0.753 R
60	0.764 R
90	0.773 R
120	0.784 R
150	0.796 R
180	0.818 R
210	0.854 R
240	0.901 R
270	0.945R
300	0.974R
330	0.995R
360	1.000R

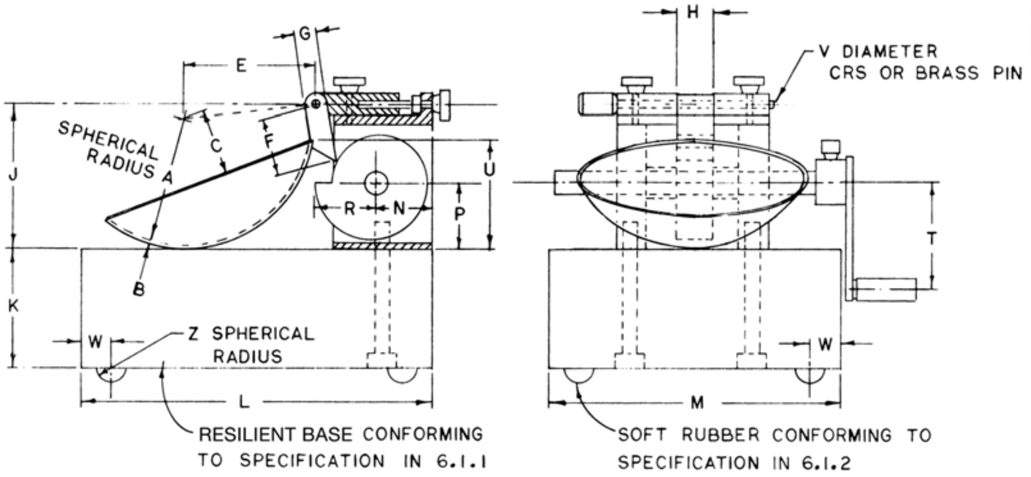


FIG. 1 Hand-Operated Liquid Limit Device

mm (0.394 in.), and designed such that the cup and cup hanger assembly is only attached to the carriage by means of a removable pin. See Fig. 2 for definition and determination of the height-of-drop of the cup.

6.1.6 *Motor Drive (Optional)*—As an alternative to the hand crank shown in Fig. 1, the device may be equipped with a motor to turn the cam. Such a motor must turn the cam at 2 ± 0.1 revolutions per second and must be isolated from the rest of the device by rubber mounts or in some other way that prevents vibration from the motor being transmitted to the rest of the apparatus. It must be equipped with an ON-OFF switch and a means of conveniently positioning the cam for height-of-drop adjustments. The results obtained using a motor-driven device must not differ from those obtained using a manually operated device.

6.2 *Flat Grooving Tool*—A tool made of plastic or noncorroding-metal having the dimensions shown in Fig. 3. The design of the tool may vary as long as the essential dimensions are maintained. The tool may, but need not, incorporate the gauge for adjusting the height-of-drop of the liquid limit device.

NOTE 3—Prior to the adoption of this test method, a curved grooving tool was specified as part of the apparatus for performing the liquid limit test. The curved tool is not considered to be as accurate as the flat tool described in 6.2 since it does not control the depth of the soil in the liquid limit cup. However, there are some data which indicate that typically the liquid limit is slightly increased when the flat tool is used instead of the curved tool.

6.3 *Gauge*—A metal gauge block for adjusting the height-of-drop of the cup, having the dimensions shown in Fig. 4. The design of the tool may vary provided the gauge will rest securely on the base without being susceptible to rocking, and the edge which contacts the cup during adjustment is straight, at least 10 mm (⅜ in.) wide, and without bevel or radius.

6.4 *Water Content Containers*—Small corrosion-resistant containers with snug-fitting lids for water content specimens. Aluminum or stainless steel cans 2.5 cm (1 in.) high by 5 cm (2 in.) in diameter are appropriate.

6.5 *Balance,* conforming to Guide D4753, Class GP1 (readability of 0.01 g).

6.6 *Mixing and Storage Container*—A container to mix the soil specimen (material) and store the prepared material. During mixing and storage, the container shall not contaminate the material in any way, and prevent moisture loss during storage. A porcelain, glass, or plastic dish about 11.4 cm (4½ in.) in diameter and a plastic bag large enough to enclose the dish and be folded over is adequate.

6.7 *Plastic Limit:*

6.7.1 *Ground Glass Plate*—A ground glass plate of sufficient size for rolling plastic limit threads.

6.7.2 *Plastic Limit-Rolling Device (optional)*—A device made of acrylic conforming to the dimensions shown in Fig. 5.[4,5] The type of unglazed paper attached to the top and bottom plate (see 16.2.2) shall be such that it does not add foreign matter (fibers, paper fragments, etc.) to the soil during the rolling process.

6.8 *Spatula*—A spatula or pill knife having a blade about 2 cm (¾ in.) wide, and about 10 to 13 cm (3 to 4 in.) long.

6.9 *Sieve(s)*—A 200-mm (8-in.) diameter, 425-μm (No. 40) sieve conforming to the requirements of Specification E11 and having a rim at least 5 cm (2 in.) above the mesh. A 2.00-mm (No. 10) sieve meeting the same requirements may also be needed.

6.10 *Wash Bottle,* or similar container for adding controlled amounts of water to soil and washing fines from coarse particles.

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

6.12 *Washing Pan,* round, flat-bottomed, at least 7.6 cm (3 in.) deep, and slightly larger at the bottom than a 20.3-cm (8-in.) diameter sieve.

7. Reagents and Materials

7.1 *Purity of Water*—Where distilled water is referred to in this test method, either distilled or demineralized water may be used. See Note 7 covering the use of tap water.

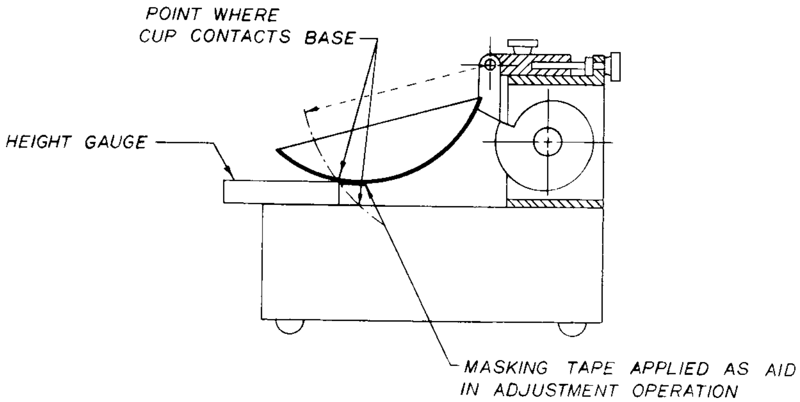


FIG. 2 Calibration for Height-of-Drop

---

[4] The plastic limit-rolling device is covered by a patent (U.S. Patent No. 5,027,660).[5] Interested parties are invited to submit information regarding the identification of an alternative(s) to this patented item to ASTM Headquarters. Your comments will receive careful consideration at a meeting of the responsible subcommittee, which you may attend.

DIMENSIONS

LETTER	A△	B△	C△	D△	E△	F△
MM	2 ± 0.1	11 ± 0.2	40 ± 0.5	8 ± 0.1	50 ± 0.5	2 ± 0.1
LETTER	G	H	J	K△	L△	N
MM	10 MINIMUM	13	60	10 ±0.05	60 DEG ± 1 DEG	20

△ *ESSENTIAL DIMENSIONS*

□ *BACK AT LEAST 15 MM FROM TIP*

NOTE: DIMENSION A SHOULD BE 1.9–2.0 AND DIMENSION D SHOULD BE 8.0–8.1 WHEN NEW TO ALLOW FOR ADEQUATE SERVICE LIFE

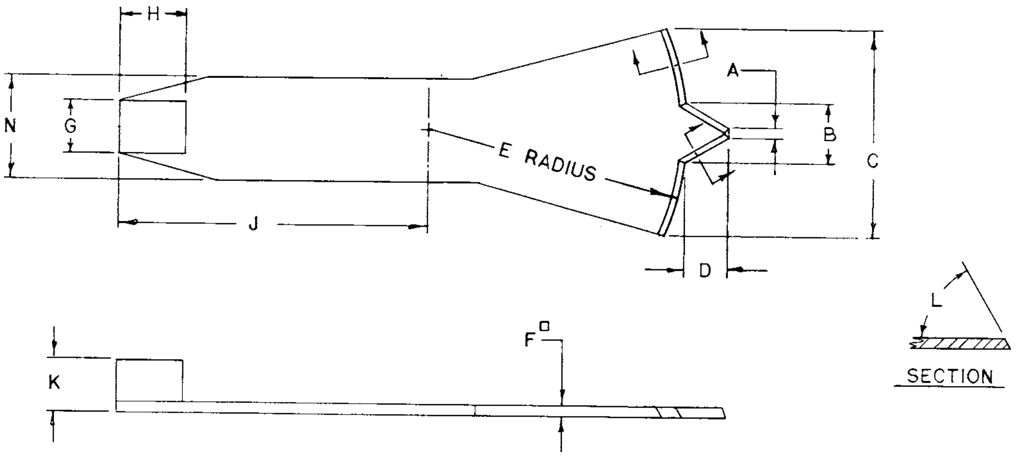
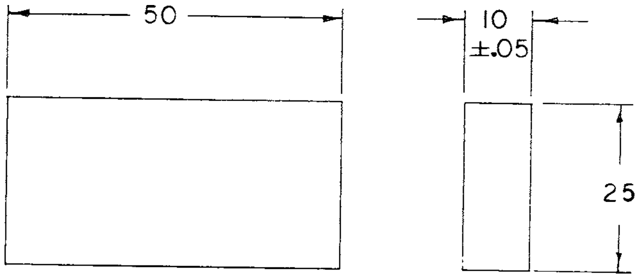


FIG. 3 Grooving Tool (Optional Height-of-Drop Gauge Attached)



DIMENSIONS IN MILLIMETRES

FIG. 4 Height-of-Drop Gauge

8. Sampling and Specimen

8.1 Samples may be taken from any location that satisfies testing needs. However, Practices C702 and D75 and Guide D420 should be used as guides for selecting and preserving samples from various types of sampling operations. Samples in which specimens will be prepared using the wet-preparation method (10.1) must be kept at their as–sampled water content prior to preparation.

8.1.1 Where sampling operations have preserved the natural stratification of a sample, the various strata must be kept separated and tests performed on the particular stratum of interest with as little contamination as possible from other strata. Where a mixture of materials will be used in construction, combine the various components in such proportions that the resultant sample represents the actual construction case.

8.1.2 Where data from these test methods are to be used for correlation with other laboratory or field test data, use the same material as used for those tests where possible.

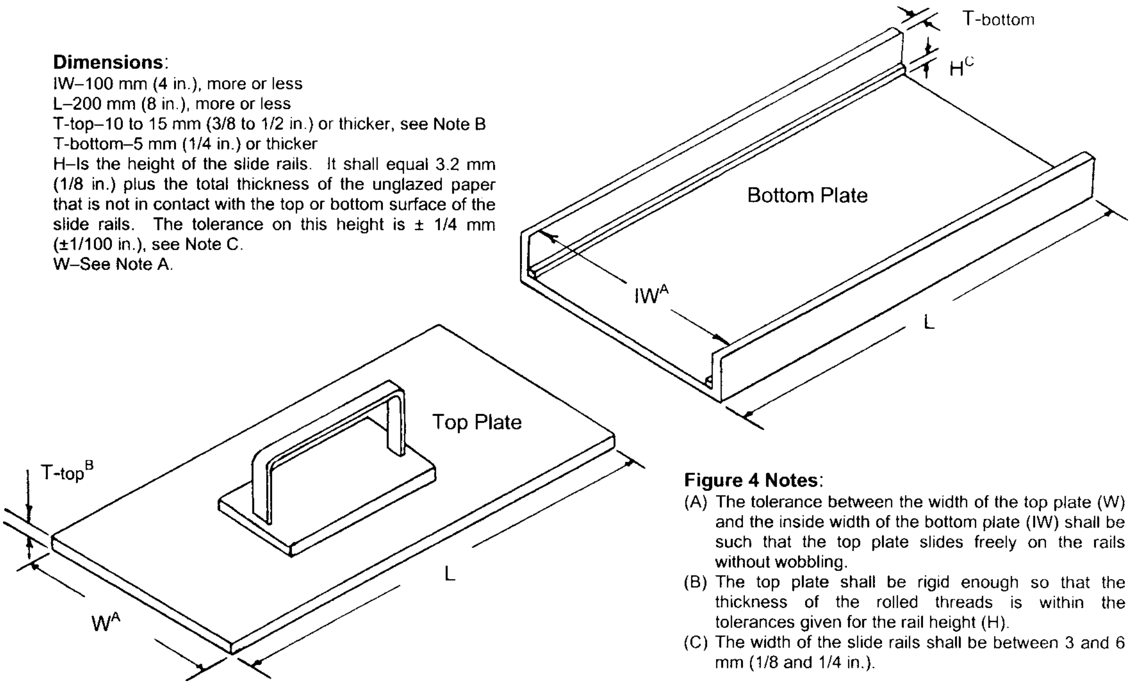
8.2 *Specimen*—Obtain a representative portion from the total sample sufficient to provide 150 to 200 g of material passing the 425-μm (No. 40) sieve. Free flowing samples (materials) may be reduced by the methods of quartering or splitting. Non-free flowing or cohesive materials shall be mixed thoroughly in a pan with a spatula or scoop and a representative portion scooped from the total mass by making one or more sweeps with a scoop through the mixed mass.

9. Calibration of Apparatus

9.1 *Inspection of Wear:*

9.1.1 *Liquid Limit Device*—Determine that the liquid limit device is clean and in good working order. Check the following specific points.

9.1.1.1 *Wear of Base*—The spot on the base where the cup makes contact should be worn no greater than 10 mm (3⁄8 in.) in diameter. If the wear spot is greater than this, the base can be machined to remove the worn spot provided the resurfacing does not make the base thinner than specified in 6.1 and the other dimensional relationships are maintained.



Dimensions:
IW–100 mm (4 in.), more or less
L–200 mm (8 in.), more or less
T-top–10 to 15 mm (3/8 to 1/2 in.) or thicker, see Note B
T-bottom–5 mm (1/4 in.) or thicker
H–Is the height of the slide rails. It shall equal 3.2 mm (1/8 in.) plus the total thickness of the unglazed paper that is not in contact with the top or bottom surface of the slide rails. The tolerance on this height is ± 1/4 mm (±1/100 in.), see Note C.
W–See Note A.

Figure 4 Notes:
(A) The tolerance between the width of the top plate (W) and the inside width of the bottom plate (IW) shall be such that the top plate slides freely on the rails without wobbling.
(B) The top plate shall be rigid enough so that the thickness of the rolled threads is within the tolerances given for the rail height (H).
(C) The width of the slide rails shall be between 3 and 6 mm (1/8 and 1/4 in.).

FIG. 5 Plastic Limit-Rolling Device

9.1.1.2 *Wear of Cup*—Replace the cup when the grooving tool has worn a depression in the cup 0.1 mm (0.004 in.) deep or when the rim of the cup has been reduced to half its original thickness. Verify that the cup is firmly attached to the cup hanger.

9.1.1.3 *Wear of Cup Hanger*—Verify that the cup hanger pivot does not bind and is not worn to an extent that allows more than 3 mm (⅛ in.) side-to-side movement of the lowest point on the rim.

9.1.1.4 *Wear of Cam*—The cam shall not be worn to an extent that the cup drops before the cup hanger (cam follower) loses contact with the cam.

9.1.1.5 *Rubber Feet*—The feet should prevent the base from bouncing or sliding on the work surface. Replace rubber feet that become hard, cracked, or brittle from age.

9.1.2 *Grooving Tools*—Inspect grooving tools for wear on a frequent and regular basis. The rapidity of wear depends on the material from which the tool is made, and the types of soils being tested. Soils containing a large proportion of fine sand particles may cause rapid wear of grooving tools; therefore, when testing these materials, tools should be inspected more frequently than for other soils.

NOTE 4—The width of the tip of grooving tools is conveniently checked using a pocket-sized measuring magnifier equipped with a millimeter scale. Magnifiers of this type are available from most laboratory supply companies. The depth of the tip of grooving tools can be checked using the depth-measuring feature of vernier calipers.

9.2 *Adjustment of Height-of-Drop*—Adjust the height-of-drop of the cup so that the point on the cup that comes in contact with the base rises to a height of 10 ± 0.2 mm. See Fig. 2 for proper location of the gauge relative to the cup during adjustment.

NOTE 5—A convenient procedure for adjusting the height-of-drop is as follows: place a piece of masking tape across the outside bottom of the cup parallel with the axis of the cup hanger pivot. The edge of the tape away from the cup hanger should bisect the spot on the cup that contacts the base. For new cups, placing a piece of carbon paper on the base and allowing the cup to drop several times will mark the contact spot. Attach the cup to the device and turn the crank until the cup is raised to its maximum height. Slide the height gauge under the cup from the front, and observe whether the gauge contacts the cup or the tape. (See Fig. 2.) If the tape and cup are both simultaneously contacted, the height-of-drop is ready to be checked. If not, adjust the cup until simultaneous contact is made. Check adjustment by turning the crank at 2 revolutions per second while holding the gauge in position against the tape and cup. If a faint ringing or clicking sound is heard without the cup rising from the gauge, the adjustment is correct. If no ringing is heard or if the cup rises from the gauge, readjust the height-of-drop. If the cup rocks on the gauge during this checking operation, the cam follower pivot is excessively worn and the worn parts should be replaced. Always remove tape after completion of adjustment operation.

10. Preparation of Test Specimen

10.1 *Wet Preparation Method*—Except where the dry method of specimen preparation is specified (10.2), prepare the specimen for testing as described in the following sections.

10.1.1 *Material Passes the 425-µm (No. 40) Sieve:*

10.1.1.1 Determine by visual and manual methods that the specimen from 8.2 has little or no material retained on a 425-µm (No. 40) sieve. If this is the case, prepare 150 to 200 g of material by mixing thoroughly with distilled or demineralized water on the glass plate or mixing dish using the spatula. If desired, soak the material in a mixing/storage dish with a small amount of water to soften the material before the start of mixing. If using Method A, adjust the water content of the material to bring it to a consistency that would require about 25 to 35 blows of the liquid limit device to close the groove (Note 6). For Method B, the number of blows should be between about 20 and 30 blows.

10.1.1.2 If, during mixing, a small percentage of material is encountered that would be retained on a 425-µm (No. 40) sieve, remove these particles by hand (if possible). If it is impractical to remove the coarser material by hand, remove small percentages (less than about 15 %) of coarser material by working the material (having the above consistency) through a 425-µm sieve. During this procedure, use a piece of rubber sheeting, rubber stopper, or other convenient device provided the procedure does not distort the sieve or degrade material that would be retained if the washing method described in 10.1.2 were used. If larger percentages of coarse material are encountered during mixing, or it is considered impractical to remove the coarser material by the procedures just described, wash the sample as described in 10.1.2. When the coarse particles found during mixing are concretions, shells, or other fragile particles, do not crush these particles to make them pass a 425-µm sieve, but remove by hand or by washing.

10.1.1.3 Place the prepared material in the mixing/storage dish, check its consistency (adjust if required), cover to prevent loss of moisture, and allow to stand (cure) for at least 16 h (overnight). After the standing period and immediately before starting the test, thoroughly remix the soil.

NOTE 6—The time taken to adequately mix a soil will vary greatly, depending on the plasticity and initial water content. Initial mixing times of more than 30 min may be needed for stiff, fat clays.

10.1.2 *Material Containing Particles Retained on a 425-µm (No. 40) Sieve:*

10.1.2.1 Place the specimen (see 8.2) in a pan or dish and add sufficient water to cover the material. Allow the material to soak until all lumps have softened and the fines no longer adhere to the surfaces of the coarse particles (Note 7).

NOTE 7—In some cases, the cations of salts present in tap water will exchange with the natural cations in the soil and significantly alter the test results if tap water is used in the soaking and washing operations. Unless it is known that such cations are not present in the tap water, distilled or demineralized water should be used. As a general rule, water containing more than 100 mg/L of dissolved solids should not be used for either the soaking or washing operations.

10.1.2.2 When the material contains a large percentage of particles retained on the 425-µm (No. 40) sieve, perform the following washing operation in increments, washing no more than 0.5 kg (1 lb) of material at one time. Place the 425-µm sieve in the bottom of the clean pan. Transfer, without any loss of material, the soil-water mixture onto the sieve. If gravel or coarse sand particles are present, rinse as many of these as possible with small quantities of water from a wash bottle, and discard. Alternatively, transfer the soil-water mixture over a 2.00-mm (No. 10) sieve nested atop the 425-µm sieve, rinse the fine material through and remove the 2.00-mm sieve. After washing and removing as much of the coarser material as possible, add sufficient water to the pan to bring the level to about 13 mm (½ in.) above the surface of the 425-µm sieve. Agitate the slurry by stirring with the fingers while raising and lowering the sieve in the pan and swirling the suspension so that fine material is washed from the coarser particles. Disaggregate fine soil lumps that have not slaked by gently rubbing them over the sieve with the fingertips. Complete the washing operation by raising the sieve above the water surface and rinsing the material retained with a small amount of clean water. Discard material retained on the 425-µm sieve.

10.1.2.3 Reduce the water content of the material passing the 425–µm (No. 40) sieve until it approaches the liquid limit. Reduction of water content may be accomplished by one or a combination of the following methods: (*a*) exposing to air currents at room temperature, (*b*) exposing to warm air currents from a source such as an electric hair dryer, (*c*) decanting clear water from surface of the suspension, (*d*) filtering in a Büchner funnel or using filter candles, or (*e*) draining in a colander or plaster of Paris dish lined with high retentivity,[6] high wet-strength filter paper. If a plaster of Paris dish is used, take care that the dish never becomes sufficiently saturated that it fails to absorb water into its surface. Thoroughly dry dish between uses. During evaporation and cooling, stir the material often enough to prevent over-drying of the fringes and soil pinnacles on the surface of the mixture. For materials containing soluble salts, use a method of water reduction (*a* or *b*) that will not eliminate the soluble salts from the test specimen.

10.1.2.4 If applicable, remove the material retained on the filter paper. Thoroughly mix this material or the above material on the glass plate or in the mixing dish using the spatula. Adjust the water content of the mixture, if necessary, by adding small increments of distilled or demineralized water or by allowing the mixture to dry at room temperature while mixing on the glass plate. If using Method A, the material should be at a water content that would require about 25 to 35 blows of the liquid limit device to close the groove. For Method B, the number of blows should be between about 20 and 30. Put, if necessary, the mixed material in the storage dish, cover to prevent loss of moisture, and allow to stand (cure) for at least 16 h. After the standing period and immediately before starting the test, thoroughly remix the specimen.

10.2 *Dry Preparation Method:*

10.2.1 Dry the specimen from 8.2 at room temperature or in an oven at a temperature not exceeding 60°C until the soil clods will pulverize readily. Disaggregation is expedited if the material is not allowed to completely dry. However, the material should have a dry appearance when pulverized.

10.2.2 Pulverize the material in a mortar with a rubber-tipped pestle or in some other way that does not cause breakdown of individual particles. When the coarse particles found during pulverization are concretions, shells, or other fragile particles, do not crush these particles to make them pass a 425-µm (No. 40) sieve, but remove by hand or other suitable means, such as washing. If a washing procedure is used, follow 10.1.2.1 – 10.1.2.4.

10.2.3 Separate the material on a 425-µm (No. 40) sieve, shaking the sieve by hand to assure thorough separation of the finer fraction. Return the material retained on the 425-µm sieve to the pulverizing apparatus and repeat the pulverizing and sieving operations. Stop this procedure when most of the fine material has been disaggregated and material retained on the 425-µm sieve consists of individual particles.

10.2.4 Place material retained on the 425-µm (No. 40) sieve after the final pulverizing operations in a dish and soak in a

---

[6] S and S 595 filter paper available in 320-mm circles has proven satisfactory. If you are aware of alternative suppliers, please provide this information to ASTM International Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee,[1] which you may attend.

small amount of water. Stir this mixture and transfer it to a 425-µm sieve, catching the water and any suspended fines in the washing pan. Pour this suspension into a dish containing the dry soil previously sieved through the 425-µm sieve. Discard material retained on the 425-µm sieve.

10.2.5 Proceed as described in 10.1.2.3 and 10.1.2.4.

MULTIPOINT LIQUID LIMIT—METHOD A

11. Procedure

11.1 Thoroughly remix the specimen (soil) in its mixing dish, and, if necessary, adjust its water content until the consistency requires about 25 to 35 blows of the liquid limit device to close the groove. Using a spatula, place a portion(s) of the prepared soil in the cup of the liquid limit device at the point where the cup rests on the base, squeeze it down, and spread it into the cup to a depth of about 10 mm at its deepest point, tapering to form an approximately horizontal surface. Take care to eliminate air bubbles from the soil pat, but form the pat with as few strokes as possible. Keep the unused soil in the mixing/storage dish. Cover the dish with a wet towel (or use other means) to retain the moisture in the soil.

11.2 Form a groove in the soil pat by drawing the tool, beveled edge forward, through the soil on a line joining the highest point to the lowest point on the rim of the cup. When cutting the groove, hold the grooving tool against the surface of the cup and draw in an arc, maintaining the tool perpendicular to the surface of the cup throughout its movement. See Fig. 6. In soils where a groove cannot be made in one stroke without tearing the soil, cut the groove with several strokes of the grooving tool. Alternatively, cut the groove to slightly less than required dimensions with a spatula and use the grooving tool to bring the groove to final dimensions. Exercise extreme care to prevent sliding the soil pat relative to the surface of the cup.

11.3 Verify that no crumbs of soil are present on the base or the underside of the cup. Lift and drop the cup by turning the crank at a rate of 1.9 to 2.1 drops per second until the two halves of the soil pat come in contact at the bottom of the groove along a distance of 13 mm (½ in.). See Fig. 7 and Fig. 8. The base of the machine shall not be held with the hand, or hands, while the crank is turned.

NOTE 8—Use of a scale is recommended to verify that the groove has closed 13 mm (½ in.).

11.4 Verify that an air bubble has not caused premature closing of the groove by observing that both sides of the groove have flowed together with approximately the same shape. If a bubble has caused premature closing of the groove, reform the soil in the cup, adding a small amount of soil to make up for that lost in the grooving operation and repeat 11.1 – 11.3. If the soil slides on the surface of the cup, repeat 11.1 – 11.3 at a higher water content. If, after several trials at successively higher water contents, the soil pat continues to slide in the cup or if the number of blows required to close the groove is always less than 25, record that the liquid limit could not be determined, and report the soil as nonplastic without performing the plastic limit test.

11.5 Record the number of drops, *N,* required to close the groove. Remove a slice of soil approximately the width of the spatula, extending from edge to edge of the soil cake at right

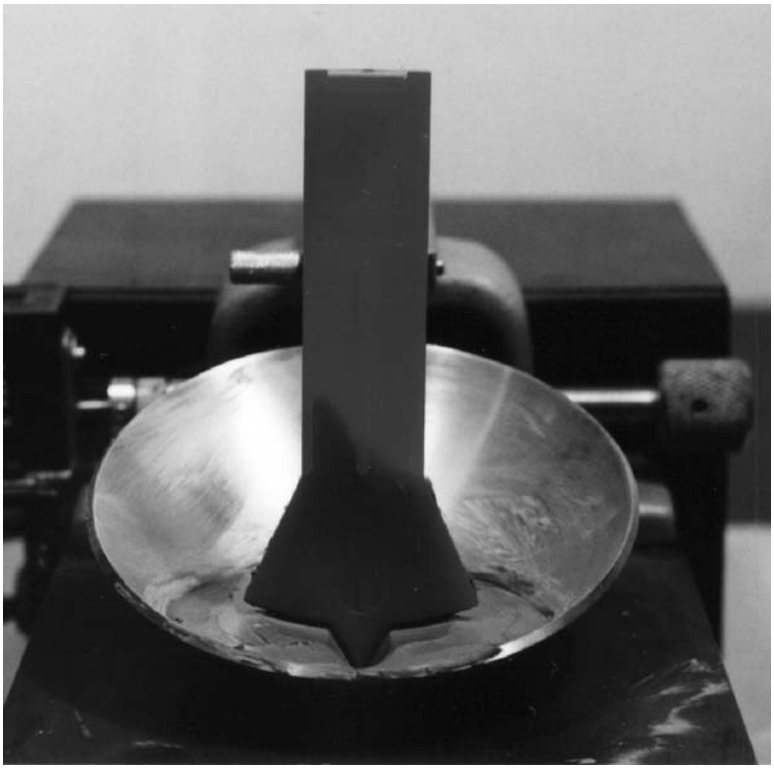


FIG. 6 Example of Grooving Tool Placed in a Properly Grooved Soil Pat

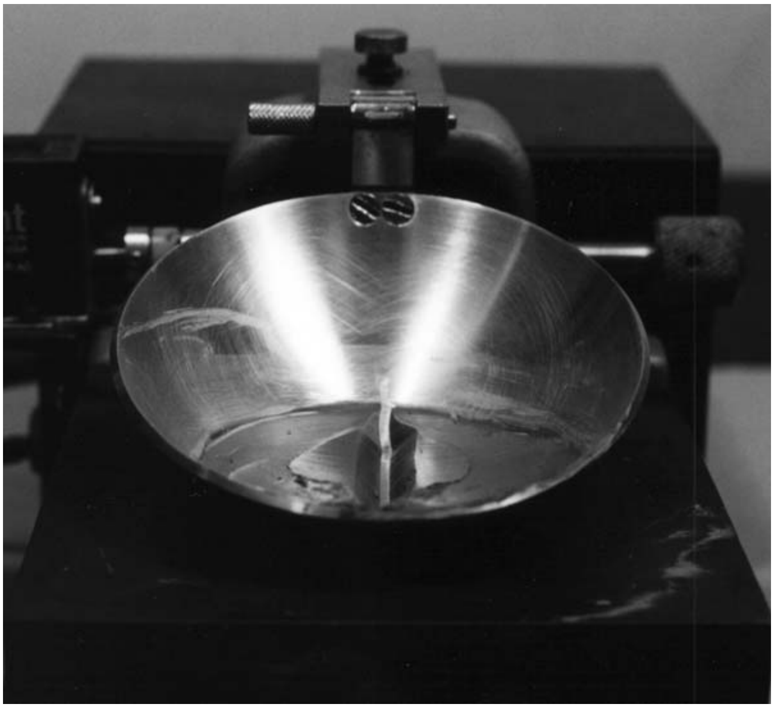


FIG. 7 Grooved Soil Pat in Liquid Limit Device

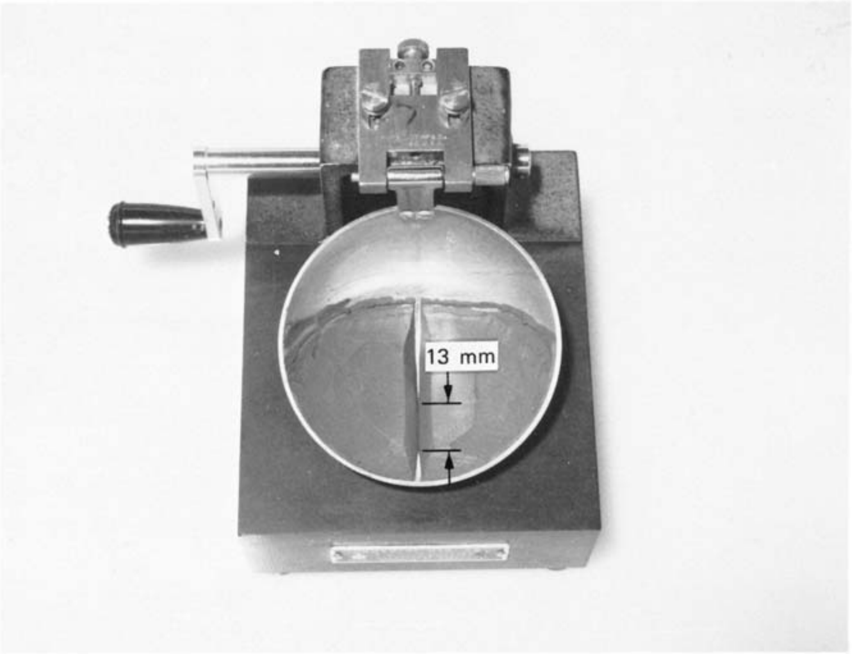


FIG. 8 Soil Pat After Groove Has Closed

angles to the groove and including that portion of the groove in which the soil flowed together, place in a container of known mass, and cover.

11.6 Return the soil remaining in the cup to the dish. Wash and dry the cup and grooving tool and reattach the cup to the carriage in preparation for the next trial.

11.7 Remix the entire soil specimen in the dish adding distilled water to increase the water content of the soil and decrease the number of blows required to close the groove. Repeat 11.1 – 11.6 for at least two additional trials producing successively lower numbers of blows to close the groove. One of the trials shall be for a closure requiring 25 to 35 blows, one for closure between 20 and 30 blows, and one trial for a closure requiring 15 to 25 blows.

11.8 Determine the water content, W^n, of the soil specimen from each trial in accordance with Test Methods D2216.

11.8.1 Determination of initial masses (container plus moist soil) should be performed immediately after completion of the test. If the test is to be interrupted for more than about 15 minutes, determine the mass of the water content specimens already obtained at the time of the interruption.

12. Calculation

12.1 Plot the relationship between the water content, W^n, and the corresponding number of drops, N, of the cup on a semilogarithmic graph with the water content as ordinates on the arithmetical scale, and the number of drops as abscissas on a logarithmic scale. Draw the best straight line through the three or more plotted points.

12.2 Take the water content corresponding to the intersection of the line with the 25-drop abscissa as the liquid limit of the soil and round to the nearest whole number. Computational methods may be substituted for the graphical method for fitting a straight line to the data and determining the liquid limit.

ONE-POINT LIQUID LIMIT—METHOD B

13. Procedure

13.1 Proceed as described in 11.1 – 11.5 except that the number of blows required to close the groove shall be 20 to 30. If less than 20 or more than 30 blows are required, adjust the water content of the soil and repeat the procedure.

13.2 Immediately after removing a water content specimen as described in 11.5, reform the soil in the cup, adding a small amount of soil to make up for that lost in the grooving and water content sampling processes.

13.2.1 As an alternative to reforming the soil in the brass cup after removing the water content specimen, the soil remaining in the cup can be removed from the cup, remixed with the soil in the mixing container and a new specimen placed in the cup as described in 11.1.

13.3 Repeat 11.2 – 11.5.

13.4 If the second closing of the groove requires the same number of drops or no more than two drops difference, secure another water content specimen. If the difference of the number of drops between the first and second closings of the groove is greater than two, remix the entire specimen and repeat the procedure, beginning at 13.1, until two successive closures having the same number of drops or no more than two drops difference are obtained.

NOTE 9—Excessive drying or inadequate mixing will cause the number of blows to vary.

13.5 Determine water contents of the two specimens in accordance with 11.8.

14. Calculation

14.1 Determine the liquid limit for each water content specimen using one of the following equations:

$$LL^n = W^n \cdot \left(\frac{N}{25}\right)^{0.121}$$

or

$$LL^n = k \cdot W^n$$

TABLE 1 Factors for Obtaining Liquid Limit from Water Content and Number of Drops Causing Closure of Groove

N (Number of Drops)	k (Factor for Liquid Limit)
20	0.973
21	0.979
22	0.985
23	0.990
24	0.995
25	1.000
26	1.005
27	1.009
28	1.014
29	1.018
30	1.022

where:

LL^n = one point liquid limit for given trial, %,
N = number of blows causing closure of the groove for given trial,
W^n = water content for given trial, %, and
k = factor given in Table 1.

14.1.1 The liquid limit, *LL*, is the average of the two trial liquid-limit values, to the nearest whole number (without the percent designation).

14.2 If the difference between the two trial liquid-limit values is greater than one percentage point, repeat the test as described in 13.1 through 14.1.1.

PLASTIC LIMIT

15. Preparation of Test Specimen

15.1 Select a 20-g or more portion of soil from the material prepared for the liquid limit test; either, after the second mixing before the test, or from the soil remaining after completion of the liquid limit test. Reduce the water content of the soil to a consistency at which it can be rolled without sticking to the hands by spreading or mixing continuously on the glass plate or in the mixing/storage dish. The drying process may be accelerated by exposing the soil to the air current from an electric fan, or by blotting with paper, that does not add any fiber to the soil. Paper such as hard surface paper toweling or high wet-strength filter paper is adequate.

16. Procedure

16.1 From this plastic-limit specimen, select a 1.5 to 2.0 g portion. Form the selected portion into an ellipsoidal mass.

16.2 Roll the soil mass by one of the following methods (hand or rolling device):

16.2.1 *Hand Method*—Roll the mass between the palm or fingers and the ground-glass plate with just sufficient pressure to roll the mass into a thread of uniform diameter throughout its length (see Note 10). The thread shall be further deformed on each stroke so that its diameter reaches 3.2 mm (⅛ in.), taking no more than 2 min (see Note 11). The amount of hand or finger pressure required will vary greatly according to the soil being tested, that is, the required pressure typically increases with increasing plasticity. Fragile soils of low plasticity are best rolled under the outer edge of the palm or at the base of the thumb.

NOTE 10—A normal rate of rolling for most soils should be 80 to 90 strokes per minute, counting a stroke as one complete motion of the hand forward and back to the starting position. This rate of rolling may have to be decreased for very fragile soils.

NOTE 11—A 3.2-mm (⅛-in.) diameter rod or tube is useful for frequent comparison with the soil thread to ascertain when the thread has reached the proper diameter.

16.2.2 *Rolling Device Method*—Attach smooth unglazed paper to both the top and bottom plates of the plastic limit-rolling device. Place the soil mass on the bottom plate at the midpoint between the slide rails. Place the top plate in contact with the soil mass(es). Simultaneously apply a slight downward force and back and forth motion to the top plate so that the top plate comes into contact with the side rails within 2 min (see Notes 10 and 12). During this rolling process, the end(s) the soil thread(s) shall not contact the side rail(s). If this occurs, roll a smaller mass of soil (even if it is less than that mentioned in Section 16.1).

NOTE 12—In most cases, two soil masses (threads) can be rolled simultaneously in the plastic limit-rolling device.

16.3 When the diameter of the thread becomes 3.2 mm, break the thread into several pieces. Squeeze the pieces together, knead between the thumb and first finger of each hand, reform into an ellipsoidal mass, and re-roll. Continue this alternate rolling to a thread 3.2 mm in diameter, gathering together, kneading and re-rolling, until the thread crumbles under the pressure required for rolling and the soil can no longer be rolled into a 3.2-mm diameter thread (see Fig. 9). It has no significance if the thread breaks into threads of shorter length. Roll each of these shorter threads to 3.2 mm in diameter. The only requirement for continuing the test is that these threads can be reformed into an ellipsoidal mass and rolled out again. The operator shall at no time attempt to produce failure at exactly 3.2-mm diameter by allowing the thread to reach 3.2 mm, then reducing the rate of rolling or the hand pressure, or both, while continuing the rolling without further deformation until the thread falls apart. It is permissible, however, to reduce the total amount of deformation for feebly plastic soils by making the initial diameter of the ellipsoidal mass nearer to the required 3.2-mm final diameter. If crumbling occurs when the thread has a diameter greater than 3.2 mm, this shall be considered a satisfactory end point, provided the soil has been previously rolled into a thread 3.2 mm in diameter. Crumbling of the thread will manifest itself differently with the various types of soil. Some soils fall apart in numerous small aggregations of particles, others may form an outside tubular layer that starts splitting at both ends. The splitting progresses toward the middle, and finally, the thread falls apart in many small platy particles. Fat clay soils require much pressure to deform the thread, particularly as they approach the plastic limit. With these soils, the thread breaks into a series of barrel-shaped segments about 3.2 to 9.5 mm (⅛ to ⅜ in.) in length.

16.4 Gather the portions of the crumbled thread together and place in a container of known mass. Immediately cover the container.

16.5 Select another 1.5 to 2.0-g portion of soil from the plastic–limit specimen and repeat the operations described in 16.1 and 16.2 until the container has at least 6 g of soil.

16.6 Repeat 16.1 – 16.5 to make another container holding at least 6 g of soil. Determine the water content of the soil contained in the containers in accordance with Test Methods D2216. See 11.8.1.

17. Calculation

17.1 Compute the average of the two water contents (trial plastic limits) and round to the nearest whole number. This

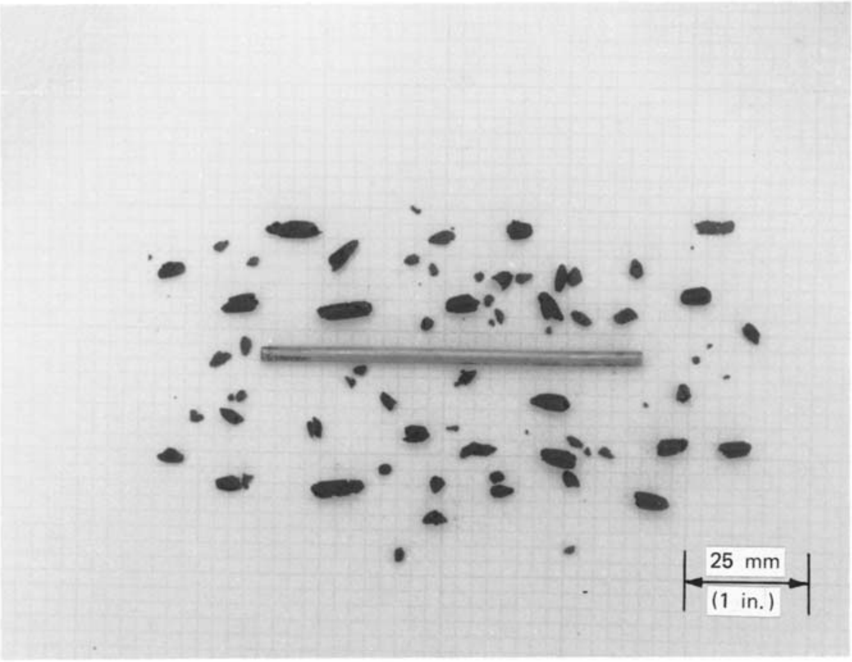


FIG. 9 Lean Clay Soil at the Plastic Limit

value is the plastic limit, *PL*. Repeat the test if the difference between the two trial plastic limits is greater than the acceptable range for two results listed in Table 2 for single-operator precision, that is, 1.4 percentage points; that is, (2.8 × 0.5).

PLASTICITY INDEX

18. Calculation

18.1 Calculate the plasticity index as follows:

$$PI = LL - PL$$

where:

LL = liquid limit (whole number), and
PL = plastic limit (whole number).

18.1.1 Both LL and PL are whole numbers. If either the liquid limit or plastic limit could not be determined, or if the plastic limit is equal to or greater than the liquid limit, report the soil as nonplastic, NP.

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

19.1 The terminology used to specify how data are recorded on the test data sheet(s)/form(s), as given below, is covered in 1.9.

19.2 Record as a minimum the following information:

19.2.1 Sample/specimen identifying information, such as project name , project number, boring number, depth (m or ft).

19.2.2 Description of sample, such as approximate maximum grain size, estimate of the percentage of sample retained on the 425-µm (No. 40) sieve, as-received water content.

19.2.3 Details of specimen preparation, such as wet or dry (air-dried or oven-dried), method of removing particles larger than the 425-µm (No. 40) sieve.

19.2.4 Any special specimen selection process used, such as removal of sand lenses from an intact (undisturbed) sample.

19.2.5 Equipment used, such as hand rolled or mechanical rolling device for plastic limit, manual or mechanical liquid limit device, metal or plastic grooving tool.

19.2.6 Liquid limit, plastic limit, and plasticity index to the nearest whole number, omitting the percent designation. If the liquid limit or plastic limit tests could not be performed, or if the plastic limit is equal to or greater than the liquid limit, report the soil as nonplastic, NP.

19.2.7 Procedure by which liquid limit was performed, if it differs from the multipoint method.

20. Precision and Bias

20.1 *Precision*—Criteria for judging the acceptability of test results obtained by these test methods on a range of soil types are given in Tables 2 and 3. In performing these test methods, Method A and the Wet Preparation Method (except soil was air-dried) were used.

20.1.1 These estimates of precision are based on the results of the interlaboratory program conducted by the ASTM Reference Soils and Testing Program.[7] In this program, some laboratories performed three replicate tests per soil type (triplicate test laboratory), while other laboratories performed a single test per soil type (single-test laboratory). A description of the soils tested is given in 20.1.5. The precision estimates vary with soil type and method(s) used. Judgment is required when applying these estimates to another soil and method used (Method A or B, or Wet or Dry Preparation Method).

20.1.2 The data in Table 2 are based on three replicate tests performed by each triplicate test laboratory on each soil type. The single operator and multilaboratory standard deviation shown in Table 2, Column 4, were obtained in accordance with Practice E691, which recommends each testing laboratory perform a minimum of three replicate tests. Results of two properly conducted tests performed by the same operator on the same material, using the same equipment, and in the shortest practical period of time should not differ by more than

TABLE 2 Summary of Test Results from Triplicate Test Laboratories (Atterberg Limits)

(1) Soil Type	(2) Number of Triplicate Test Laboratories			(3) Average Value^A (Percentage Points)			(4) Standard Deviation^B (Percentage Points)			(5) Acceptable Range of Two Results^C (Percentage Points)		
	Type Test											
	LL	PL	PI	LL	PL	PI	LL	PL	PI	LL	PL	PI
	Single-Operator Results (Within-Laboratory Repeatability)											
CH	13	13	13	59.8	20.6	39.2	0.7	0.5	0.8	2	1	2
CL	14	13	13	33.4	19.9	13.6	0.3	0.4	0.5	1	1	1
ML	12	11	11	27.4	23.4^D	4.1^D	0.5	0.3	0.6	2	1	2
	Multilaboratory Results (Between-Laboratory Reproducibility)											
CH	13	13	13	59.8	20.6	39.2	1.3	2.0	2.5	4	6	7
CL	14	13	13	33.4	19.9	13.6	1.0	1.2	1.7	3	3	5
ML	12	11	11	27.4	23.4^D	4.1^D	1.3	0.9	1.9	4	3	5

[A] The number of significant digits and decimal places presented are representative of the input data. In accordance with Practice D6026, the standard deviation and acceptable range of results can not have more decimal places than the input data.

[B] Standard deviation is calculated in accordance with Practice E691 and is referred to as the 1*s* limit.

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

[D] For the ML soil, 2 out of 14 triplicate test laboratories reported the soil as nonplastic.

---

[7] Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:D18-1013. Contact ASTM Customer Service at service@astm.org.

TABLE 3 Summary of Single-Test Result from Each Laboratory (Atterberg Limits)[A]

(1) Soil Type	(2) Number of Test Laboratories	(3) Average Value (Percentage Points)			(4) Standard Deviation (Percentage Points)			(5) Acceptable Range of Two Results (Percentage Points)		
		Type Test								
		LL	PL	PI	LL	PL	PI	LL	PL	PI
CH	24	59.9	20.4	39.5	2.1	2.7	3.1	6	7	9
CL	24	33.3	19.9	13.4	0.8	1.3	1.6	2	4	4
ML	18	27.1	23.2[B]	3.9[B]	1.3	1.2	1.8	4	3	5

[A] For column footnotes, see Table 3.

[B] For the ML soil, 6 out of 24 laboratories reported the soil as nonplastic.

the single-operator d2*s* limits shown in Table 2, Column 5. For definition of d2*s* see Footnote C in Table 2. Results of two properly conducted tests performed by different operators and on different days should not differ by more than the multilaboratory d2*s* limits shown in Table 2, Column 5.

20.1.3 In the ASTM Reference Soils and Testing Program, many of the laboratories performed only a single test on each soil type. This is common practice in the design and construction industry. The data for each soil type in Table 3 are based upon the first test results from the triplicate test laboratories and the single test results from the other laboratories. Results of two properly conducted tests performed by two different laboratories with different operators using different equipment and on different days should not vary by more than the d2*s* limits shown in Table 3, Column 5. The results in Table 2 and Table 3 are dissimilar because the data sets are different.

20.1.4 Table 2 presents a rigorous interpretation of triplicate test data in accordance with Practice E691 from pre-qualified laboratories. Table 3 is derived from test data that represents common practice.

20.1.5 *Soil Types*—Based on the multilaboratory test results, the soils used in the program are described below in accordance with Practice D2487. In addition, the local names of the soils are given.

CH—Fat clay, CH, 99 % fines, LL=60, PI=39, grayish brown, soil had been air dried and pulverized. Local name—Vicksburg Buckshot Clay

CL—Lean clay, CL, 89 % fines, LL=33, PI=13, gray, soil had been air dried and pulverized. Local name—Annapolis Clay

ML—Silt, ML, 99 % fines, LL=27, PI=4, light brown, soil had been air dried and pulverized. Local name—Vicksburg Silt

20.2 *Bias*—There is no acceptable reference value for these test methods; therefore, bias cannot be determined.

21. Keywords

21.1 activity; Atterberg limits; liquid limit; plasticity index; plastic limit

ANNEX

(Mandatory Information)

A1. RESILIENCE TESTER

A1.1 A device for measuring the resilience of liquid limit device bases is shown in Fig. A1.1. The device consists of a clear acrylic plastic tube and cap, a 5⁄16-in. diameter steel ball, and a small bar magnet. The cylinder may be cemented to the cap or threaded as shown. The small bar magnet is held in the recess of the cap and the steel ball is fixed into the recess in the underside of the cap with the bar magnet. The cylinder is then turned upright and placed on the top surface of the base to be tested. Holding the tube lightly against the liquid limit device base with one hand, release the ball by pulling the magnet out of the cap. Use the scale markings on the outside of the cylinder to determine the highest point reached by the bottom of the ball. Repeat the drop at least three times, placing the tester in a different location for each drop. Tests should be conducted at room temperature.

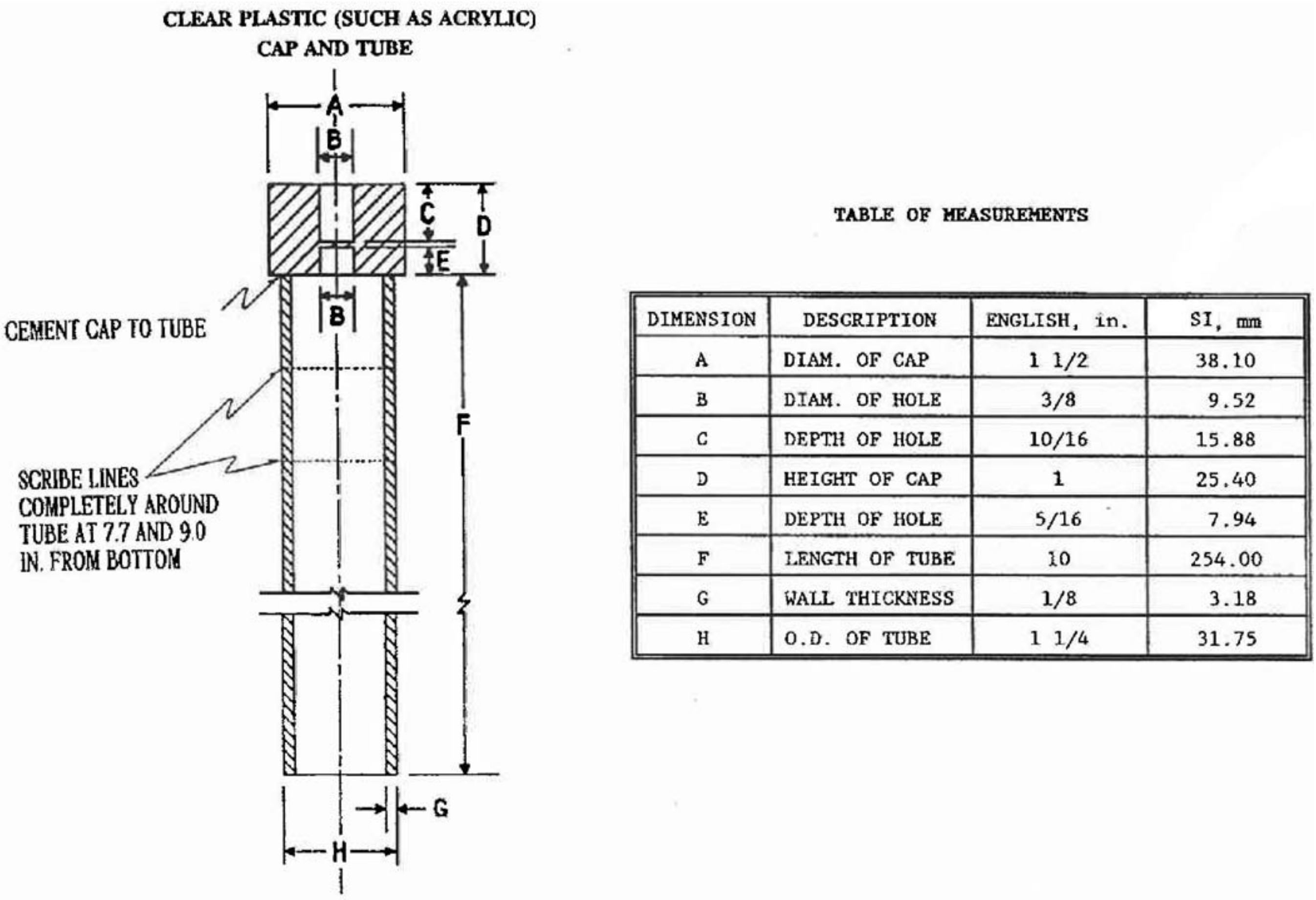


TABLE OF MEASUREMENTS

DIMENSION	DESCRIPTION	ENGLISH, in.	SI, mm
A	DIAM. OF CAP	1 1/2	38.10
B	DIAM. OF HOLE	3/8	9.52
C	DEPTH OF HOLE	10/16	15.88
D	HEIGHT OF CAP	1	25.40
E	DEPTH OF HOLE	5/16	7.94
F	LENGTH OF TUBE	10	254.00
G	WALL THICKNESS	1/8	3.18
H	O.D. OF TUBE	1 1/4	31.75

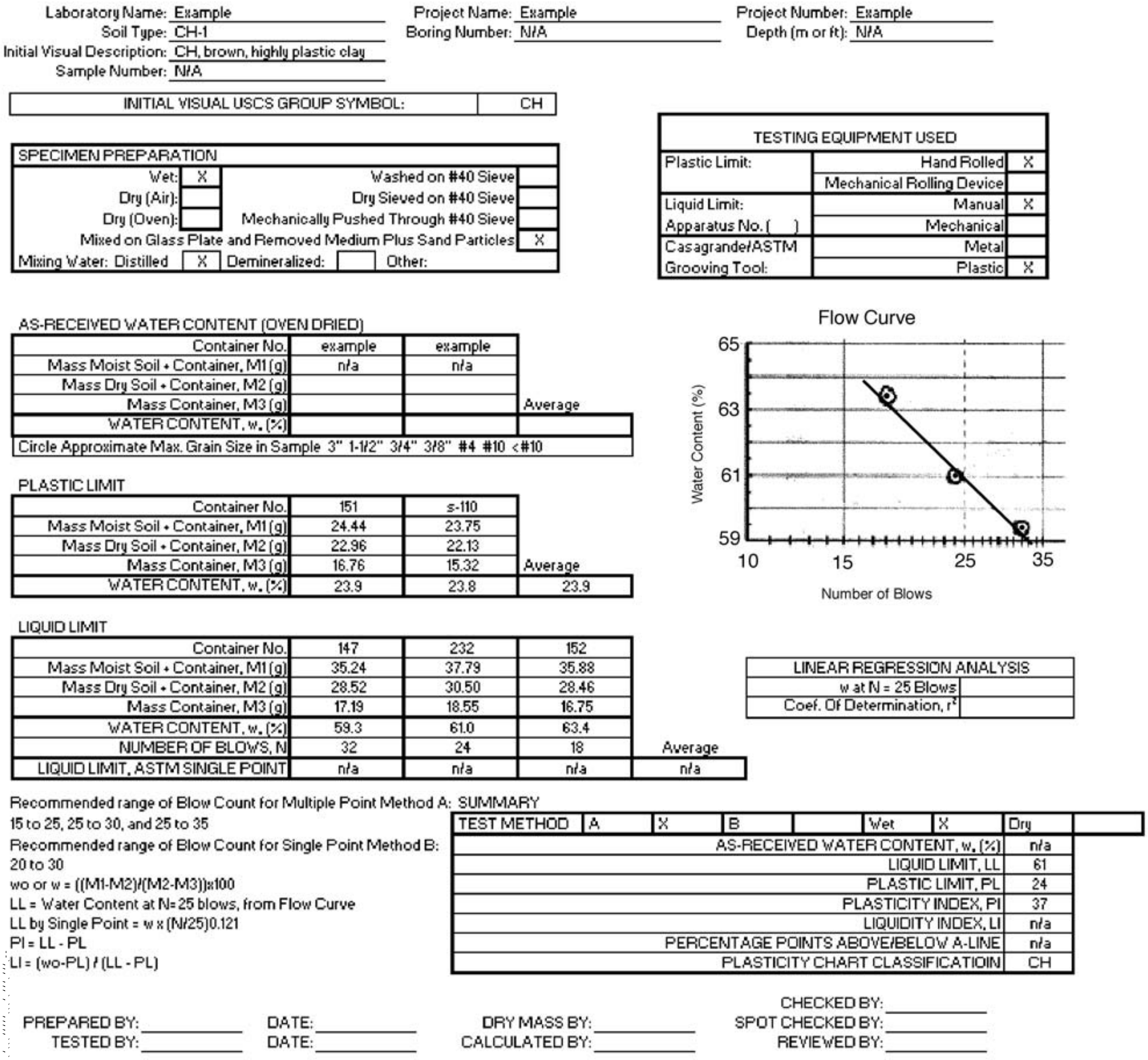
FIG. A1.1 Resilience Tester

APPENDIX

(Nonmandatory Information)

X1. SAMPLE DATA SHEET

X1.1 See Fig. X1.1.



Laboratory Name: Example
Soil Type: CH-1
Initial Visual Description: CH, brown, highly plastic clay
Sample Number: N/A
Project Name: Example
Boring Number: N/A
Project Number: Example
Depth (m or ft): N/A

INITIAL VISUAL USCS GROUP SYMBOL:	CH

SPECIMEN PREPARATION			
Wet:	X	Washed on #40 Sieve	
Dry (Air):		Dry Sieved on #40 Sieve	
Dry (Oven):		Mechanically Pushed Through #40 Sieve	
		Mixed on Glass Plate and Removed Medium Plus Sand Particles	X
Mixing Water: Distilled	X	Demineralized:	Other:

TESTING EQUIPMENT USED		
Plastic Limit:	Hand Rolled	X
	Mechanical Rolling Device	
Liquid Limit:	Manual	X
Apparatus No. ( )	Mechanical	
Casagrande/ASTM	Metal	
Grooving Tool:	Plastic	X

AS-RECEIVED WATER CONTENT (OVEN DRIED)

Container No.	example	example	
Mass Moist Soil + Container, M1 (g)	n/a	n/a	
Mass Dry Soil + Container, M2 (g)			
Mass Container, M3 (g)			Average
WATER CONTENT, w, (%)			
Circle Approximate Max. Grain Size in Sample 3" 1-1/2" 3/4" 3/8" #4 #10 <#10			

PLASTIC LIMIT

Container No.	151	s-110	
Mass Moist Soil + Container, M1 (g)	24.44	23.75	
Mass Dry Soil + Container, M2 (g)	22.96	22.13	
Mass Container, M3 (g)	16.76	15.32	Average
WATER CONTENT, w, (%)	23.9	23.8	23.9

Flow Curve

LIQUID LIMIT

Container No.	147	232	152	
Mass Moist Soil + Container, M1 (g)	35.24	37.79	35.88	
Mass Dry Soil + Container, M2 (g)	28.52	30.50	28.46	
Mass Container, M3 (g)	17.19	18.55	16.75	
WATER CONTENT, w, (%)	59.3	61.0	63.4	
NUMBER OF BLOWS, N	32	24	18	Average
LIQUID LIMIT, ASTM SINGLE POINT	n/a	n/a	n/a	n/a

LINEAR REGRESSION ANALYSIS	
w at N = 25 Blows	
Coef. Of Determination, r^2	

Recommended range of Blow Count for Multiple Point Method A:
15 to 25, 25 to 30, and 25 to 35
Recommended range of Blow Count for Single Point Method B:
20 to 30
wo or w = ((M1-M2)/(M2-M3))x100
LL = Water Content at N=25 blows, from Flow Curve
LL by Single Point = w x (N/25)0.121
PI = LL - PL
LI = (wo-PL) / (LL - PL)

SUMMARY

TEST METHOD	A	X	B		Wet	X	Dry	
AS-RECEIVED WATER CONTENT, w, (%)							n/a	
LIQUID LIMIT, LL							61	
PLASTIC LIMIT, PL							24	
PLASTICITY INDEX, PI							37	
LIQUIDITY INDEX, LI							n/a	
PERCENTAGE POINTS ABOVE/BELOW A-LINE							n/a	
PLASTICITY CHART CLASSIFICATIOIN							CH	

PREPARED BY: ____________ DATE: ____________
TESTED BY: ____________ DATE: ____________
DRY MASS BY: ____________
CALCULATED BY: ____________
CHECKED BY: ____________
SPOT CHECKED BY: ____________
REVIEWED BY: ____________

FIG. X1.1 Sample Data Sheet

SUMMARY OF CHANGES

Committee D18 has identified the location of selected changes to this standard since the last issue (D4318 – 05) that may impact the use of this standard. (Approved January 15, 2010.)

(1) Corrected 1.6 to reference D4542 and added D4542 to Referenced Documents in Section 2.
(2) In 1.8 and 1.8.1, clarified use of SI units.
(3) Added 1.9 referencing D6026 and the use of significant digits and renumbered 1.9 as 1.10.
(4) In 6.1 and 6.1.1 reworded the requirements for the composition of the base and removed the word "rubber." "Rubber" was also removed from the label in Fig. 1.
(5) In 6.1.2 removed the Durometer hardness requirement for the rubber feet.
(6) In 6.7.1 removed the dimensional requirements for the Ground Glass Plate.
(7) In 9.1.1.5 added guidance for replacement of rubber feet.
(8) In 11.1 changed "cup" to "dish" for consistency.
(9) In 11.3 added instruction that the base shall not be held during testing.
(10) In 13.2 to 13.5 clarified the instructions to allow two alternative test procedures.
(11) Section 19 was updated to comply with the D18.91 Special Memorandum on Report Section.

استاندارد آزمایش دانسیته برجا

ASTM-D1556-07

استاندارد آزمایش ظرفیت باربری

کالیفرنیا (CBR)

ASTM-D1883-14

Designation: D1883 – 14

Standard Test Method for California Bearing Ratio (CBR) of Laboratory-Compacted Soils[1]

This standard is issued under the fixed designation D1883; 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 California Bearing Ratio (CBR) of pavement subgrade, subbase, and base course materials from laboratory compacted specimens. The test method is primarily intended for, but not limited to, evaluating the strength of materials having maximum particle size less than ¾ in. (19 mm).

1.2 When materials having a maximum particle size greater than ¾ in. (19 mm) are to be tested, this test method provides for modifying the gradation of the material so that the material used for tests all passes the ¾-in. (19-mm) sieve while the total gravel (3 in. (75 mm) to plus No. 4 (4.75 mm)) fraction remains the same. While traditionally this method of specimen preparation has been used to avoid the error inherent in testing materials containing large particles in the CBR test apparatus, the modified material may have significantly different strength properties than the original material. However, a large experience database has been developed using this test method for materials for which the gradation has been modified, and satisfactory design methods are in use based on the results of tests using this procedure.

1.3 Past practice has shown that CBR results for those materials having substantial percentages of particles retained on the No. 4 (4.75 mm) sieve are more variable than for finer materials. Consequently, more trials may be required for these materials to establish a reliable CBR.

1.4 This test method provides for the determination of the CBR of a material at optimum water content or a range of water content from a specified compaction test and a specified dry unit weight. The dry unit weight is usually given as a percentage of maximum dry unit weight determined by Test Methods D698 or D1557.

1.5 The client requesting the test may specify the water content or range of water contents and the dry unit weight for which the CBR is desired.

1.6 Unless specified otherwise by the requesting client, or unless it has been shown to have no effect on test results for the material being tested, all specimens shall be soaked prior to penetration.

1.7 For the determination of CBR of field in-place materials, see Test Method D4429.

1.8 *Units*—The values stated in inch-pound units are to be regarded as standard. The SI units given in parentheses are mathematical conversions, which are provided for information purposes only and are not considered standard. Reporting of test results in units other than inch-pound units shall not be regarded as nonconformance with this test method.

1.8.1 The gravitational system of inch-pound units is used when dealing with inch-pound units. In this system, the pound (lbf) represents a unit of force (weight), while the unit for mass is slugs. The slug unit is not given, unless dynamic (F = ma) calculations are involved.

1.8.2 The slug unit of mass is almost never used in commercial practice; that is, density, balances, etc. Therefore, the standard unit for mass in this standard is either kilogram (kg) or gram (g), or both. Also, the equivalent inch-pound unit (slug) is not given/presented in parentheses.

1.8.3 It is common practice in the engineering/construction profession, in the United States, to concurrently use pounds to represent both a unit of mass (lbm) and 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 inchpound units within a single standard. As stated, this standard includes the gravitational system of inch-pound units and does not use/present the slug unit for mass. However, the use of balances or scales recording pounds of mass (lbm) or recording density in lbm/ft^3 shall not be regarded as nonconformance with this standard.

1.8.4 The terms density and unit weight are often used interchangeably. Density is mass per unit volume whereas unit weight is force per unit volume. In this standard, density is

---

[1] This test method is under the jurisdiction of ASTM Committee D18 on Soil and Rock and is the direct responsibility of Subcommittee D18.05 on Strength and Compressibility of Soils.

Current edition approved Dec. 1, 2014. Published January 2015. Originally approved in 1961. Last previous edition approved in 2007 as D1883 – 07$^{\epsilon 2}$. DOI: 10.1520/D1883-14.

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

given only in SI units. After the density has been determined, the unit weight is calculated in SI or inch-pound units, or both.

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

1.9.1 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, and it is common practice to increase or reduce significant digits or 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.

1.10 *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]

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))

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

D2168 Practices for Calibration of Laboratory Mechanical-Rammer Soil Compactors

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

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

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

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

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

D4429 Test Method for CBR (California Bearing Ratio) of Soils in Place

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

3. Terminology

3.1 *Definitions:*

3.1.1 For common definitions of terms in this standard, refer to Terminology D653.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *water content of the compaction specimen, w_i*—water content in percent of material used to compact the test specimen.

3.2.2 *water content top 1 in. (25.4-mm) after soaking w_s*—water content in percent of upper 1 in. (25.4 mm) of material removed from the compacted specimen after soaking and penetration.

3.2.3 *water content after testing, w_f*—water content in percent of the compacted specimen after soaking and final penetration; does not include material described in 3.2.2.

3.2.4 *dry density as compacted and before soaking, ρ_{di}*—dry density of the as compacted test specimen using the measured wet mass and calculating the dry mass using the water content defined in 3.2.1.

4. Summary of Test Method

4.1 The California Bearing Ratio (CBR) test is used in evaluating subgrade, subbase and base materials as an aid to the design of pavements. The laboratory test uses a circular piston to penetrate material compacted in a mold at a constant rate of penetration. The CBR is expressed as the ratio of the unit load on the piston required to penetrate 0.1 in. (2.5 mm) and 0.2 in (5.1 mm) of the test material to the unit load required to penetrate a standard material of well-graded crushed stone.

4.2 This test method is used to determine the CBR of a material compacted in a specified mold. It is incumbent on the requesting client to specify the scope of testing to satisfy the client's protocol or specific design requirements. Possible scope of testing includes:

4.2.1 CBR penetration tests can be performed on each point of a compaction test performed in accordance with Method C of D698 or D1557. The CBR mold with the spacer disk specified in this standard has the same internal dimensions as a 6.000-in. (152.4-mm) diameter compaction mold.

4.2.2 Another alternative is for the CBR test to be performed on material compacted to a specific water content and density. Alternatively, a water content range may be stated for one or more density values and will often require a series of specimens prepared using two or three compactive efforts for the specified water content or over the range of water contents requested. The compactive efforts are achieved by following procedures of D698 or D1557 but varying the blows per layer to produce densities above and below the desired density.

5. Significance and Use

5.1 This test method is used to evaluate the potential strength of subgrade, subbase, and base course materials, including recycled materials for use in the design of road and

---

[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.

airfield pavements. The CBR value obtained in this test forms an integral part of several flexible pavement design methods.

5.2 For applications where the effect of compaction water content on CBR is small, such as cohesionless, coarse-grained materials, or where an allowance is made for the effect of differing compaction water contents in the design procedure, the CBR may be determined at the optimum water content of a specified compaction effort. The specified dry unit weight is normally the minimum percent compaction allowed by the using client's field compaction specification.

5.3 For applications where the effect of compaction water content on CBR is unknown or where it is desired to account for its effect, the CBR is determined for a range of water contents, usually the range of water content permitted for field compaction by using the client's protocol or specification for field compaction.

5.4 The criteria for test specimen preparation of self-cementing (and other) materials which gain strength with time must be based on a geotechnical engineering evaluation. As directed by the client, self-cementing materials shall be properly cured until bearing ratios representing long term service conditions can be measured.

NOTE 1—The quality of the results 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/etc. 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 *Loading Machine*—The loading machine shall be equipped with a movable head or base that travels at a uniform (not pulsating) rate of 0.05 in. (1.3 mm)/min for use in pushing the penetration piston into the specimen. The load rate of 0.05 in. (1.3 mm)/min shall be maintained within ±20% over the range of loads developed during penetration. The minimum capacity of the loading machine shall be based on the requirements indicated in Table 1.

6.1.1 The machine shall be equipped with a load-indicating device matched to the anticipated maximum penetration load. The load-indicating device shall have a minimum accuracy of: 10 lbf (44 N) or less for a 10,000 lbf (44 kN) capacity; 5 lbf (20 N) or less for 5,000 lbf (22 kN) and 2 lbf (9 N) or less for 2,500 lbf (11 kN).

6.2 *Penetration Measuring Device*—The penetration measuring device (such as a mechanical dial indicator or electronic displacement transducer) shall be capable of reading to the nearest 0.001 in. (0.025 mm) and provided with appropriate mounting hardware. The mounting assembly of the deformation measuring device shall be connected to the penetrating piston and the edge of the mold providing accurate penetration measurements. Mounting the deformation holder assembly to a stressed component of the load frame (such as tie rods) will introduce inaccuracies of penetration measurements.

TABLE 1 Minimum Load Capacity

Maximum Measurable CBR	Minimum Load Capacity	
	(lbf)	(kN)
20	2500	11.2
50	5000	22.3
>50	10 000	44.5

6.3 *Mold*—The mold shall be a rigid metal cylinder with an inside diameter of 6.000 ± 0.026 in. (152.4 ± 0.66 mm) and a height of 7.000 ± 0.018 in. (177.8 ± 0.46 mm). It shall be provided with a metal extension collar at least 2.0 in. (50.8 mm) in height and a metal base plate having at least twenty eight 1⁄16-in. (1.59-mm) diameter holes uniformly spaced over the plate within the inside circumference of the mold. When assembled with the spacer disc placed in the bottom of the mold, the mold shall have an internal volume (excluding extension collar) of 0.0750 ± 0.0009 ft^3 (2124 ± 25 cm^3). A mold assembly having the minimum required features is shown in Fig. 1. A calibration procedure shall be used to confirm the actual volume of the mold with the spacer disk inserted. Suitable calibration procedures are contained in Test Methods D698 and D1557.

6.4 *Spacer Disk*—A circular metal spacer disc (see Fig. 1) having a minimum outside diameter of 5 15⁄16 in. (150.8 mm) but no greater than will allow the spacer disc to easily slip into the mold. The spacer disc shall be 2.416 ± 0.005 in. (61.37 ± 0.13 mm) in height.

6.5 *Rammer*—A rammer as specified in either Test Methods D698 or D1557 except that if a mechanical rammer is used it must be equipped with a circular foot, and when so equipped, must provide a means for distributing the rammer blows uniformly over the surface of the soil when compacting in a 6.000-in. (152.4-mm) diameter mold. The mechanical rammer must be calibrated and adjusted in accordance with Test Methods D2168.

6.6 *Expansion-Measuring Apparatus*—An adjustable metal stem and perforated metal plate, similar in configuration to that shown in Fig. 1. The perforated plate shall be 5 7⁄8 to 5 15⁄16 in. (149.2 to 150.8 mm) in diameter and have at least forty-two 1⁄16-in. (1.59-mm) diameter holes uniformly spaced over the plate. A metal tripod to support the dial gauge for measuring the amount of swell during soaking is also required. The expansion measuring apparatus shall not weigh more than 2.8 lbf or a mass of 1.3 kg.

6.6.1 *Swell Measurement Device*—Generally mechanical dial indicators capable of reading to 0.001 in. (0.025 mm) with a range of 0.200-in. (5-mm) minimum.

6.7 *Surcharge Weights*—These "weights" are actually "masses" converted to a force. One or two annular metal weights having a total weight of 10 lbf (4.54 ± 0.02 kg) and slotted metal weights each having a weight of 5 lbf (2.27 ± 0.02 kg). The annular weight shall be 5 7⁄8 to 5 15⁄16 in. (149.2 to 150.8 mm) in diameter and shall have a center hole of approximately 2 1⁄8 in. (53.98 mm).

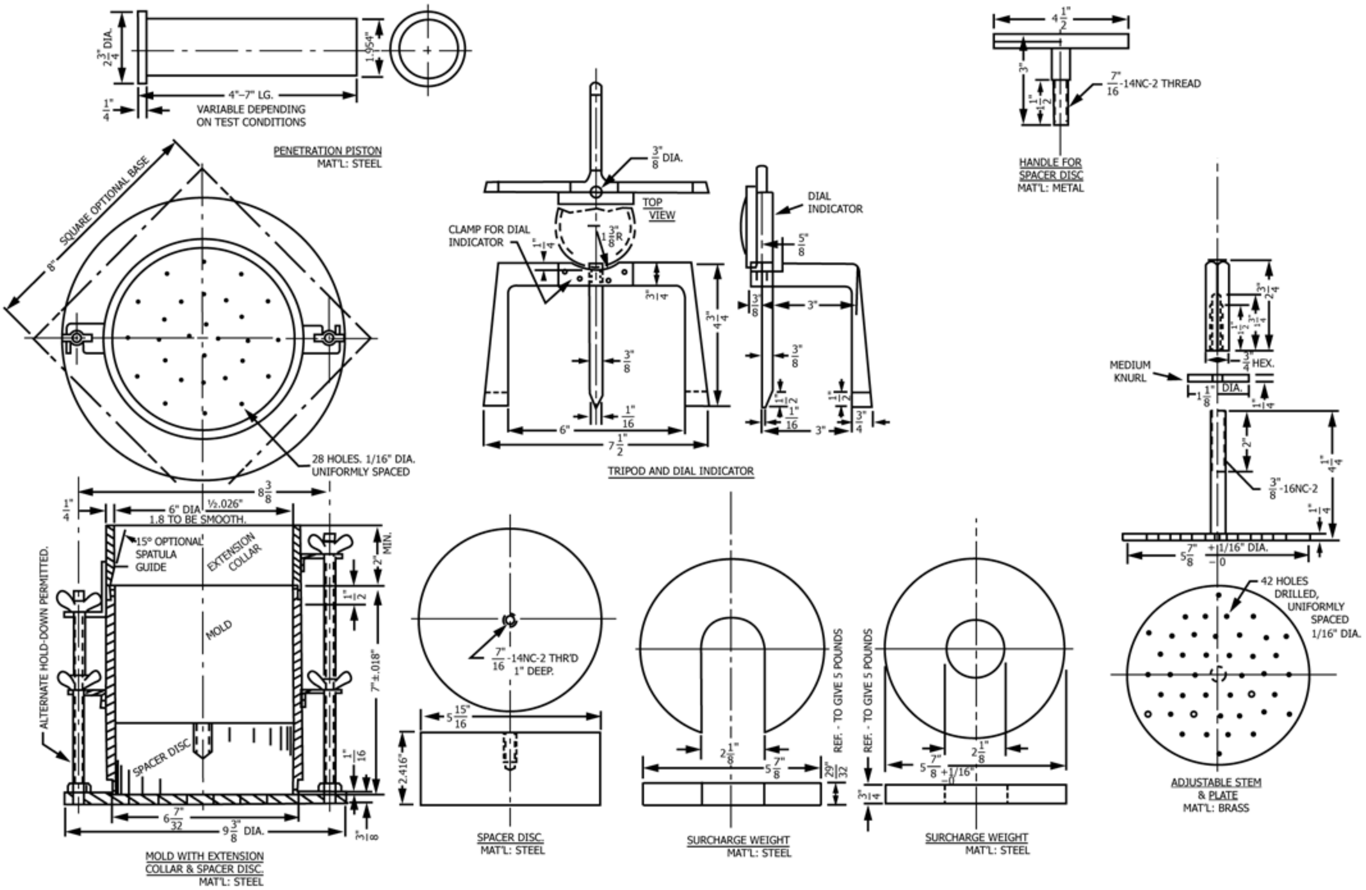
6.8 *Penetration Piston*—A metal piston 1.954 ± 0.005 in. (49.63 ± 0.13 mm) in diameter and not less than 4 in. (101.6 mm) long (see Fig. 1).

6.9 *Balance*—A class GP5 balance meeting the requirements of Specifications D4753 for a balance of 1-g readability.

TABLE 2 SI Equivalents for Figs. 1 and 2

Inch-Pound Units, in.	SI Equivalent, mm	Inch-Pound Units, in.	SI Equivalent, mm	Inch-Pound Units, in.	SI Equivalent, mm
1.954	49.63	1¼	31.8	4½	114.3
2.416	61.37	1⅜	34.90	4¾	120.7
1⁄16	1.59	1½	38.1	5⅞	149.2
¼	6.4	1¾	44.5	5 15⁄16	150.8
⅜	9.53	1⅛	28.58	6.000	152.4
7⁄16	11.11	2	50.8	6 7⁄32	158.0
½	12.70	2⅛	53.98	7.000	177.8
⅝	15.9	2¾	69.85	7½	190.5
¾	19.1	3	76.20	8⅜	212.7
1⅛	28.58	4¼	108.0	9⅜	238.1

Inch-Pound Units, lb	SI Equivalent, kg	Inch-Pound Units, psi	SI Equivalent, MPa
0.10	2.5	200	1.4
0.20	5.1	400	2.8
0.30	7.6	600	4.1
0.40	10.2	800	5.5
0.50	12.7	1000	6.9
		1200	8.3
		1400	9.7



NOTE 1—See Table 2 for SI equivalents.

FIG. 1 Bearing Ratio Test Apparatus

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

6.11 *Sieves*—¾ in. (19 mm) and No. 4 (4.75 mm), conforming to the requirements of Specification E11.

6.12 *Filter Paper*—A fast filtering, high grade hardened, low ash filter paper, 6.000 in. (152.4 mm) diameter.

6.13 *Straightedge*—A stiff metal straightedge of any convenient length but not less than 10.0 in. (254 mm). The total length of the straightedge shall be machined straight to a tolerance of ±0.005 in. (±0.13 mm). The scraping edge shall be beveled if it is thicker than ⅛ in. (3 mm).

6.14 *Soaking Tank or Pan*—A tank or pan of sufficient depth and breath to allow free water around and over the assembled mold. The tank or pan should have a bottom grating that allows free access of water to the perforations in the mold's base.

6.15 *Mixing Tools*—Miscellaneous tools such as mixing pan, spoon, trowel, spatula, etc., or a mechanical device for thoroughly mixing the sample of soil with water.

7. Sample

7.1 The specimen(s) for compaction shall be prepared in accordance with the procedures given in Method C of Test Methods D698 or D1557 for compaction in a 6.000-in. (152.4-mm) mold except as follows:

7.1.1 If all material passes a ¾-in. (19-mm) sieve, the entire gradation shall be used for preparing specimens for compaction without modification. If material is retained on the ¾-in. (19-mm) sieve, the material retained on the ¾-in. (19-mm) sieve shall be removed and replaced by an equal mass of material passing the ¾-in. (19-mm) sieve and retained on the No. 4 (4.75 mm) sieve obtained by separation from portions of the sample not used for testing.

8. Test Specimens

8.1 *Bearing Ratio at Optimum Water Content Only*—Using material prepared as described in 7.1, conduct a control compaction test with a sufficient number of test specimens to establish the optimum water content for the soil using the compaction method specified, either Test Methods D698 or D1557. A previously performed compaction test on the same material may be substituted for the compaction test just described, provided that if the sample contains material retained on the ¾-in. (19-mm) sieve, soil prepared as described in 7.1 is used.

NOTE 2—Maximum dry unit weight obtained from a compaction test performed in a 4.000-in. (101.6-mm) diameter mold may be slightly greater than the maximum dry unit weight obtained from compaction in the 6.000-in. (152.4-mm) compaction mold or CBR mold.

8.1.1 For cases where the CBR is desired at 100 % maximum dry unit weight and optimum water content, compact a specimen using the specified compaction procedure, either Test Methods D698 or D1557, from soil prepared to within ±0.5 percentage point of optimum water content determined in accordance with Test Method D2216.

8.1.2 Where the CBR is desired at optimum water content and some percentage of maximum dry unit weight, compact three specimens from soil prepared to within ±0.5 percentage point of optimum water content and using the specified compaction but using a different number of blows per layer for each specimen. The number of blows per layer shall be varied as necessary to prepare specimens having unit weights above and below the desired value. Typically, if the CBR for soil at 95 % of maximum dry unit weight is desired, specimens compacted using 56, 25, and 10 blows per layer is satisfactory. Penetration shall be performed on each of these specimens.

8.2 *Bearing Ratio for a Range of Water Contents*—Prepare specimens in a manner similar to that described in 8.1 except that each specimen used to develop the compaction curve shall be penetrated. In addition, the complete water content-unit weight relationship for the 25-blows and 10-blows per layer compactions shall be developed and each test specimen compacted shall be penetrated. Perform all compaction in the CBR mold. In cases where the specified unit weight is at or near 100 % maximum dry unit weight, it will be necessary to include a compactive effort greater than 56-blows per layer.

NOTE 3—Where the maximum dry unit weight was determined from compaction in the 4-in. (101.6-mm) mold, it may be necessary to compact specimens as described in 8.1.2, using 75 blows per layer or some other value sufficient to produce a specimen having a unit weight equal to or greater than that required.

NOTE 4—A semilog log plot of dry unit weight versus compactive effort usually gives a straight line relationship when compactive effort in ft-lb/ft^3 is plotted on the log scale. This type of plot is useful in establishing the compactive effort and number of blows per layer needed to bracket the specified dry unit weight and water content range.

8.2.1 Take a representative sample of the material before it is soaked for the determination of water content in accordance with Test Method D2216. If the compaction process is conducted under a controlled temperature range, 65 to 75°F (18 to 24°C), and the processed material is kept sealed during the compaction process, only one representative water content sample is required. However if the compaction process is being conducted in an uncontrolled environment take two water content samples one at the beginning of compaction and another sample of the remaining material after compaction. Use Test Method D2216 to determine the water contents and average the two values for reporting. The two samples should not differ more than 1.5 percentage points to assume reasonable uniformity of the compacted specimen's water content.

8.2.2 If the sample is not to be soaked, take a water content sample in accordance with Test Methods D698 or D1557 if the average water content is desired.

8.2.3 Clamp the mold (with extension collar attached) to the base plate with the hole for the extraction handle facing down. Insert the spacer disk over the base plate and place a disk of filter paper on top of the spacer disk. Compact the soil-water mixture into the mold in accordance with 8.1, 8.1.1, or 8.1.2.

8.2.4 Remove the extension collar and carefully trim the compacted soil even with the top of the mold by means of a straightedge. Patch with smaller size material any holes that may have developed in the surface by the removal of coarse material. Remove the perforated base plate and spacer disk, weigh, and record the mass of the mold plus compacted soil. Place a disk of filter paper on the perforated base plate, invert the mold and compacted soil, and clamp the perforated base plate to the mold with compacted soil in contact with the filter paper.

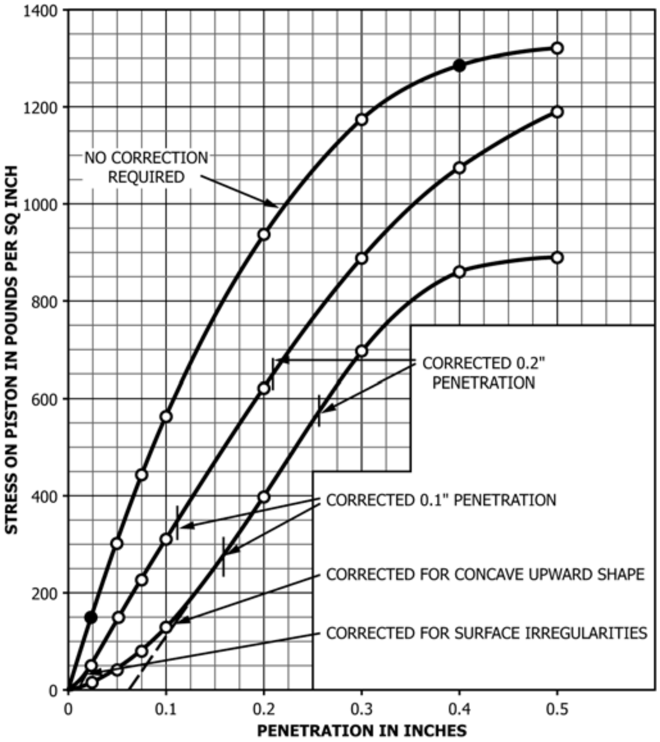
8.2.5 Place the surcharge weights on the perforated plate and adjustable stem assembly and carefully lower onto the compacted soil specimen in the mold. Apply a surcharge equal to the weight of the base material and pavement within 5 lbf or a mass of 2.27 kg, but in no case shall the total weight used be less than 10 lbf or a mass of not less than 4.54 kg. If no surcharge weight is specified, use 10 lbf. The mass of the Expansion Measuring Apparatus is ignored. Immerse the mold and weights in water allowing free access of water to the top and bottom of the specimen. Take initial measurements for swell and allow the specimen to soak for 96 ± 2 hours. Maintain a constant water level during this period. A shorter immersion period is permissible for fine grained soils or granular soils that take up moisture readily, if tests show that the shorter period does not affect the results. At the end of the immersion period, take final swell measurements and calculate the swell as a percentage of the initial height of the specimen.

8.2.6 Remove the free water from the top surface of the specimen and allow the specimen to drain downward for at least 15 minutes. Take care not to disturb the surface of the specimen during the removal of the water. It may be necessary to tilt the specimen in order to remove the surface water. Remove the weights, perforated plate, and filter paper, and determine and record the mass.

NOTE 5—The user may find it convenient to set the mold's base on the rim of a shallow pan to provide the tilt and carefully using a bulb syringe and adsorbent towels to remove free water.

9. Procedure for Bearing Test

9.1 Place a surcharge of weights on the specimen sufficient to produce an intensity of the pavement weight or other loading specified; if no pavement weight is specified, use 10 lbf or a mass of 4.54 kg. If the specimen has been soaked previously, the surcharge shall be equal to that used during the immersion period. To prevent upheaval of soil into the hole of the surcharge weights, place the 5-lbf or a mass of 2.27-kg annular surcharge weight on the soil surface prior to seating the penetration piston, after which place the remainder of the surcharge weights.



NOTE 1—See Table 2 for SI equivalents.

FIG. 2 Correction of Load-Penetration Curves

9.2 Seat the penetration piston with the smallest possible load, but in no case in excess of 10 lbf (44 N). Either set both the load and penetration gauges to zero or make provisions to subtract any initial values from all subsequently collected data. This initial load is required to ensure satisfactory seating of the piston and shall be considered as the zero load when determining the load penetration relation. Attach the penetrating measuring device in accordance with 6.2.

9.3 Apply the load on the penetration piston so that the rate of penetration is approximately 0.05 in. (1.27 mm)/min. Record the load readings at penetrations of 0.025 in. (0.64 mm), 0.050 in. (1.3 mm), 0.075 in. (1.9 mm), 0.100 in. (2.5 mm), 0.125 in. (3.18 mm), 0.150 in. (3.8 mm), 0.175 in. (4.45 mm), 0.200 in. (5.1 mm), 0.300 in. (7.6 mm), 0.400 in. (10 mm) and 0.500 in. (13 mm). Note the maximum load and penetration if it occurs for a penetration of less than 0.500 in. (13 mm). With manually operated loading devices, it may be necessary to take load readings at closer intervals to control the rate of penetration. Measure the depth of piston penetration into the soil by putting a ruler into the indentation and measuring the difference from the top of the soil to the bottom of the indentation. If the depth does not closely match the depth of penetration gauge, determine the cause and test a new sample.

NOTE 6—At high loads the supports may torque and affect the reading of the penetration gauge. Checking the depth of piston penetration is one means of checking for erroneous strain indications.

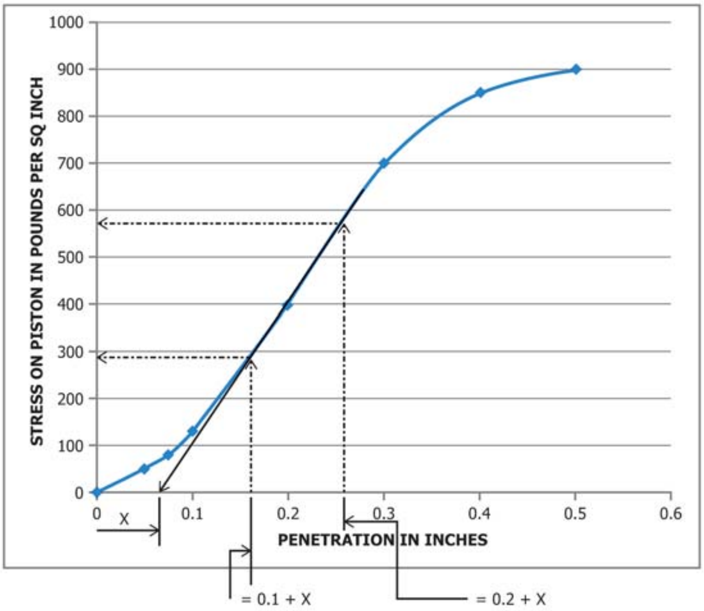
9.4 If the test specimen was previously soaked, remove the soil from the mold and determine the water content of the top 1-in. (25.4-mm) layer in accordance with Test Method D2216. If the test specimen was not soaked, take the water content sample in accordance with Test Methods D698 or D1557.

10. Calculation

10.1 *Load-Penetration Curve*—Calculate the penetration stress in pounds per square inch (psi) or megapascals (MPa) and plot the stress versus penetration curve. In some instances, the stress-penetration curve may be concave upward initially, because of surface irregularities or other causes, and in such cases the zero point shall be adjusted as shown in Figs. 2 and 3.

NOTE 7—Figs. 2 and 3 should be used as an example of correction of load-penetration curves only. It is not meant to imply that stress on piston at the 0.2-in. penetration is always greater than the applied stress at the 0.1-in. penetration.

10.2 *Bearing Ratio*—Using corrected stress values taken from the stress penetration curve for 0.100 in. (2.54 mm) and 0.200 in. (5.08 mm) penetrations, calculate the bearing ratios for each by dividing the corrected stresses by the standard stresses of 1000 psi (6.9 MPa) and 1500 psi (10 MPa) respectively, and multiplying by 100. Also, calculate the bearing ratios for the maximum stress, if the penetration is less



When adjusting a concave upward shaped curve, project a straight line through the straight line portion of the stress-penetration curve downward until it intersects the penetration axis. Measure the distance (X) from the origin to the intersection. This distance (X) is then added to 0.1 and 0.2 of the penetrations and this creates a new 0.1 and 0.2 penetration. Project a straight line upward from these new penetration points until it intersects the stress-penetration curve and then select the appropriate stress values that correspond with new 0.1 and 0.2 penetrations.

FIG. 3 Method for Adjusting Concave Upward Shaped Curve

than 0.200 in. (5.08 mm) by interpolating the standard stress. The bearing ratio reported for the soil is normally the one at 0.100 in. (2.5 mm) penetration. When the ratio at 0.200 in. (5.08 mm) penetration is greater, rerun the test. If the check test gives a similar result, use the bearing ratio at 0.200 in. (5.08 mm) penetration.

NOTE 8—On occasion the testing agency may be requested to determine the CBR value for a dry unit weight not represented by the laboratory compaction curve. For example, the corrected CBR value for the dry unit weight at 95 % of maximum dry unit weight and at optimum water content might be requested. A recommended method to achieve this value is to compact two or three CBR test specimens at the same molding water content but compact each specimen to different compaction energies to achieve a density below and above the desired value. The corrected CBR values are plotted against the dry unit weight and the desired CBR value interpreted as illustrated in Fig. 4. For consistency the corrected CBR values should be of identical origin, for example, all either soaked or un-soaked and all either at 0.1 or 0.2 corrected penetration values.

10.3 Calculate the dry density, ρ_d, of the compacted specimen (before soaking) as follows:

$$\rho_d = \frac{M_{sas}}{V_m}$$

where:

$$M_{sac} = \frac{M_{m+ws} - M_m}{(1 + w_{ac})}$$

M_{sac} = dry mass of soil as compacted, Mg or g,
M_{m+ws} = wet mass of soil as molded plus mold mass, Mg or g,
M_m = mold mass, Mg or g,
w_{ac} = water content determination of representative scraps taken during the compaction process, and
V_m = volume of mold (area of mold × initial height), a calibrated value, m^3 or cm^3.

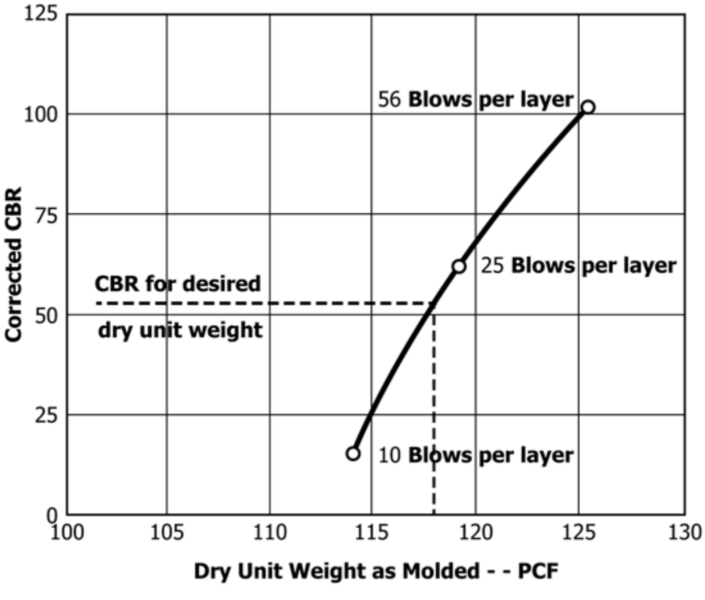


FIG. 4 Dry Unit Weight Versus CBR

10.3.1 Calculate the dry unit weight as follows:

$$\gamma_d = 9.8066 \times \rho_d,\ kN/m^3$$

or,

$$\gamma_d = 62.428 \times \rho_d,\ lbf/ft^3$$

where:

γ_d = dry unit weight, kN/m^3 or lbf/ft^3,
9.8066 = conversion factor, Mg/m^3 or g/cm^3 to kN/m^3, and
62.428 = conversion factor, Mg/m^3 or g/cm^3 to lbf/ft^3.

10.4 If the test specimen was soaked, calculate the percent swell as follows:

$$s = \left(\frac{S}{h_i} \right) \times 100$$

where:

s = swell that occurred during soaking, %,
S = vertical swell determined from the final minus initial swell measurement, in. (mm)
h_i = height of test specimen before swell, in. (mm).

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

11.1 The methodology used to specify how data are recorded on the test data sheet(s)/form(s), as given below, is covered in 1.9.

11.2 Record as a minimum the following general information (data):

11.2.1 Any special sample preparation and testing procedures (for example, for self-cementing materials).

11.2.2 Sample identification (location, boring number, etc.).

11.2.3 Any pertinent testing done to describe the test sample such as: as-received water content per Test Method D2216, soil classifications per Test Method D2487, visual classification per Practice D2488, Atterberg Limits per Test Method D4318, gradation per Method D422, etc.

11.2.4 The percent material retained on the 19-mm sieve for those cases where scalping and replacement is used.

11.2.5 Technician name/initials of personnel performing the test.

11.2.6 Date(s) of testing.

11.3 Record as a minimum the following test specimen data:

11.3.1 Method used for preparation and compaction of specimen: Test Methods D698 or D1557, or other, with description.

11.3.2 Condition of sample (unsoaked or soaked).

11.3.3 Dry unit weight of sample as compacted (before soaking).

11.3.4 Water content of sample in percent:

11.3.4.1 As compacted.

11.3.4.2 Top 1-in (25.4-mm) layer after soaking.

11.3.5 Swell (percentage of initial height).

11.3.6 Stress-penetration curve.

11.3.7 Corrected CBR value of sample (unsoaked or soaked) at 0.100 in. (2.5 mm) penetration or at 0.200 in. (5.08 mm) penetration, percent.

11.3.8 Surcharge weight(s) used for the testing.

11.3.9 Immersion period, hours.

12. Precision and Bias

12.1 *Precision*—Test data on precision is not presented due to the nature of the materials tested by this test method. It is either not feasible or too costly at this time to have ten or more laboratories participate in a round-robin testing program. Notwithstanding this statement the following is offered for guidance:

12.1.1 One user, based on seven repetitions, has developed a IS % of 8.2 % (compacted per Test Method D698) and 5.9 % (compacted per Test Method D1557). See Appendix X1 for the data used.

12.1.2 Subcommittee D18.05 is seeking any data from the users of this test method that might be used to make a more thorough statement on precision.

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

13. Keywords

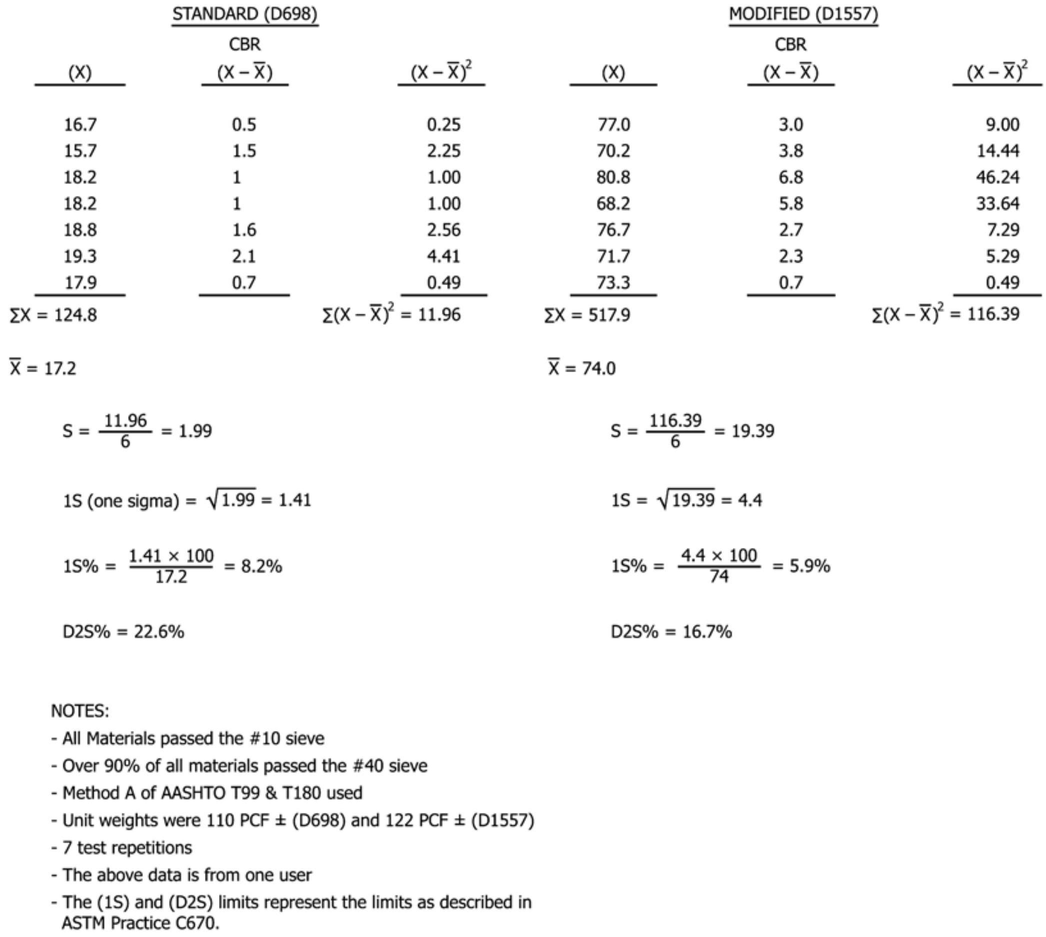
13.1 California Bearing Ratio; CBR; pavement subgrade; subbase; strength; pavement design

APPENDIX

(Nonmandatory Information)

X1.

X1.1 See Fig. X1.1 for more information.



STANDARD (D698)			MODIFIED (D1557)		
	CBR			CBR	
(X)	$(X - \bar{X})$	$(X - \bar{X})^2$	(X)	$(X - \bar{X})$	$(X - \bar{X})^2$
16.7	0.5	0.25	77.0	3.0	9.00
15.7	1.5	2.25	70.2	3.8	14.44
18.2	1	1.00	80.8	6.8	46.24
18.2	1	1.00	68.2	5.8	33.64
18.8	1.6	2.56	76.7	2.7	7.29
19.3	2.1	4.41	71.7	2.3	5.29
17.9	0.7	0.49	73.3	0.7	0.49
$\Sigma X = 124.8$		$\Sigma(X - \bar{X})^2 = 11.96$	$\Sigma X = 517.9$		$\Sigma(X - \bar{X})^2 = 116.39$

$\bar{X} = 17.2$

$$S = \frac{11.96}{6} = 1.99$$

$$1S \text{ (one sigma)} = \sqrt{1.99} = 1.41$$

$$1S\% = \frac{1.41 \times 100}{17.2} = 8.2\%$$

$D2S\% = 22.6\%$

$\bar{X} = 74.0$

$$S = \frac{116.39}{6} = 19.39$$

$$1S = \sqrt{19.39} = 4.4$$

$$1S\% = \frac{4.4 \times 100}{74} = 5.9\%$$

$D2S\% = 16.7\%$

NOTES:
- All Materials passed the #10 sieve
- Over 90% of all materials passed the #40 sieve
- Method A of AASHTO T99 & T180 used
- Unit weights were 110 PCF ± (D698) and 122 PCF ± (D1557)
- 7 test repetitions
- The above data is from one user
- The (1S) and (D2S) limits represent the limits as described in ASTM Practice C670.

FIG. X1.1 Compactive Effort

SUMMARY OF CHANGES

Committee D18 has identified the location of selected changes to this standard since the last issue (D1883 – 07$^{\epsilon 2}$) that may impact the use of this standard. (Approved December 1, 2014)

(1) Revised Section 1 to address units of measurement.
(2) Revised 3.1.1.
(3) Revised Table 2 to remove conversions not needed.
(4) Revised several typos and significant digits.
(5) Revised sentences for clarity.
(6) Added some clairification to 9.4 and 10.1.
(7) Changes were made throughout to bring standard up to current Committee D18 wording and formatting.

استاندارد آزمایش تک محوری محدود نشده

ASTM-D2166-13

Designation: D2166/D2166M – 13

Standard Test Method for Unconfined Compressive Strength of Cohesive Soil[1]

This standard is issued under the fixed designation D2166/D2166M; 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 This test method covers the determination of the unconfined compressive strength of cohesive soil in the intact, remolded, or reconstituted condition, using strain-controlled application of the axial load.

1.2 This test method provides an approximate value of the strength of cohesive soils in terms of total stresses.

1.3 This test method is applicable only to cohesive materials which will not expel or bleed water (water expelled from the soil due to deformation or compaction) during the loading portion of the test and which will retain intrinsic strength after removal of confining pressures, such as clays or cemented soils. Dry and crumbly soils, fissured or varved materials, silts, peats, and sands cannot be tested with this method to obtain valid unconfined compression strength values.

NOTE 1—The determination of the unconsolidated, undrained strength of cohesive soils with lateral confinement is covered by Test Method D2850.

1.4 This test method is not a substitute for Test Method D2850.

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

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

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

1.6.1 The gravitational system of inch-pound units is used when dealing with inch-pound units. In this system, the pound (lbf) represents a unit of force (weight), while the unit for mass is slugs. The rationalized slug unit is not given, unless dynamic (F = ma) calculations are involved.

1.6.2 It is common practice in the engineering/construction profession to concurrently use pounds to represent both a unit of mass (lbm) and 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. As stated, this standard includes the gravitational system of inch-pound units and does not use/present the slug unit for mass. However, the use of balances or scales recording pounds of mass (lbm) or recording density in lbm/ft^3 shall not be regarded as nonconformance with this standard.

1.7 *This standard does not purport to address all of the safety problems, 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
D854 Test Methods for Specific Gravity of Soil Solids by Water Pycnometer
D1587 Practice for Thin-Walled Tube Sampling of Soils for Geotechnical Purposes
D2216 Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass
D2488 Practice for Description and Identification of Soils (Visual-Manual Procedure)

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

---

[1] This test method is under the jurisdiction of ASTM Committee D18 on Soil and Rock and is the direct responsibility of Subcommittee D18.05 on Strength and Compressibility of Soils.

Current edition approved May 15, 2013. Published August 2013. Originally approved in 1963. Last previous edition approved in 2006 as D2166 – 06. DOI: 10.1520/D2166_D2166M-13.

[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.

D2850 Test Method for Unconsolidated-Undrained Triaxial Compression Test on Cohesive Soils
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
D4318 Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils
D6026 Practice for Using Significant Digits in Geotechnical Data
D6913 Test Methods for Particle-Size Distribution (Gradation) of Soils Using Sieve Analysis
D7263 Test Methods for Laboratory Determination of Density (Unit Weight) of Soil Specimens
E177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods
E691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method

3. Terminology

3.1 *Definitions:*

3.1.1 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 *unconfined compressive strength (q_u)*—the compressive stress at which an unconfined cylindrical specimen of soil will fail in a simple compression test; in this test method, unconfined compressive strength is taken as the maximum load attained per unit area or the load per unit area at 15 % axial strain, whichever is secured first during the performance of a test.

3.2.2 *shear strength (s_u)*—for unconfined compressive strength test specimens, the shear strength is calculated to be ½ of the compressive stress at failure, as defined in 3.2.1.

4. Summary of Test Method

4.1 In this test method, a cylindrical soil specimen is unconfined laterally while loaded axially at an axial strain rate between 0.5 to 2 %/min. Measurements are made of elapsed time, axial deformation, and axial load. The unconfined compressive stress, q_u, is calculated as the compressive stress at failure. The shear strength, s_u, is one half of the unconfined compressive strength.

5. Significance and Use

5.1 The primary purpose of the unconfined compression test is to quickly obtain a measure of compressive strength for those soils that possess sufficient cohesion to permit testing in the unconfined state.

5.2 Samples of soils having slickensided or fissured structure, samples of some types of loess, very soft clays, dry and crumbly soils and varved materials, or samples containing significant portions of silt or sand, or both (all of which usually exhibit cohesive properties), frequently display higher shear strengths when tested in accordance with Test Method D2850. Also, unsaturated soils will usually exhibit different shear strengths when tested in accordance with Test Method D2850.

5.3 If tests on the same sample in both its intact and remolded states are performed, the sensitivity of the material can be determined. This method of determining sensitivity is suitable only for soils that can retain a stable specimen shape in the remolded state.

NOTE 2—For soils that will not retain a stable shape, a vane shear test or Test Method D2850 can be used to determine sensitivity.

NOTE 3—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. 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 *Compression Device*—The compression device may be a platform weighing scale equipped with a screw-jack-activated load yoke, a hydraulic loading device, or any other compression device with sufficient capacity and control to provide the rate of loading prescribed in 8.1. The compression device shall be capable of measuring the compressive stress to three significant digits at the maximum stress, or within 1 kPa [0.01 ton/ft^2], whichever is larger.

6.2 *Sample Extruder,* capable of extruding the soil core from the sampling tube at a uniform rate in the same direction of travel in which the sample entered the tube, and with negligible disturbance of the sample. Conditions at the time of sample removal may dictate the direction of removal, but the principal concern is to reduce the potential for additional disturbance beyond that incurred during initial sampling.

6.3 *Deformation Indicator*—The deformation indicator shall be a dial indicator graduated to 0.03 mm [0.001 in.] or better and having a travel range of at least 20 % of the length of the test specimen, or some other measuring device, such as an electronic deformation measuring device, meeting these requirements.

6.4 *Dial Comparator,* or other suitable device, for measuring the physical dimensions of the specimen to within 0.1 % of the measured dimension.

NOTE 4—Vernier calipers are not recommended for soft specimens, which will deform as the calipers are applied on the specimen.

6.5 *Timer*—A timing device indicating the elapsed testing time to the nearest second shall be used for establishing the rate of strain application prescribed in 8.1.

6.6 *Balance*—The balance used to weigh specimens shall determine the mass of the specimen to within 0.1 % of its total mass.

6.7 *Equipment,* as specified in Test Method D2216.

6.8 *Miscellaneous Apparatus,* including specimen trimming and carving tools, remolding apparatus, water content cans, and data sheets, as required.

7. Preparation of Test Specimens

7.1 *Specimen Size*—Specimens shall have a minimum diameter of 30 mm [1.3 in.] and the largest particle contained within the test specimen shall be smaller than one tenth of the specimen diameter. For specimens having a diameter of 72 mm [2.8 in.] or larger, the largest particle size shall be smaller than one sixth of the specimen diameter. If, after completion of a test on an intact specimen, it is found, based on visual observation, that larger particles than permitted are present, indicate this information in the remarks section of the report of test data (Note 5). The height-to-diameter ratio shall be between 2 and 2.5. Determine the average height and diameter of the test specimen using the apparatus specified in 6.4. Take a minimum of three height measurements (approximately 120° apart), and at least three diameter measurements at approximately the quarter points of the height.

NOTE 5—If large soil particles are found in the specimen after testing, a particle-size analysis performed in accordance with Test Method D6913 may be performed to confirm the visual observation and the results provided with the test report.

7.2 *Intact Specimens*—Prepare intact specimens from large samples or from samples secured in accordance with Practice D1587 and preserved and transported in accordance with the practices for Group C samples in Practices D4220. Tube specimens may be tested without trimming except for the squaring of ends, if conditions of the sample justify this procedure. Handle specimens carefully to reduce the potential for additional disturbance, changes in cross section, or loss of water content. If compression or any type of noticeable disturbance would be caused by the extrusion device, split the sample tube lengthwise or cut it off in small sections to facilitate removal of the specimen with minimal disturbance. Prepare carved specimens with minimal disturbance, and whenever possible, in a humidity-controlled room. Make every effort to prevent a change in water content of the soil. Specimens shall be of uniform circular cross section with ends perpendicular to the longitudinal axis of the specimen. When carving or trimming, remove any small pebbles or shells encountered. Carefully fill voids on the surface of the specimen with remolded soil obtained from the trimmings. When pebbles or crumbling result in excessive irregularity at the ends, cap the specimen with a minimum thickness of plaster of paris, hydrostone, or similar material. When sample condition permits, a vertical lathe that will accommodate the total sample may be used as an aid in carving the specimen to the required diameter. Where prevention of the development of appreciable capillary forces is deemed important, seal the specimen with a rubber membrane, thin plastic coatings, or with a coating of grease or sprayed plastic immediately after preparation and during the entire testing cycle. Determine the mass and dimensions of the test specimen. If the specimen is to be capped, its mass and dimensions should be determined before capping. If the entire test specimen is not to be used for determination of water content, secure a representative sample of trimmings for this purpose, placing them immediately in a covered container. The water content determination shall be performed in accordance with Test Method D2216. Initial dry density determination shall be performed in accordance with Test Method D7263.

7.3 *Remolded Specimens*—Specimens may be prepared either from a failed intact specimen or from a disturbed sample, providing it is representative of the failed intact specimen. In the case of failed intact specimens, wrap the material in a thin rubber membrane and work the material thoroughly with the fingers to assure complete remolding. Avoid entrapping air in the specimen. Exercise care to obtain a uniform density, to remold to the same void ratio as the intact specimen, and to preserve the natural water content of the soil. Form the disturbed material into a mold of circular cross section having dimensions meeting the requirements of 7.1. After removal from the mold, determine the mass and dimensions of the test specimens.

7.4 *Reconstituted Specimens*—Specimens shall be prepared to the predetermined water content and density prescribed by the individual assigning the test (Note 6). After a specimen is formed, trim the ends perpendicular to the longitudinal axis, remove from the mold, and determine the mass and dimensions of the test specimen.

NOTE 6—Experience indicates that it is difficult to compact, handle, and obtain valid results with specimens that have a degree of saturation that is greater than 90 %.

8. Procedure

8.1 Place the specimen in the loading device so that it is centered on the bottom platen. Adjust the loading device carefully so that the upper platen just makes contact with the specimen. Zero the deformation indicator or record the initial reading of the electronic deformation device. Apply the load so as to produce an axial strain at a rate of ½ to 2 %/min. Record load, deformation, and time values at sufficient intervals to define the shape of the stress-strain curve (usually 10 to 15 points are sufficient). The rate of strain should be chosen so that the time to failure does not exceed about 15 min (Note 7). Continue loading until the load values decrease with increasing strain, or until 15 % strain is reached. Indicate the rate of strain in the report of the test data, as required in 10.3.6. Determine the water content of the test specimen using the entire specimen, unless representative trimmings are obtained for this purpose, as in the case of intact specimens. Indicate on the test report whether the water content sample was obtained before or after the shear test, as required in 10.3.1.

NOTE 7—Softer materials that will exhibit larger deformation at failure should be tested at a higher rate of strain. Conversely, stiff or brittle materials that will exhibit small deformations at failure should be tested at a lower rate of strain.

8.2 Make a sketch, or take a photo, of the test specimen at failure showing the slope angle of the failure surface if the angle is measurable.

8.3 A copy of a example data sheet is included in Appendix X1. Any data sheet can be used, provided the form contains all the required data.

9. Calculation

9.1 Calculate the axial strain, ε_1, to the nearest 0.1 %, for a given applied load, as follows:

$$\varepsilon_1 = \frac{\Delta L}{L_0} \times 100$$

where:

ΔL = length change of specimen as read from deformation indicator or computed from the electronic device, mm [in.], and

L_0 = initial length of test specimen, mm [in.].

9.2 Calculate the average cross-sectional area, A, for a given applied load, as follows:

$$A = \frac{A_0}{\left(1 - \frac{\varepsilon_1}{100}\right)}$$

where:

A_0 = initial average cross-sectional area of the specimen, mm^2 [in.^{2}], and

ε_1 = axial strain for the given load, expressed as a percent.

9.3 Calculate the compressive stress, σ_c, to three significant figures or nearest 1 kPa [0.01 ton/ft^2], for a given applied load, as follows:

$$\sigma_c = (P/A)$$

where:

P = given applied load, kN [lbf],

A = corresponding average cross-sectional area mm^2 [in.^{2}].

9.4 *Graph*—If desired, a graph showing the relationship between compressive stress (ordinate) and axial strain (abscissa) may be plotted. Select the maximum value of compressive stress, or the compressive stress at 15 % axial strain, whichever is secured first, and report as the unconfined compressive strength, q_u. Whenever it is considered necessary for proper interpretation, include the graph of the stress-strain data as part of the data reported.

9.5 If both the intact and remolded compressive strengths are measured, determine the sensitivity, S_T, as follows:

$$S_T = \frac{q_u\,(\text{intact specimen})}{q_u\,(\text{remolded specimen})}$$

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

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 1.5.

10.2 Record as a minimum the following general information (data):

10.2.1 Identification and visual description of the specimen, including soil classification, symbol, and whether the specimen is intact, remolded, reconstituted, etc. Also include specimen identifying information, such as project, location, boring number, sample number, depth, etc. Visual descriptions shall be made in accordance with Practice D2488.

10.3 Record as a minimum the following test data:

10.3.1 Initial dry density and water content (specify if the water content specimen was obtained before or after shear, and whether from trimmings or the entire specimen),

10.3.2 Degree of saturation (Note 8), if computed,

NOTE 8—The specific gravity determined in accordance with Test Method D854 is required for calculation of the degree of saturation.

10.3.3 Unconfined compressive strength and shear strength,

10.3.4 Average height and diameter of specimen,

10.3.5 Height-to-diameter ratio,

10.3.6 Average rate of strain to failure, %,

10.3.7 Strain at failure, %,

10.3.8 Liquid and plastic limits, if determined, in accordance with Test Method D4318,

10.3.9 Failure sketch or photo,

10.3.10 Stress-strain graph, if prepared,

10.3.11 Sensitivity, if determined,

10.3.12 Particle size analysis, if determined, in accordance with Test Method D6913, and

10.3.13 *Remarks*—Note any unusual conditions or other data that would be considered necessary to properly interpret the results obtained, for example, slickensides, stratification, shells, pebbles, roots, or brittleness, the type of failure (that is, bulge, diagonal shear, etc.).

11. Precision and Bias

11.1 *Precision*—Criteria for judging the acceptability of test results obtained by this test method on rigid polyurethane foam (density about 0.09 g/cm^3) is given in Table 1. These estimates of precision are based on the results of the interlaboratory program conducted by the ASTM Reference Soils and Testing Program.[3] The precision estimates will vary with the material/soil type being tested, and judgement is required when applying these estimates to soil.

11.1.1 The data in Table 1 are based on three replicate tests performed by each test laboratory. The single-operator and multilaboratory standard deviation shown in Table 1, Column 4, were obtained in accordance with Practice E691. Results of two properly conducted tests performed by the same operator

---

[3] Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:D18-1014. Contact ASTM Customer Service at service@astm.org.

TABLE 1 Summary of Test Results from Each Laboratory (Compressive Strength Data on Rigid Polyurethane Foam (density about 0.09 g/cm^3))

(1) Number of Triplicate Test Laboratories	(2) Test Parameter[A]	(3) Average Value[B]	(4) Standard Deviation[C]	(5) Acceptable Range of Two Results[D]
Single-Operator Results (Wiithin-Laboratory Repeatability):				
22	Strength, kPa	989	42	120
22	Strain, %	4.16	0.32	0.9
Multilaboratory Results (Between- Laboratory Reproducibility):				
22	Strength, kPa	989	53	150
22	Strain, %	4.16	0.35	1.0

[A] Strength = peak compressive stress and strain = axial strain at peak compressive stress.

[B] The number of significant digits and decimal places presented are representative of the input data. In accordance with Practice D6026, the standard deviation and acceptable range of results can not have more decimal places than the input data.

[C] Standard deviation is calculated in accordance with Practice E691 and is referred to as the 1*s* limit.

[D] Acceptable range of two results is referred to as the *d2s* limit. It is calculated as $1.960\sqrt{2}\cdot 1s$, as defined by Practice E177. The difference between two properly conducted tests should not exceed this limit. The number of significant digits/decimal places presented is equal to that prescribed by this test method or Practice D6026. In addition, the value presented can have the same number of decimal places as the standard deviation, even if that result has more significant digits than the standard deviation.

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 *d2s* limits shown in Table 1, Column 5. For definition of *d2s* see Footnote D in Table 1. Results of two properly conducted tests performed by different operators and on different days should not differ by more than the multilaboratory *d2s* limits shown in Table 1, Column 5.

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

12. Keywords

12.1 cohesive soil; sensitivity; strain-controlled loading; strength; stress-strain relationships; unconfined compression

APPENDIX

(Nonmandatory Information)

X1. EXAMPLE DATA SHEET

X1.1 See Fig. X1.1.

UNCONFINED COMPRESSION TEST—UI

Name ______________________ Date ______________ Job No. ______________

Location ____

Boring No. ______________________ Sample No. ______________ Depth/Elev. ______________

Description of Sample ____

____

Proving Ring No. ______________________________ Apparatus No. ______________

Water Content Determination

Tare No. ______________

Wt. Specimen Wet + Tare

Wt. Specimen Dry + Tare

Wt. Water ______________

Wt. Tare ______________

Wt. Specimen Wet ______________

Wt. Specimen Dry ______________

Water Content in % Dry Wt.

at 105°C ______________ %

Wet Density ______________

Dry Density ______________

Unconfined Compressive Strength

Initial Diameter D_o ______________

Initial Area A_o ______________

Initial Height L_o ______________

Initial Volume V_o ______________

Specific Gravity ______________

Stress = $\frac{\text{Load}}{\text{Corr. Area}}$

Test Data

Unit Strain $\frac{\Delta L}{L_o}$

$\frac{L}{D}$ = ______________

Corr. Area = $\frac{A_o}{1 - \text{Unit Strain}}$

Elapsed Time-min	Load Dial	Axial Load	Strain Dial	Total Strain	Unit Strain	Corrected Area	Stress	

Type of Sample ______________

Attach a photo or sketch of the specimen after failure to this form

Strain Rate ______________ %/Min

Remarks ____

____

FIG. X1.1 Example Data Sheet

SUMMARY OF CHANGES

Committee D18 has identified the location of selected changes to this standard since the last issue (D2166 – 06) that may impact the use of this standard. (Approved May 15, 2013.)

(1) Updated units of measurement in 1.6 and throughout.
(2) Revised Sections 3 and 10.
(3) Added Section 4.
(4) Revised 6.1 to be consistent with 9.3.
(5) Added reference to D7263 in Section 2.1 and 7.2.
(6) Corrected 9.2 for consistency.

استاندارد آزمایش تراکم

ASTM-D698-12

Designation: D698 – 12$^{\varepsilon 1}$

Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (12 400 ft-lbf/ft^3 (600 kN-m/m^3))[1]

ε^1 NOTE—Editorial corrections made throughout in January 2014.

---

1. Scope*

1.1 These test methods cover laboratory compaction methods used to determine the relationship between molding water content and dry unit weight of soils (compaction curve) compacted in a 4 or 6-in. (101.6 or 152.4-mm) diameter mold with a 5.50-lbf (24.5-N) rammer dropped from a height of 12.0 in. (305 mm) producing a compactive effort of 12 400 ft-lbf/ft^3 (600 kN-m/m^3).

NOTE 1—The equipment and procedures are similar as those proposed by R. R. Proctor (*Engineering News Record*—September 7, 1933) with this one major exception: his rammer blows were applied as "12 inch firm strokes" instead of free fall, producing variable compactive effort depending on the operator, but probably in the range 15 000 to 25 000 ft-lbf/ft^3 (700 to 1200 kN-m/m^3). The standard effort test (see 3.1.4) is sometimes referred to as the Proctor Test.

1.1.1 Soils and soil-aggregate mixtures are to be regarded as natural occurring fine- or coarse-grained soils, or composites or mixtures of natural soils, or mixtures of natural and processed soils or aggregates such as gravel or crushed rock. Hereafter referred to as either soil or material.

1.2 These test methods apply only to soils (materials) that have 30 % or less by mass of particles retained on the ¾-in. (19.0-mm) sieve and have not been previously compacted in the laboratory; that is, do not reuse compacted soil.

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

1.3 Three alternative methods are provided. 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 material gradation.

1.3.1 *Method A:*

1.3.1.1 *Mold*—4-in. (101.6-mm) diameter.

1.3.1.2 *Material*—Passing No. 4 (4.75-mm) sieve.

1.3.1.3 *Layers*—Three.

1.3.1.4 *Blows per Layer*—25.

1.3.1.5 *Usage*—May be used if 25 % or less (see 1.4) by mass of the material is retained on the No. 4 (4.75-mm) sieve.

1.3.1.6 *Other Usage*—If this gradation requirement cannot be met, then Method C may be used.

1.3.2 *Method B:*

1.3.2.1 *Mold*—4-in. (101.6-mm) diameter.

1.3.2.2 *Material*—Passing ⅜-in. (9.5-mm) sieve.

1.3.2.3 *Layers*—Three.

1.3.2.4 *Blows per Layer*—25.

1.3.2.5 *Usage*—May be used if 25 % or less (see 1.4) by mass of the material is retained on the ⅜-in. (9.5-mm) sieve.

1.3.2.6 *Other Usage*—If this gradation requirement cannot be met, then Method C may be used.

1.3.3 *Method C:*

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

1.3.3.2 *Material*—Passing ¾-in. (19.0-mm) sieve.

1.3.3.3 *Layers*—Three.

1.3.3.4 *Blows per Layer*—56.

1.3.3.5 *Usage*—May be used if 30 % or less (see 1.4) by mass of the material is retained on the ¾-in. (19.0-mm) sieve.

1.3.4 The 6-in. (152.4-mm) diameter mold shall not be used with Method A or B.

NOTE 2—Results have been found to vary slightly when a material is tested at the same compactive effort in different size molds, with the smaller mold size typically yielding larger values of density/unit weight (**1**, pp. 21+).[2]

1.4 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 mass and molding water content of the specimen or to the appropriate field-in-place density test specimen using Practice D4718.

---

[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.

Current edition approved May 1, 2012. Published June 2012. Originally approved in 1942. Last previous edition approved in 2000 as D698 – 07$^{\varepsilon 1}$. DOI: 10.1520/D0698-12E01.

[2] The boldface numbers in parentheses refer to the list of references at the end of this standard.

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

1.5 This test method will generally produce a well-defined maximum dry unit weight for non-free draining soils. If this test method is used for free-draining soils the maximum unit weight may not be well defined, and can be less than obtained using Test Methods D4253.

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

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

1.7 The values in inch-pound units are to be regarded as the standard. The values stated in SI units are provided for information only, except for units of mass. The units for mass are given in SI units only, g or kg.

1.7.1 It is common practice in the engineering profession to concurrently use pounds to represent both a unit of mass (lbm) and a 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) or the recording of density in lbm/ft^3 shall not be regarded as a nonconformance with this standard.

1.8 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[3]

C127 Test Method for Density, Relative Density (Specific Gravity), and Absorption of Coarse Aggregate
C136 Test Method for Sieve Analysis of Fine and Coarse Aggregates
D653 Terminology Relating to Soil, Rock, and Contained Fluids
D854 Test Methods for Specific Gravity of Soil Solids by Water Pycnometer
D2168 Practices for Calibration of Laboratory Mechanical-Rammer Soil Compactors
D2216 Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass
D2487 Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)
D2488 Practice for Description and Identification of Soils (Visual-Manual Procedure)
D3740 Practice for Minimum Requirements for Agencies Engaged in Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction
D4253 Test Methods for Maximum Index Density and Unit Weight of Soils Using a Vibratory Table
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
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
D6913 Test Methods for Particle-Size Distribution (Gradation) of Soils Using Sieve Analysis
E11 Specification for Woven Wire Test Sieve Cloth and Test Sieves
E177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods
E691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method
IEEE/ASTM SI 10 Standard for Use of the International System of Units (SI): the Modern Metric System

3. Terminology

3.1 *Definitions:*

3.1.1 See Terminology D653 for general definitions.

3.1.2 *molding water content, n*—the adjusted water content of a soil (material) that will be compacted/reconstituted.

3.1.3 *standard effort—in compaction testing*, the term for the 12 400 ft-lbf/ft^3 (600 kN-m/m^3) compactive effort applied by the equipment and methods of this test.

3.1.4 *standard maximum dry unit weight, $\gamma_{d,max}$ in lbf/ft^3 (kN/m^3)—in compaction testing*, the maximum value defined by the compaction curve for a compaction test using standard effort.

3.1.5 *standard optimum water content, w_{opt}* in %—*in compaction testing*, the molding water content at which a soil can be compacted to the maximum dry unit weight using standard compactive effort.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *oversize fraction (coarse fraction), P_C in %*—the portion of total specimen not used in performing the compaction

---

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

test; it may be the portion of total specimen retained on the No. 4 (4.75-mm) sieve in Method A, ⅜-in. (9.5-mm) sieve in Method B, or ¾-in. (19.0-mm) sieve in Method C.

3.2.2 *test fraction (finer fraction), P_F in %*—the portion of the total specimen used in performing the compaction test; it is the fraction passing the No. 4 (4.75-mm) sieve in Method A, passing the ⅜-in. (9.5-mm) sieve in Method B, or passing the ¾-in. (19.0-mm) sieve in Method C.

4. Summary of Test Method

4.1 A soil at a selected molding water content is placed in three layers into a mold of given dimensions, with each layer compacted by 25 or 56 blows of a 5.50-lbf (24.47-N) rammer dropped from a distance of 12.00 in. (304.8 mm), subjecting the soil to a total compactive effort of about 12 400 ft-lbf/ft^3 (600 kN-m/m^3). The resulting dry unit weight is determined. The procedure is repeated for a sufficient number of molding water contents to establish a relationship between the dry unit weight and the molding water content for the soil. This data, when plotted, represents a curvilinear relationship known as the compaction curve. The values of optimum water content and standard maximum dry unit weight are determined from the compaction curve.

5. Significance and Use

5.1 Soil placed as engineering fill (embankments, foundation pads, road bases) is compacted to a dense state to obtain satisfactory engineering properties such as, shear strength, compressibility, or permeability. In addition, foundation soils are often compacted to improve their engineering properties. Laboratory compaction tests provide the basis for determining the percent compaction and molding water content needed to achieve the required engineering properties, and for controlling construction to assure that the required compaction and water contents are achieved.

5.2 During design of an engineered fill, shear, consolidation, permeability, or other tests require preparation of test specimens by compacting at some molding water content to some unit weight. It is common practice to first determine the optimum water content (w_{opt}) and maximum dry unit weight ($\gamma_{d,max}$) by means of a compaction test. Test specimens are compacted at a selected molding water content (w), either wet or dry of optimum (w_{opt}) or at optimum (w_{opt}), and at a selected dry unit weight related to a percentage of maximum dry unit weight ($\gamma_{d,max}$). The selection of molding water content (w), either wet or dry of optimum (w_{opt}) or at optimum (w_{opt}) and the dry unit weight ($\gamma_{d,max}$) may be based on past experience, or a range of values may be investigated to determine the necessary percent of compaction.

5.3 Experience indicates that the methods outlined in 5.2 or the construction control aspects discussed in 5.1 are extremely difficult to implement or yield erroneous results when dealing with certain soils. 5.3.1 – 5.3.3 describe typical problem soils, the problems encountered when dealing with such soils and possible solutions for these problems.

5.3.1 *Oversize Fraction*—Soils containing more than 30 % oversize fraction (material retained on the ¾-in. (19-mm) sieve) are a problem. For such soils, there is no ASTM test method to control their compaction and very few laboratories are equipped to determine the laboratory maximum unit weight (density) of such soils (USDI Bureau of Reclamation, Denver, CO and U.S. Army Corps of Engineers, Vicksburg, MS). Although Test Methods D4914 and D5030 determine the "field" dry unit weight of such soils, they are difficult and expensive to perform.

5.3.1.1 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 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, acceptable range in molding water content, and the number of passes.

NOTE 3—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.

5.3.1.2 Another method is to apply the use of density correction factors developed by the USDI Bureau of Reclamation (**2**, **3**) and U.S. Corps of Engineers (**4**). These correction factors may be applied for soils containing up to about 50 to 70 % oversize fraction. Each agency uses a different term for these density correction factors. The USDI Bureau of Reclamation uses *D* ratio (or *D*–VALUE), while the U.S. Corps of Engineers uses Density Interference Coefficient (I_c).

5.3.1.3 The use of the replacement technique (Test Method D698–78, Method D), in which the oversize fraction is replaced with a finer fraction, is inappropriate to determine the maximum dry unit weight, $\gamma_{d,max}$, of soils containing oversize fractions (**4**).

5.3.2 *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 (**1**, p. 73) 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.

5.3.2.1 Again, for soils subject to degradation, the use of test fills and method specifications may help. Use of replacement techniques is not correct.

5.3.3 *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 judgement.

NOTE 4—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 *Mold Assembly*—The molds shall be cylindrical in shape, made of rigid metal and be within the capacity and dimensions indicated in 6.1.1 or 6.1.2 and Figs. 1 and 2. See also Table 1. 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./ft (16.7 mm/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. (51 mm) which may include an upper section that flares out to form a funnel, provided there is at least a 0.75 in. (19 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 within ±0.005 in. (±0.1 mm).

6.1.1 *Mold, 4 in.*—A mold having a 4.000 ± 0.016-in. (101.6 ± 0.4-mm) average inside diameter, a height of 4.584 ± 0.018 in. (116.4 ± 0.5 mm) and a volume of 0.0333 ± 0.0005 ft^3 (943.0 ± 14 cm^3). A mold assembly having the minimum required features is shown in Fig. 1.

6.1.2 *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 0.0750 ± 0.0009 ft^3 (2124 ± 25 cm^3). A mold assembly having the minimum required features is shown in Fig. 2.

6.2 *Rammer*—A rammer, either manually operated as described further in 6.2.1 or mechanically operated as described in 6.2.2. The rammer shall fall freely through a distance of 12.00 ± 0.05 in. (304.8 ± 1 mm) from the surface of the specimen. The weight of the rammer shall be 5.50 ± 0.02 lbf (24.47 ± 0.09 N, or mass of 2.495 ± 0.009 kg), except that the weight of the mechanical rammers may be adjusted as described in Practices D2168; see Note 5. The striking face of the rammer shall be planar and circular, except as noted in 6.2.2.1, with a diameter when new of 2.000 ± 0.005 in. (50.80 ± 0.13 mm). The rammer shall be replaced if the striking face becomes worn or bellied to the extent that the diameter exceeds 2.000 ± 0.01 in. (50.80 ± 0.25 mm).

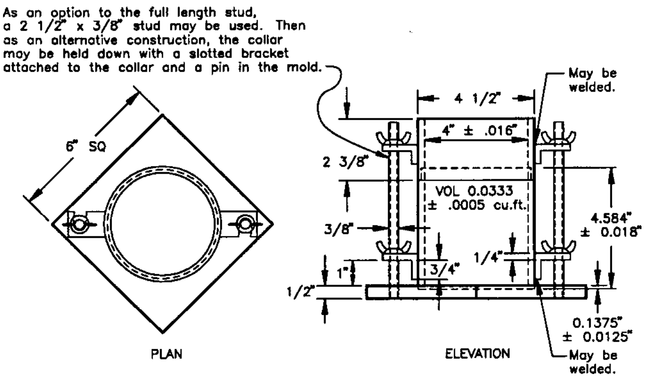


FIG. 1 4.0-in. Cylindrical Mold

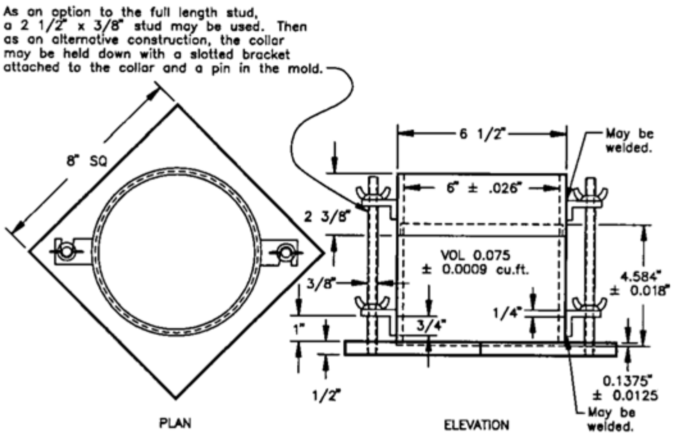


FIG. 2 6.0-in. Cylindrical Mold

TABLE 1 Metric Equivalents for Figs. 1 and 2

in.	mm
0.016	0.41
0.026	0.66
0.032	0.81
0.028	0.71
½	12.70
2½	63.50
2⅝	66.70
4	101.60
4½	114.30
4.584	116.43
4¾	120.60
6	152.40
6½	165.10
6⅝	168.30
6¾	171.40
8¼	209.60
ft^3	cm^3
1⁄30 (0.0333)	943
0.0005	14
(0.0750)	2,124
0.0011	31

NOTE 5—It is a common and acceptable practice to determine the weight of the rammer using either a kilogram or pound balance and assume 1 lbf is equivalent to 0.4536 kg, 1 lbf is equivalent to 1 lbm, or 1 N is equivalent to 0.2248 lbf or 0.1020 kg.

6.2.1 *Manual Rammer*—The rammer shall be equipped with a guide sleeve that has sufficient clearance that the free fall of the rammer shaft and head is not restricted. The guide sleeve shall have at least four vent holes at each end (eight holes total) located with centers ¾ ± 1⁄16 in. (19 ± 2 mm) from each end and spaced 90 degrees apart. The minimum diameter of the vent holes shall be ⅜ in. (9.5 mm). Additional holes or slots may be incorporated in the guide sleeve.

6.2.2 *Mechanical Rammer-Circular Face*—The rammer shall operate mechanically in such a manner as to provide uniform and complete coverage of the specimen surface. There shall be 0.10 ± 0.03-in. (2.5 ± 0.8-mm) clearance between the rammer and the inside surface of the mold at its smallest diameter. The mechanical rammer shall meet the standardization/calibration requirements of Practices D2168.

The mechanical rammer shall be equipped with a positive mechanical means to support the rammer when not in operation.

6.2.2.1 *Mechanical Rammer-Sector Face*—The sector face can be used with the 6-in. (152.4-mm) mold, as an alternative to the circular face mechanical rammer described in 6.2.2. The striking face shall have the shape of a sector of a circle of radius equal to 2.90 ± 0.02 in. (73.7 ± 0.5 mm) and an area about the same as the circular face, see 6.2. The rammer shall operate in such a manner that the vertex of the sector is positioned at the center of the specimen and follow the compaction pattern given in Fig. 3b.

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

6.4 *Balance*—A Class GP5 balance meeting the requirements of Guide D4753 for a balance of 1-g readability. If the water content of the compacted specimens is determined using a representative portion of the specimen, rather than the whole specimen, and if the representative portion is less than 1000 g, a Class GP2 balance having a 0.1-g readability is needed in order to comply with Test Methods D2216 requirements for determining water content to 0.1 %.

NOTE 6—Use of a balance having an equivalent capacity and a readability of 0.002 lbm as an alternative to a class GP5 balance should not be regarded as nonconformance to this standard.

6.5 *Drying Oven*—Thermostatically controlled oven, capable of maintaining a uniform temperature of 230 ± 9°F (110 ± 5°C) throughout the drying chamber. These requirements typically require the use of a forced-draft type oven. Preferably the oven should be vented outside the building.

6.6 *Straightedge*—A stiff metal straightedge of any convenient length but not less than 10 in. (250 mm). 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).

6.7 *Sieves*—¾ in. (19.0 mm), ⅜ in. (9.5 mm), and No. 4 (4.75 mm), conforming to the requirements of Specification E11.

6.8 *Mixing Tools*—Miscellaneous tools such as mixing pan, spoon, trowel, spatula, spraying device (to add water evenly), and (preferably, but optional) suitable mechanical device for thoroughly mixing the subspecimen of soil with increments of water.

7. Standardization/Calibration

7.1 Perform standardizations before initial use, after repairs or other occurrences that might affect the test results, at intervals not exceeding 1,000 test specimens, or annually, whichever occurs first, for the following apparatus:

7.1.1 *Balance*—Evaluate in accordance with Guide D4753.

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

7.1.3 *Manual Rammer*—Verify the free fall distance, rammer weight, and rammer face are in accordance with 6.2. Verify the guide sleeve requirements are in accordance with 6.2.1.

7.1.4 *Mechanical Rammer*—Verify and adjust if necessary that the mechanical rammer is in accordance with Practices D2168. In addition, the clearance between the rammer and the inside surface of the mold shall be verified in accordance with 6.2.2.

8. Test Specimen

8.1 The minimum specimen (test fraction) mass for Methods A and B is about 16 kg, and for Method C is about 29 kg of dry soil. Therefore, the field sample should have a moist mass of at least 23 kg and 45 kg, respectively. Greater masses would be required if the oversize fraction is large (see 10.2 or 10.3) or an additional molding water content is taken during compaction of each point (see 10.4.2.1).

8.2 If gradation data is not available, estimate the percentage of material (by mass) retained on the No. 4 (4.75-mm), ⅜-in. (9.5-mm), or ¾-in. (19.0-mm) sieve as appropriate for selecting Method A, B, or C, respectively. If it appears the percentage retained of interest is close to the allowable value for a given Method (A, B, or C), then either:

8.2.1 Select a Method that allows a higher percentage retained (B or C).

8.2.2 Using the Method of interest, process the specimen in accordance with 10.2 or 10.3, this determines the percentage retained for that method. If acceptable, proceed, if not go to the next Method (B or C).

8.2.3 Determine percentage retained values by using a representative portion from the total sample, and performing a simplified or complete gradation analysis using the sieve(s) of interest and Test Methods D6913 or C136. It is only necessary to calculate the retained percentage(s) for the sieve or sieves for which information is desired.

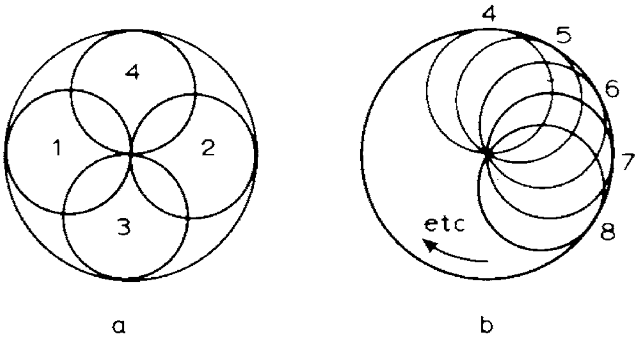


FIG. 3 Rammer Pattern for Compaction in 4 in. (101.6 mm) Mold

9. Preparation of Apparatus

9.1 Select the proper compaction mold(s), collar, and base plate in accordance with the Method (A, B, or C) being used. Check that its volume is known and determined with or without base plate, free of nicks or dents, and will fit together properly.

NOTE 7—Mass requirements are given in 10.4.

9.2 Check that the manual or mechanical rammer assembly is in good working condition and that parts are not loose or worn. Make any necessary adjustments or repairs. If adjustments or repairs are made, the rammer must be re-standardized.

10. Procedure

10.1 *Soils:*

10.1.1 Do not reuse soil that has been previously compacted in the laboratory. The reuse of previously compacted soil yields a significantly greater maximum dry unit weight (**1**, p. 31).

10.1.2 When using this test method for soils containing hydrated halloysite, or in which past experience indicates that results will be altered by air-drying, use the moist preparation method (see 10.2). In referee testing, each laboratory has to use the same method of preparation, either moist (preferred) or air-dried.

10.1.3 Prepare the soil specimens for testing in accordance with 10.2 (preferred) or with 10.3.

10.2 *Moist Preparation Method (preferred)*—Without previously drying the sample/specimen, process it over a No. 4 (4.75-mm), ⅜-in. (9.5-mm), or ¾-in. (19.0-mm) sieve, depending on the Method (A, B, or C) being used or required as covered in 8.2. For additional processing details, see Test Methods D6913. Determine and record the mass of both the retained and passing portions (oversize fraction and test fraction, respectively) to the nearest g. Oven dry the oversize fraction and determine and record its dry mass to the nearest g. If it appears more than 0.5 % of the total dry mass of the specimen is adhering to the oversize fraction, wash that fraction. Then determine and record its oven dry mass to the nearest g. Determine and record the water content of the processed soil (test fraction). Using that water content, determine and record the oven dry mass of the test fraction to the nearest g. Based on these oven dry masses, the percent oversize fraction, P_C, and test fraction, P_F, shall be determined and recorded, unless a gradation analysis has already been performed, see Section 11 on Calculations.

10.2.1 From the test fraction, select and prepare at least four (preferably five) subspecimens having molding water contents such that they bracket the estimated optimum water content. A subspecimen having a molding water content close to optimum should be prepared first by trial additions or removals of water and mixing (see Note 8). Select molding water contents for the rest of the subspecimens to provide at least two subspecimens wet and two subspecimens dry of optimum, and molding water contents varying by about 2 %. At least two molding water contents are necessary on the wet and dry side of optimum to define the dry-unit-weight compaction curve (see 10.5). Some soils with very high optimum water content or a relatively flat compaction curve may require larger molding water content increments to obtain a well-defined maximum dry unit weight. Molding water content increments should not exceed about 4 %.

NOTE 8—With practice it is usually possible to visually judge a point near optimum water content. Typically, cohesive soils at the optimum water content can be squeezed into a lump that sticks together when hand pressure is released, but will break cleanly into two sections when "bent." They tend to crumble at molding water contents dry of optimum; while, they tend to stick together in a sticky cohesive mass wet of optimum. The optimum water content is typically slightly less than the plastic limit. While for cohesionless soils, the optimum water content is typically close to zero or at the point where bleeding occurs.

10.2.2 Thoroughly mix the test fraction, then using a scoop select representative soil for each subspecimen (compaction point). Select about 2.3 kg when using Method A or B, or about 5.9 kg for Method C. Test Methods D6913 section on Specimen and Annex A2 gives additional details on obtaining representative soil using this procedure and why it is the preferred method. To obtain the subspecimen's molding water contents selected in 10.2.1, add or remove the required amounts of water as follows. To add water, spray it into the soil during mixing; to remove water, allow the soil to dry in air at ambient temperature or in a drying apparatus such that the temperature of the sample does not exceed 140°F (60°C). Mix the soil frequently during drying to facilitate an even water content distribution. Thoroughly mix each subspecimen to facilitate even distribution of water throughout and then place in a separate covered container to stand (cure) in accordance with Table 2 prior to compaction. For selecting a standing time, the soil may be classified using Practice D2487, Practice D2488, or data on other samples from the same material source. For referee testing, classification shall be by Practice D2487.

10.3 *Dry Preparation Method*—If the sample/specimen is too damp to be friable, reduce the water content by air drying until the material is friable. Drying may be in air or by the use of drying apparatus such that the temperature of the sample does not exceed 140°F (60°C). Thoroughly break up the aggregations in such a manner as to avoid breaking individual particles. Process the material over the appropriate sieve: No. 4 (4.75-mm), ⅜-in. (9.5-mm), or ¾-in. (19.0-mm). When preparing the material by passing over the ¾-in. sieve for compaction in the 6-in. mold, break up aggregations sufficiently to at least pass the ⅜-in. sieve in order to facilitate the distribution of water throughout the soil in later mixing. Determine and record the water content of the test fraction and all masses covered in 10.2, as applicable to determine the percent oversize fraction, P_C, and test fraction, P_F.

10.3.1 From the test fraction, select and prepare at least four (preferably five) subspecimens in accordance with 10.2.1 and 10.2.2, except for the following: Use either a mechanical splitting or quartering process to obtain the subspecimens. As

TABLE 2 Required Standing Times of Moisturized Specimens

Classification	Minimum Standing Time, h
GW, GP, SW, SP	No Requirement
GM, SM	3
All other soils	16

stated in Test Methods D6913, both of these processes will yield non-uniform subspecimens compared to the moist procedure. Typically, only the addition of water to each subspecimen will be required.

10.4 *Compaction*—After standing (curing), if required, each subspecimen (compaction point) shall be compacted as follows:

10.4.1 Determine and record the mass of the mold or mold and base plate, see 10.4.7.

10.4.2 Assemble and secure the mold and collar to the base plate. Check the alignment of the inner wall of the mold and mold extension collar. Adjust if necessary. The mold shall rest, without wobbling/rocking on a uniform rigid foundation, such as provided by a cylinder or cube of concrete with a weight or mass of not less than 200-lbf or 91-kg, respectively. Secure the base plate to the rigid foundation. The method of attachment to the rigid foundation shall allow easy removal of the assembled mold, collar and base plate after compaction is completed.

10.4.2.1 During compaction, it is advantageous but not required to determine the water content of each subspecimen. This provides a check on the molding water content determined for each compaction point and the magnitude of bleeding, see 10.4.9. However, more soil will have to be selected for each subspecimen than stated in 10.2.2.

10.4.3 Compact the soil in three layers. After compaction, each layer should be approximately equal in thickness and extend into the collar. Prior to compaction, place the loose soil into the mold and spread into a layer of uniform thickness. Lightly tamp the soil prior to compaction until it is not in a fluffy or loose state, using either the manual rammer or a 2±-in. (50±-mm) diameter cylinder. Following compaction of each of the first two layers, any soil that has not been compacted; such as adjacent to the mold walls or extends above the compacted surface (up the mold walls) shall be trimmed. The trimmed soil shall be discarded. A knife or other suitable device may be used. The total amount of soil used shall be such that the third compacted layer slightly extends into the collar, but does not extend more than approximately ¼-in. (6-mm) above the top of the mold. If the third layer does extend above this limit, then the compaction point shall be discarded. In addition, the compaction point shall be discarded when the last blow on the rammer for the third layer results in the bottom of the rammer extending below the top of the compaction mold; unless the soil is pliable enough, that this surface can easily be forced above the top of the compaction mold during trimming (see Note 9).

10.4.4 Compact each layer with 25 blows for the 4-in. (101.6-mm) mold or with 56 blows for the 6-in. (152.4-mm) mold. The manual rammer shall be used for referee testing.

10.4.5 In operating the manual rammer, take care to avoid lifting the guide sleeve during the rammer upstroke. Hold the guide sleeve steady and within 5° of vertical. Apply the blows at a uniform rate of about 25 blows/min and in such a manner as to provide complete, uniform coverage of the specimen surface. When using a 4-in. (101.6-mm) mold and manual rammer, follow the blow pattern given in Fig. 3a and Fig. 3b; while for a mechanical rammer, follow the pattern in Fig. 3b. When using a 6-in. (152.4-mm) mold and manual rammer, follow the blow pattern given in Fig. 4 up to the 9th blow, then systematically around the mold (Fig. 3b) and in the middle. When using a 6-in. (152.4-mm) mold and a mechanical rammer equipped with a sector face, the mechanical rammer shall be designed to follow the compaction pattern given in Fig. 3b. When using a 6-in. (152.4-mm) mold and a mechanical rammer equipped with a circular face, the mechanical rammer shall be designed to distribute the blows uniformly over the

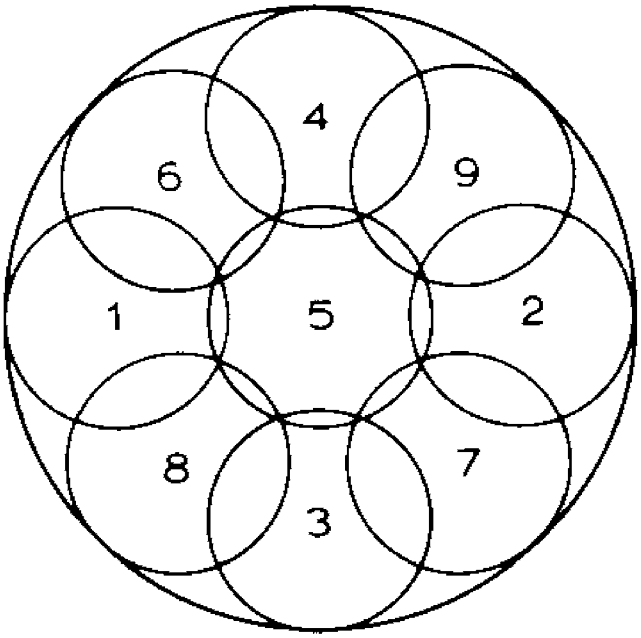


FIG. 4 Rammer Pattern for Compaction in 6 in. (152.4 mm) Mold

surface of the specimen. If the surface of the compacted soil becomes highly uneven (see Note 9), then adjust the pattern to follow the logic given in Fig. 3a or Fig. 4. This will most likely void the use of a mechanical rammer for such compaction points.

NOTE 9—When compacting specimens wetter than optimum water content, uneven compacted surfaces can occur and operator judgement is required as to the average height of the specimen and rammer pattern during compaction.

10.4.6 Following compaction of the last layer, remove the collar and base plate (except as noted in 10.4.7) from the mold. A knife may be used to trim the soil adjacent to the collar to loosen the soil from the collar before removal to avoid disrupting the soil below the top of the mold. In addition, to prevent/reduce soil sticking to the collar or base plate, rotate them before removal.

10.4.7 Carefully trim the compacted specimen even with the top of the mold by means of the straightedge scraped across the top of the mold to form a plane surface even with the top of the mold. Initial trimming of the specimen above the top of the mold with a knife may prevent the soil from tearing below the top of the mold. Fill 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. If gravel size particles are encountered, trim around them or remove them, whichever is the easiest and reduces the disturbance of the compacted soil. The estimated volume of particles above the surface of the compacted soil and holes in that surface shall be equal, fill in remaining holes as mentioned above. Repeat the appropriate preceding operations on the bottom of the specimen when the mold volume was determined without the base plate. For very wet or dry soils, soil or water may be lost if the base plate is removed. For these situations, leave the base plate attached to the mold. When the base plate is left attached, the volume of the mold must be calibrated with the base plate attached to the mold rather than a plastic or glass plate as noted in Annex A1, A1.4.

10.4.8 Determine and record the mass of the specimen and mold to the nearest g. When the base plate is left attached, determine and record the mass of the specimen, mold and base plate to the nearest g.

10.4.9 Remove the material from the mold. Obtain a specimen for molding water content by using either the whole specimen (preferred method) or a representative portion. When the entire specimen is used, break it up to facilitate drying. Otherwise, obtain a representative portion of the three layers, removing enough material from the specimen to report the water content to 0.1 %. The mass of the representative portion of soil shall conform to the requirements of Table 1, Method B, of Test Methods D2216. Determine the molding water content in accordance with Test Methods D2216.

10.5 Following compaction of the last specimen, compare the wet unit weights to ensure that a desired pattern of obtaining data on each side of the optimum water content will be attained for the dry-unit-weight compaction curve. Plotting the wet unit weight and molding water content of each compacted specimen can be an aid in making the above evaluation. If the desired pattern is not obtained, additional compacted specimens will be required. Generally, for experienced plotters of compaction curves, one compaction point wet of the optimum water content is adequate to define the maximum wet unit weight, see 11.2.

11. Calculations and Plotting (Compaction Curve)

11.1 *Fraction Percentages*—If gradation data from Test Methods D6913 is not available, calculate the dry mass of the test fraction, percentage of oversize fraction and test fraction as covered below and using the data from 10.2 or 10.3:

11.1.1 *Test Fraction*—Determine the dry mass of the test fraction as follows:

$$M_{d,tf} = \frac{M_{m,tf}}{1 + \frac{w_{tf}}{100}} \tag{1}$$

where:

$M_{d,tf}$ = dry mass of test fraction, nearest g or 0.001 kg,
$M_{m,tf}$ = moist mass of test fraction, nearest g or 0.001 kg, and
w_{tf} = water content of test fraction, nearest 0.1 %.

11.1.2 *Oversize Fraction Percentage*—Determine the oversize (coarse) fraction percentage as follows:

$$P_C = \frac{M_{d,of}}{M_{d,of} + M_{d,tf}} \tag{2}$$

where:

P_C = percentage of oversize (coarse) fraction, nearest %, and
$M_{d,of}$ = dry mass of oversize fraction, nearest g or 0.001 kg,

11.1.3 *Test Fraction Percentage*—Determine the test (finer) fraction percentage as follows:

$$P_F = 100 - P_C \tag{3}$$

where:

P_F = percentage of test (finer) fraction, nearest %.

11.2 *Density and Unit Weight*—Calculate the molding water content, moist density, dry density, and dry unit weight of each compacted specimen as explained below.

11.2.1 *Molding Water Content, w*—Calculate in accordance with Test Methods D2216 to nearest 0.1 %.

11.2.2 *Density and Unit Weights*—Calculate the moist (total) density (Eq 4), the dry density (Eq 5), and then the dry unit weight (Eq 6) as follows:

11.2.2.1 *Moist Density:*

$$\rho_m = K \times \frac{(M_t - M_{md})}{V} \tag{4}$$

where:

ρ_m = moist density of compacted subspecimen (compaction point), four significant digits, g/cm^3 or kg/m^3,
M_t = mass of moist soil in mold and mold, nearest g,
M_{md} = mass of compaction mold, nearest g,
V = volume of compaction mold, cm^3 or m^3 (see Annex A1), and

K = conversion constant, depending on density units and volume units.
Use 1 for g/cm^3 and volume in cm^3.
Use 1000 for g/cm^3 and volume in m^3.
Use 0.001 for kg/cm^3 and volume in m^3.
Use 1000 for kg/m^3 and volume in cm^3.

11.2.2.2 *Dry Density:*

$$\rho_d = \frac{\rho_m}{1 + \frac{w}{100}} \tag{5}$$

where:

ρ_d = dry density of compaction point, four significant digits, g/cm^3 or kg/m^3, and
w = molding water content of compaction point, nearest 0.1 %.

11.2.2.3 *Dry Unit Weight:*

$$\gamma_d = K_1 \times \rho_d \text{ in lbf/ft}^3 \tag{6}$$

or

$$\gamma_d = K_2 \times \rho_d \text{ in kN/m}^3 \tag{7}$$

where:

γ_d = dry unit weight of compacted specimen, four significant digits, in lbf/ft^3 or kN/m^3,
K_1 = conversion constant, depending on density units,
Use 62.428 for density in g/cm^3, or
Use 0.062428 for density in kg/m^3,
K_2 = conversion constant, depending on density units,
Use 9.8066 for density in g/cm^3, or
Use 0.0098066 for density in kg/m^3.

11.3 *Compaction Curve*—Plot the dry unit weight and molding water content values, the saturation curve (see 11.3.2), and draw the compaction curve as a smooth curve through the points (see example, Fig. 5). For each point on the compaction curve, calculate, record, and plot dry unit weight to the nearest 0.1 lbf/ft^3 (0.02 kN/m^3) and molding water content to the nearest 0.1 %. From the compaction curve, determine the compaction results: optimum water content, to nearest 0.1 % and maximum dry unit weight, to the nearest 0.1 lbf/ft^3 (0.02 kN/m^3). If more than 5 % by mass of oversize material was removed from the sample/specimen, calculate the corrected optimum water content and maximum dry unit weight of the total material using Practice D4718. This correction may be made to the appropriate field in-place density test specimen rather than to the laboratory compaction results.

11.3.1 In these plots, the scale sensitivities should remain the same, that is the change in molding water content or dry unit weight per division is constant between plots. Typically, the change in dry unit weight per division is twice that of molding water content's (2 lbf/ft^3 to 1 % w per major division). Therefore, any change in the shape of the compaction curve is a result of testing different material, not the plotting scale. However, a one to one ratio should be used for soils that have a relatively flat compaction curve (see 10.2.1), such as highly plastic soils or relatively free draining ones up to the point of bleeding.

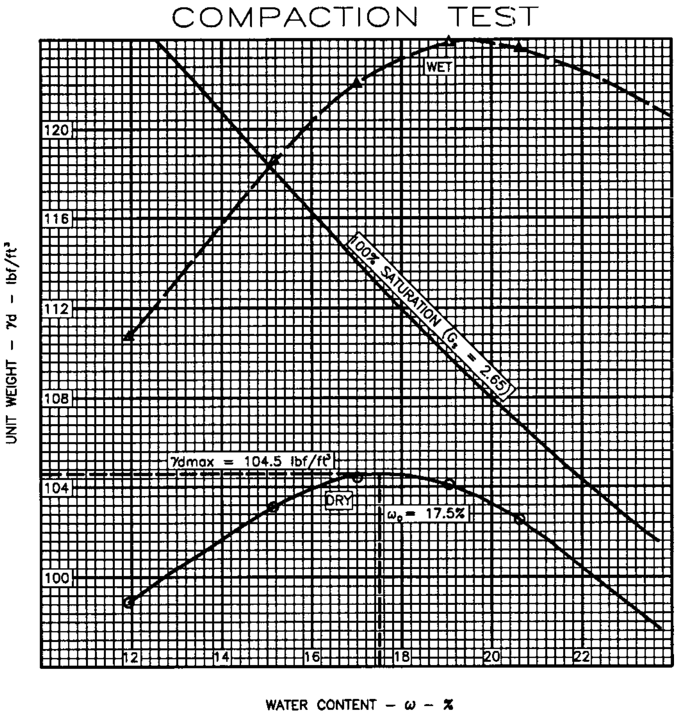


FIG. 5 Example Compaction Curve Plotting

11.3.1.1 The shape of the compaction curve on the wet side on optimum should typically follow that of the saturation curve. The shape of the compaction curve on the dry side of optimum may be relatively flat or up and down when testing some soils, such as relatively free draining ones or plastic soils prepared using the moist procedure and having molding water contents close to or less than the shrinkage limit.

11.3.2 Plot the 100 % saturation curve, based on either an estimated or a measured specific gravity. Values of water content for the condition of 100 % saturation can be calculated as explained in 11.4 (see example, Fig. 5).

NOTE 10—The 100 % saturation curve is an aid in drawing the compaction curve. For soils containing more than about 10 % fines and molding water contents well above optimum, the two curves generally become roughly parallel with the wet side of the compaction curve between 92 to 95 % saturation. Theoretically, the compaction curve cannot plot to the right of the 100 % saturation curve. If it does, there is an error in specific gravity, in measurements, in calculations, in testing, or in plotting. The 100 % saturation curve is sometimes referred to as the zero air voids curve or the complete saturation curve.

11.4 *Saturation Points*—To calculate points for plotting the 100 % saturation curve or zero air voids curve, select values of dry unit weight, calculate corresponding values of water content corresponding to the condition of 100 % saturation as follows:

$$w_{sat} = \frac{(\gamma_w)(G_s) - \gamma_d}{(\gamma_d)(G_s)} \times 100 \tag{8}$$

where:

w_{sat} = water content for complete saturation, nearest 0.1 %,
γ_w = unit weight of water, 62.32 lbf/ft ^{3} (9.789 kN/m^3) at 20°C,

γ_d = dry unit weight of soil, lbf/ft^3 (kN/m ^{3}), three significant digits, and
G_s = specific gravity of soil (estimated or measured), to nearest 0.01 value, see 11.4.1.

11.4.1 Specific gravity may be estimated for the test fraction based on test data from other soils having the same soil classification and source or experience. Otherwise, a specific gravity test (Test Methods C127 or D854, or both) is necessary.

12. Report: Data Sheet(s)/Form(s)

12.1 The methodology used to specify how data are recorded on the test data sheet(s)/form(s), as described below, is covered in 1.6.

12.2 The data sheet(s)/form(s) shall contain as a minimum the following information:

12.2.1 Method used (A, B, or C).

12.2.2 Preparation method used (moist or dry).

12.2.3 As received water content if determined, nearest 1 %.

12.2.4 Standard optimum water content, Std-w_{opt} to nearest 0.1 %.

12.2.5 Standard maximum dry unit weight, Std-$\gamma_{d,max}$ nearest 0.1 lbf/ft^3 or 0.02 kN/m^3.

12.2.6 Type of rammer (manual or mechanical).

12.2.7 Soil sieve data when applicable for selection of Method (A, B, or C) used.

12.2.8 Description of sample used in test (as a minimum, color and group name and symbol), by Practice D2488, or classification by Practice D2487.

12.2.9 Specific gravity and method of determination, nearest 0.01 value.

12.2.10 Identification of sample used in test; for example, project number/name, location, depth, and the like.

12.2.11 Compaction curve plot showing compaction points used to establish compaction curve, and 100 % saturation curve, value or point of maximum dry unit weight and optimum water content.

12.2.12 Percentages for the fractions retained (P_C) and passing (P_F) the sieve used in Method A, B, or C, nearest 1 %. In addition, if compaction data (Std-w_{opt} and Std-$\gamma_{d,max}$) are corrected for the oversize fraction, include that data.

13. Precision and Bias

13.1 *Precision*—Criteria for judging the acceptability of test results obtained by these test methods on a range of soil types are given in Tables 3 and 4. These estimates of precision are based on the results of the interlaboratory program conducted by the ASTM Reference Soils and Testing Program.[4] In this program, Method A and the Dry Preparation Method were used. In addition, some laboratories performed three replicate tests per soil type (triplicate test laboratory), while other laboratories performed a single test per soil type (single test laboratory). A description of the soils tested is given in 13.1.4. The precision estimates vary with soil type, and may vary with methods used (Method A, B, or C, or wet/dry preparation method). Judgement is required when applying these estimates to another soil, method, or preparation method.

TABLE 3 Summary of Test Results from Triplicate Test Laboratories (Standard Effort Compaction)

(1) Number of Triplicate Test Labs	(2) Test Value^A (Units)	(3) Average Value^B	(4) Standard Deviation^C	(5) Acceptable Range of Two Results^{D,E}
		Soil Type:		
CH CL ML		CH CL ML	CH CL ML	CH CL ML
		Single-Operator Results (Within-Laboratory Repeatability):		
11 12 11	$\gamma_{d,max}$ (pcf)	97.2 109.2 106.3	0.5 0.4 0.5	1.3 1.2 1.3
11 12 11	w_{opt} (%)	22.8 16.6 17.1	0.2 0.3 0.3	0.7 0.9 0.9
		Multilaboratory Results (Between-Laboratory Reproducibility):		
11 12 11	$\gamma_{d,\ max}$ (pcf)	97.2 109.2 106.3	1.4 0.8 0.6	3.9 2.3 1.6
11 12 11	w_{opt} (%)	22.8 16.6 17.1	0.7 0.5 0.5	1.8 1.5 1.3

[A] $\gamma_{d,max}$(pcf) = standard maximum dry unit weight in lbf/ft^3 and w_{opt}(%) = standard optimum water in percent.

[B] The number of significant digits and decimal places presented are representative of the input data. In accordance with Practice D6026, the standard deviation and acceptable range of results can not have more decimal places than the input data.

[C] Standard deviation is calculated in accordance with Practice E691 and is referred to as the 1 s limit.

[D] Acceptable range of two results is referred to as the d2*s* limit. It is calculated as $1.960 \sqrt{2} \cdot 1s$, as defined by Practice E177. The difference between two properly conducted tests should not exceed this limit. The number of significant digits/decimal places presented is equal to that prescribed by this standard or Practice D6026. In addition, the value presented can have the same number of decimal places as the standard deviation, even if that result has more significant digits than the standard deviation.

[E] Both values of $\gamma_{d,max}$ and w_{opt} have to fall within values given for the selected soil type.

TABLE 4 Summary of Single Test Results from Each Laboratories (Standard Effort Compaction)^A

(1) Number of Test Laboratories	(2) Test Value (Units)	(3) Average Value	(4) Standard Deviation	(5) Acceptable Range of Two Results
		Soil Type:		
CH CL ML		CH CL ML	CH CL ML	CH CL ML
		Multilaboratory Results (Between-Laboratory Reproducibility):		
26 26 25	$\gamma_{d,max}$ (pcf)	97.3 109.2 106.2	1.6 1.1 1.0	4.5 3.0 2.9
	w_{opt} (%)	22.6 16.4 16.7	0.9 0.7 1.0	2.4 1.8 2.9

[A] See footnotes in Table 3.

13.1.1 The data in Table 3 are based on three replicate tests performed by each triplicate test laboratory on each soil type. The single operator and multilaboratory standard deviation show in Table 3, Column 4 were obtained in accordance with Practice E691, which recommends each testing laboratory perform a minimum of three replicate tests. Results of two properly conducted tests performed by the same operator on the same material, using the same equipment, and in the shortest practical period of time should not differ by more than the single-operator d2*s* shown in Table 3, Column 5. For definition of d2*s*, see footnote D in Table 1. Results of two properly conducted tests performed by different operators and on different days should not differ by more than the multilaboratory d2*s* limits shown in Table 3, Column 5.

13.1.2 In the ASTM Reference Soils and Testing Program, many of the laboratories performed only a single test on each

---

[4] Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:D18-1008. Contact ASTM Customer Service at service@astm.org.

soil type. This is common practice in the design and construction industry. The data for each soil type in Table 4 are based upon the first test result from the triplicate test laboratories and the single test results from the other laboratories. Results of two properly conducted tests performed by two different laboratories with different operators using different equipment and on different days should not vary by more than the d2*s* limits shown in Table 4, Column 5. The results in Tables 3 and 4 are dissimilar because the data sets are different.

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

13.1.4 *Soil Types*—Based on the multilaboratory test results the soils used in the program are described below in accordance with Practice D2487. In addition, the local names of the soils are given.

CH	Fat clay, CH, 99 % fines, LL=60, PI=39, grayish brown, soil had been air dried and pulverized. Local name—Vicksburg Buckshot Clay
CL	Lean clay, CL, 89 % fines, LL=33, PI=13, gray, soil had been air dried and pulverized. Local name—Annapolis Clay
ML	Silt, ML, 99 % fines, LL=27, PI=4, light brown, soil had been air dried and pulverized. Local name—Vicksburg Silt

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

14. Keywords

14.1 compaction characteristics; density; impact compaction; laboratory tests ; moisture-density curves; proctor test; soil; soil compaction; standard effort

ANNEX

(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 two methods, a water-filled and linear-measurement method.

A1.1.3 The water filling method for the 4-in. (106.5-mm) mold, when using a balance readable to nearest g, does not yield four significant figures for its volume, just three. Based on Practice D6026, this limits the density/unit weight determinations previously presented from four to three significant figures. To prevent this limitation, the water filling method has been adjusted from that presented in early versions of this test 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 6 in. (0 to 150 mm) and readable to at least 0.001 in. (0.02 mm).

A1.2.1.2 *Inside Micrometer (optional),* 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 *Depth Micrometer (optional)* , having a measuring range of at least 0 to 6 in. (0 to 150 mm) and readable to at least 0.001 in. (0.02 mm).

A1.2.1.4 *Plastic or Glass Plates*—Two plastic or glass plates about 8 in. square by ¼ in. thick (200 by 200 by 6 mm).

A1.2.1.5 *Thermometer or Other Thermometric Device,* having graduation increments of 0.1°C.

A1.2.1.6 *Stopcock Grease,* or similar sealant.

A1.2.1.7 *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 and place it on one of the plastic or glass plates. Lightly grease the top of the mold. Be careful not to get grease on the inside of the mold. If it is necessary to use the base plate, as noted in 10.4.7, place the greased mold onto the base plate and secure with the locking studs.

A1.4.1.2 Determine the mass of the greased mold and both plastic or glass plates to the nearest 1 g and record, M_{mp}. When the base plate is being used in lieu of the bottom plastic or glass plate, determine the mass of the mold, base plate and a single plastic or glass plate to be used on top of the mold to the nearest 1 g and record.

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

A1.4.1.4 Slide the second 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 1 g, $M_{mp,w}$.

A1.4.1.7 Determine the temperature of the water in the mold to the nearest 0.1°C and record. Determine and record the density of water from the table given in Test Methods D854 or as follows:

$$\rho_{w,c} = 1.00034038 - (7.77 \times 10^{-6}) \times T - (4.95 \times 10^{-6}) \times T^2 \tag{A1.1}$$

where:

$\rho_{w,c}$ = density of water, nearest 0.00001 g/cm^3, and
T = calibration test temperature, nearest 0.1°C.

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. Record this volume to the nearest 0.1 cm^3 for the 4-in. (101.6-mm) mold or nearest 1 cm^3 for the 6-in. (152.4-mm) mold. To determine the volume of the mold in m^3, multiply the volume in cm^3 by 1 × 10^{-6}. Record this volume, as prescribed.

A1.4.1.10 If the filling method is being used to determine the mold's volume and checked by linear measurement method, repeat this volume determination (A1.4.1.3 – A1.4.1.9) and determine and record the average value, V_w as prescribed.

A1.4.2 *Linear Measurement Method:*

A1.4.2.1 Using either the vernier caliper or the inside micrometer (preferable), measure the inside diameter (ID) of the mold 6 times at the top of the mold and 6 times at the bottom of the mold, spacing each of the six top and bottom measurements equally around the ID of the mold. Record the values to the nearest 0.001-in. (0.02-mm). Determine and record the average ID to the nearest 0.001-in. (0.02-mm), d_{avg}. Verify that this ID is within specified tolerances, 4.000 ± 0.016 in. (101.6 ± 0.4 mm), if not discard the mold.

A1.4.2.2 Using the vernier caliper or depth micrometer (preferably), measure the inside height of the mold attached to the base plate. In these measurements, make three or more measurements equally spaced around the ID of the mold, and preferably one in the center of the mold, but not required (used the straightedge to facilitate the later measurement and correct measurement for thickness of straightedge). Record these values to the nearest 0.001-in. (0.02-mm). Determine and record the average of these height measurements to the nearest 0.001 in. (0.02 mm), h_{avg}. Verify that this height is within specified tolerances, 4.584 ± 0.018 in. (116.4 ± 0.5 mm), if not discard the mold.

A1.4.2.3 Calculate the volume of the mold to four significant digits in cm^3 as follows:

$$V_{lm} = K_3 \frac{\pi \times h_{avg} \times (d_{avg})^2}{4} \tag{A1.2}$$

where:

V_{lm} = volume of mold by linear measurements, to four significant digits, cm^3,
K_3 = constant to convert measurements made in inch (in.) or mm,
Use 16.387 for measurements in inches.
Use 10^{-6} for measurements in mm.
π = 3.14159,
h_{avg} = average height, in. (mm), and
d_{avg} = average of the top and bottom diameters, in. (mm).

A1.4.2.4 If the volume in m^3 is required, then multiply the above value by 10^{-6}.

A1.5 Comparison of Results and Standardized Volume of Mold

A1.5.1 The volume obtained by either method should be within the volume tolerance requirements of 6.1.1 and 6.1.2, using either or cm^3 to ft^3. To convert cm^3 to ft^3, divide cm^3 by 28 317, record to the nearest 0.0001 ft^3.

A1.5.2 The difference between the two methods should not exceed 0.5 % of the nominal volume of the mold, cm^3 to ft^3.

A1.5.3 Repeat the determination of volume, which is most suspect or both if these criteria are not met.

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

A1.5.5 Use the volume of the mold determined using the water-filling or linear method, or average of both methods as the standardized volume for calculating the moist density (see 11.4). This value (V) in cm^3 or m^3 shall have four significant digits. The use of a volume in ft^3, along with masses in lbm shall not be regarded as a nonconformance with this standard.

REFERENCES

(1) 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.

(2) *Earth Manual*, Unites States Bureau of Reclamation, Part 1, Third Edition, 1998, pp. 255–260.

(3) *Earth Manual*, Unites States Bureau of Reclamation, Part 2, Third Edition, 1990, USBR 5515.

(4) Torrey, V. H., and Donaghe, R. T., "Compaction Control of Earth-Rock Mixtures: A New Approach," *Geotechnical Testing Journal*, GTJODJ, Vol 17, No. 3, September 1994, pp. 371–386.

SUMMARY OF CHANGES

Committee D18 has identified the location of selected changes to this standard since the last issue (D698–07$^{\varepsilon 1}$) that may impact the use of this standard. (Approved May 1, 2012.)

(1) Revised 6.2.2.1 and 10.4.5.

استاندارد آزمایش تحکیم

ASTM-D2435-11

Designation: D2435/D2435M – 11

Standard Test Methods for One-Dimensional Consolidation Properties of Soils Using Incremental Loading[1]

This standard is issued under the fixed designation D2435/D2435M; 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 procedures for determining the magnitude and rate of consolidation of soil when it is restrained laterally and drained axially while subjected to incrementally applied controlled-stress loading. Two alternative procedures are provided as follows:

1.1.1 *Test Method A*—This test method is performed with constant load increment duration of 24 h, or multiples thereof. Time-deformation readings are required on a minimum of two load increments. This test method provides only the compression curve of the specimen and the results combine both primary consolidation and secondary compression deformations.

1.1.2 *Test Method B*—Time-deformation readings are required on all load increments. Successive load increments are applied after 100 % primary consolidation is reached, or at constant time increments as described in Test Method A. This test method provides the compression curve with explicit data to account for secondary compression, the coefficient of consolidation for saturated materials, and the rate of secondary compression.

NOTE 1—The determination of the rate and magnitude of consolidation of soil when it is subjected to controlled-strain loading is covered by Test Method D4186.

1.2 These test methods are most commonly performed on saturated intact samples of fine grained soils naturally sedimented in water, however, the basic test procedure is applicable, as well, to specimens of compacted soils and intact samples of soils formed by other processes such as weathering or chemical alteration. Evaluation techniques specified in these test methods assume the pore space is fully saturated and are generally applicable to soils naturally sedimented in water. Tests performed on other unsaturated materials such as compacted and residual (weathered or chemically altered) soils may require special evaluation techniques. In particular, the rate of consolidation (interpretation of the time curves) is only applicable to fully saturated specimens.

1.3 It shall be the responsibility of the agency requesting this test to specify the magnitude and sequence of each load increment, including the location of a rebound cycle, if required, and, for Test Method A, the load increments for which time-deformation readings are desired. The required maximum stress level depends on the purpose of the test and must be agreed on with the requesting agency. In the absence of specific instructions, Section 11 provides the default load increment and load duration schedule for a standard test.

NOTE 2—Time-deformation readings are required to determine the time for completion of primary consolidation and for evaluating the coefficient of consolidation, c_v. Since c_v varies with stress level and loading type (loading or unloading), the load increments with timed readings must be selected with specific reference to the individual project. Alternatively, the requesting agency may specify Test Method B wherein the time-deformation readings are taken on all load increments.

1.4 These test methods do not address the use of a back pressure to saturate the specimen. Equipment is available to perform consolidation tests using back pressure saturation. The addition of back pressure saturation does not constitute non-conformance to these test methods.

1.5 *Units*—The values stated in either SI units or inch-pound units [given in brackets] are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in non-conformance with the standard.

1.5.1 In the engineering profession it is customary practice to use, interchangeably, units representing both mass and force, unless dynamic calculations ($F = Ma$) are involved. This implicitly combines two separate systems of units, that is, the absolute system and the gravimetric system. It is scientifically undesirable to combine two separate systems within a single standard. This test method has been written using SI units; however, inch-pound conversions are given in the gravimetric system, where the pound (lbf) represents a unit of force (weight). The use of balances or scales recording pounds of mass (lbm), or the recording of density in lb/ft^3 should not be regarded as nonconformance with this test method.

---

[1] These test methods are under the jurisdiction of ASTM Committee D18 on Soil and Rock .

Current edition approved May 1, 2011. Published July 2011. Originally approved in 1965. Last previous edition approved in 2004 as D2435–04. DOI: 10.1520/D2435_D2435M-11.

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

1.6 Observed and calculated values shall conform to the guidelines for significant digits and rounding established in Practice D6026, unless superseded by this test method.

1.6.1 The method used to specify how data are collected, calculated, or recorded in this standard is not directly related to the accuracy to which the data can be applied in design or other uses, or both. How one applies the results obtained using this standard is beyond its scope.

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]

D422 Test Method for Particle-Size Analysis of Soils
D653 Terminology Relating to Soil, Rock, and Contained Fluids
D854 Test Methods for Specific Gravity of Soil Solids by Water Pycnometer
D1587 Practice for Thin-Walled Tube Sampling of Soils for Geotechnical Purposes
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)
D3550 Practice for Thick Wall, Ring-Lined, Split Barrel, Drive Sampling of Soils
D3740 Practice for Minimum Requirements for Agencies Engaged in Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction
D4186 Test Method for One-Dimensional Consolidation Properties of Saturated Cohesive Soils Using Controlled-Strain Loading
D4220 Practices for Preserving and Transporting Soil Samples
D4318 Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils
D4452 Practice for X-Ray Radiography of Soil Samples
D4546 Test Methods for One-Dimensional Swell or Collapse of Cohesive Soils
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
D6027 Practice for Calibrating Linear Displacement Transducers for Geotechnical Purposes

3. Terminology

3.1 For definitions of technical terms used in these test methods, see Terminology D653.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *axial deformation (L, L, %, or -), n*—the change in axial dimension of the specimen which can be expressed in terms of length, height of specimen, strain or void ratio.

3.2.2 *estimated preconsolidation stress* (F/L^2), *n*—the value of the preconsolidation stress determined by the technique prescribed in these test methods for the purpose of aiding the laboratory in the performance of the test. This estimation should not be considered equivalent to an engineering interpretation of the test measurements.

3.2.3 *load (F), n*—in the context of soil testing, the act of applying force or deformation to the boundary of a test specimen. In the incremental consolidation test this is generally performed using weights on a hanger.

3.2.4 *load increment, n*—one individual step of the test during which the specimen is under a constant total axial stress.

3.2.5 *load increment duration (T), n*—the length of time that one value of total axial stress is maintained on the specimen.

3.2.6 *load increment ratio, LIR (-), n*—the change (increase or decrease) in total axial stress to be applied to the specimen in a single step divided by the current total axial stress.

3.2.6.1 *Discussion*—Load Increment Ratio is historically used in consolidation testing to reflect the fact that the test was performed by adding weights to apply the total axial stress to the specimen.

3.2.7 *total axial stress* (F/L^2), *n*—the force acting on the specimen divided by the specimen area. Once consolidation is complete, the effective axial stress is assumed to equal the total axial stress.

3.2.8 *total axial stress increment* (F/L^2), *n*—the change (increase or decrease) in total axial stress applied in one single step. The change may be an increase or a decrease in stress.

4. Summary of Test Methods

4.1 In these test methods a soil specimen is restrained laterally and loaded axially with total stress increments. Each stress increment is maintained until excess pore water pressures are essentially dissipated. Pore pressure is assumed to be dissipated based on interpretation of the time deformation under constant total stress. This interpretation is founded on the assumption that the soil is 100% saturated. Measurements are made of change in the specimen height and these data are used to determine the relationship between the effective axial stress and void ratio or strain. When time deformation readings are taken throughout an increment, the rate of consolidation is evaluated with the coefficient of consolidation.

5. Significance and Use

5.1 The data from the consolidation test are used to estimate the magnitude and rate of both differential and total settlement of a structure or earthfill. Estimates of this type are of key importance in the design of engineered structures and the evaluation of their performance.

5.2 The test results can be greatly affected by sample disturbance. Careful selection and preparation of test specimens is required to reduce the potential of disturbance effects.

---

[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.

NOTE 3—Notwithstanding the statement on precision and bias contained in this standard, the precision of this test method is dependent on the competence of the personnel performing the test and suitability of the equipment and facilities used. Agencies that meet the criteria of Practice D3740 generally are considered capable of competent and objective testing. Users of this test method are cautioned that compliance with Practice D3740 does not assure reliable testing. Reliable testing depends on many factors, and Practice D3740 provides a means of evaluation some of these factors.

5.3 Consolidation test results are dependent on the magnitude of the load increments. Traditionally, the axial stress is doubled for each increment resulting in a load increment ratio of 1. For intact samples, this loading procedure has provided data from which estimates of the preconsolidation stress, using established interpretation techniques, compare favorably with field observations. Other loading schedules may be used to model particular field conditions or meet special requirements. For example, it may be desirable to inundate and load the specimen in accordance with the wetting or loading pattern expected in the field in order to best evaluate the response. Load increment ratios of less than 1 may be desirable for soils that are highly sensitive or whose response is highly dependent on strain rate.

5.4 The interpretation method specified by these test methods to estimate the preconsolidation stress provides a simple technique to verify that one set of time readings are taken after the preconsolidation stress and that the specimen is loaded to a sufficiently high stress level. Several other evaluation techniques exist and may yield different estimates of the preconsolidation stress. Alternative techniques to estimate the preconsolidation stress may be used when agreed to by the requesting agency and still be in conformance with these test methods.

5.5 Consolidation test results are dependent upon the duration of each load increment. Traditionally, the load duration is the same for each increment and equal to 24 h. For some soils, the rate of consolidation is such that complete consolidation (dissipation of excess pore pressure) will require more than 24 h. The apparatus in general use does not have provisions for formal verification of pore pressure dissipation. It is necessary to use an interpretation technique which indirectly determines that consolidation is essentially complete. These test methods specify procedures for two techniques (Method A and Method B), however alternative techniques may be used when agreed to by the requesting agency and still be in conformance with these test methods.

5.6 The apparatus in general use for these test methods do not have provisions for verification of saturation. Most intact samples taken from below the water table will be saturated. However, the time rate of deformation is very sensitive to degree of saturation and caution must be exercised regarding estimates for duration of settlements when partially saturated conditions prevail. Inundation of the test specimen does not significantly change the degree of saturation of the test specimen but rather provides boundary water to eliminate negative pore pressure associated with sampling and prevents evaporation during the test. The extent to which partial saturation influences the test results may be a part of the test evaluation and may include application of theoretical models other than conventional consolidation theory. Alternatively, the test may be performed using an apparatus equipped to saturate the specimen.

5.7 These test methods use conventional consolidation theory based on Terzaghi's consolidation equation to compute the coefficient of consolidation, c_v. The analysis is based upon the following assumptions:

5.7.1 The soil is saturated and has homogeneous properties;

5.7.2 The flow of pore water is in the vertical direction;

5.7.3 The compressibility of soil particles and pore water is negligible compared to the compressibility of the soil skeleton;

5.7.4 The stress-strain relationship is linear over the load increment;

5.7.5 The ratio of soil permeability to soil compressibility is constant over the load increment; and

5.7.6 Darcy's law for flow through porous media applies.

6. Apparatus

6.1 *Load Device*—A suitable device for applying axial loads or total stresses to the specimen. The device shall be capable of maintaining the specified loads for long periods of time with a precision of ± 0.5 % of the applied load and shall permit quick application of a given load increment without significant impact. Load application should be completed in a time corresponding to 0.01 times t_{100} or less.

NOTE 4—As an example, for soils where primary consolidation is completed in 3 min, the applied load should be stable in less than 2 s.

6.2 *Consolidometer*—A device to hold the specimen in a ring that is either fixed to the base or floating (supported by friction on the periphery of specimen) with porous disks on each face of the specimen. The inside diameter of the ring shall be fabricated to a tolerance of at least 0.1 % of the diameter. The consolidometer shall also provide a means of submerging the specimen in water, for transmitting the concentric axial load to the porous disks, and for measuring the axial deformation of specimen.

6.2.1 *Minimum Specimen Diameter*—The minimum specimen diameter or inside diameter of the specimen ring shall be 50 mm [2.0 in.].

6.2.2 *Minimum Specimen Height*—The minimum initial specimen height shall be 12 mm [0.5 in.], but shall be not less than ten times the maximum particle diameter.

6.2.3 *Minimum Specimen Diameter-to-Height Ratio*—The minimum specimen diameter-to-height ratio shall be 2.5.

NOTE 5—The use of greater diameter-to-height ratios is recommended. To minimize the effects of friction between the periphery of the specimen and the inside of the ring, a diameter-to-height ratio greater than four is preferable.

6.2.4 *Specimen Ring Rigidity*—The ring shall be stiff enough to prevent significant lateral deformation of the specimen throughout the test. The rigidity of the ring shall be such that, under hydrostatic stress conditions in the specimen, the change in diameter of the ring will not exceed 0.04 % of the diameter under the greatest load applied.

NOTE 6—For example, a ring thickness (for metallic rings) of 3.2 mm [⅛ in.] will be adequate for stresses up to 6000 kPa [900 lbf/in^2] for a specimen diameter of 63.5 mm [2.5 in.].

6.2.5 *Specimen Ring Material*—The ring shall be made of a material that is noncorrosive in relation to the soil or pore fluid. The inner surface shall be highly polished or shall be coated with a low-friction material. Silicone grease or molybdenum disulfide is recommended; polytetrafluoroethylene is recommended for nonsandy soils.

6.3 *Porous Disks*—The porous disks shall be of silicon carbide, aluminum oxide, or other material of similar stiffness that is not corroded by the specimen or pore fluid. The disks shall be fine enough that the soil will not penetrate into their pores, but have sufficient hydraulic conductivity so as not to impede the flow of water from the specimen. Exact criteria have not been established but the disk thickness and hydraulic conductivity should result in an impedance factor of at least 100.

NOTE 7—The impedance factor is defined as the ratio of the hydraulic conductivity of the stones times the drainage thickness of the soil to the hydraulic conductivity of the soil times the thickness of the stone. Bishop and Gibson (1963) provides further information on the calculation and importance of the impedance factor.

6.3.1 *Diameter*—The diameter of the top disk shall be 0.2 to 0.5 mm [0.01 to 0.02 in.] less than the inside diameter of the ring. If a floating ring is used, the bottom disk shall meet the same requirement as the top disk.

NOTE 8—The use of tapered disks is recommended to prevent the disk from binding with the inside of the ring. The surface matching l, the larger diameter should be in contact with the soil or filter screen.

6.3.2 *Thickness*—Thickness of the disks shall be sufficient to prevent breaking. The top disk shall be loaded through a corrosion-resistant plate of sufficient rigidity to prevent breakage of the disk.

6.3.3 *Maintenance*—The disks shall be clean and free from cracks, chips, and nonuniformities. New porous disks should be boiled for at least 10 minutes and left in the water to cool to ambient temperature before use. Immediately after each use, clean the porous disks with a nonabrasive brush and boil or sonicate to remove clay particles that may reduce their permeability.

NOTE 9—It is recommended that porous disks be stored in clean test water between tests. Each drying cycle has the potential to draw particles into the pores of the stone causing a progressive reduction in hydraulic conductivity. When performing tests that require dry stones during the setup procedure, the stones can be blotted dry just prior to the test.

6.4 *Filter Screen*—To prevent intrusion of material into the pores of the porous disk, a filter screen may be placed between the porous disk and the specimen. The screen must be included when evaluating the impedance factor. Monofilament-nylon filter screen or hardened, low ash, grade 54 filter paper may be used for the filter screen material.

NOTE 10—Filters should be cut to approximately the same dimension as the cross section of the test specimen. When following the wet setup procedure, soak the filter paper, if used, in a container of water to allow it to equilibrate before testing.

6.5 *Specimen Trimming Device*—A trimming turntable or a cylindrical cutting ring may be used for trimming the sample down to the inside diameter of the consolidometer ring with minimal disturbance. A cutter having the same inside diameter (or up to 0.05 mm larger) as the specimen ring shall attach to or be integral with the specimen ring. The cutter shall have a sharp edge, a highly polished surface and be coated with a low-friction material. Alternatively, a turntable or trimming lathe may be used. The cutting tool must be properly aligned to form a specimen of the same diameter as that of the ring.

6.6 *Deformation Indicator*—To measure the axial deformation of the specimen with a resolution of 0.0025 mm [0.0001 in.] or better. Practice D6027 provides details on the evaluation of displacement transducers.

6.7 *Recess Spacer Plate*—A plate usually of acrylic with a flat raised circular surface that fits inside the specimen ring and used to depress the top surface of the specimen about 2 mm [0.08 in] into the ring. A second plate that produces about twice the recess will be required when using a floating ring. The spacer plate(s) is not required if the consolidometer provides a means to center the porous disks.

6.8 *Balances*—The balance(s) shall be suitable for determining the mass of the specimen plus the containment ring and for making the water content measurements. The balance(s) shall be selected as discussed in Specification D4753. The mass of specimens shall be determined to at least four significant digits.

6.9 *Drying Oven*—in accordance with Method D2216.

6.10 *Water Content Containers*—in accordance with Method D2216.

6.11 *Environment*—Unless otherwise specified by the requesting agency, the standard test temperature shall be in the range of 22 ± 5 °C. In addition, the temperature of the consolidometer, test specimen, and submersion reservoir shall not vary more than ± 2 °C throughout the duration of the test. Normally, this is accomplished by performing the test in a room with a relatively constant temperature. If such a room is not available, the apparatus shall be placed in an insulated chamber or other device that maintains the temperature within the tolerance specified above. The apparatus should be located in an area that does not have direct exposure to sunlight.

6.12 *Test Water*—Water is necessary to saturate the porous stones and fill the submersion reservoir. Ideally, this water would be similar in composition to the specimen pore fluid. Options include extracted pore water from the field, potable tap water, demineralized water, or saline water. The requesting agency should specify the water option. In the absence of a specification, the test should be performed with potable tap water.

6.13 *Miscellaneous Equipment*—Including timing device with 1 s readability, spatulas, knives, and wire saws, used in preparing the specimen.

7. Sampling

7.1 *Collection*—Practices D1587 and D3550 cover procedures and apparatus that may be used to obtain intact samples generally satisfactory for testing. Specimens may also be trimmed from large intact block samples which have been fabricated and sealed in the field. Finally, remolded specimens may be prepared from bulk samples to density and moisture conditions stipulated by the agency requesting the test.

7.2 *Transport*—Intact samples intended for testing in accordance with this test method shall be preserved, handled, and transported in accordance with the practices for Group C and D samples in Practices D4220. Bulk samples for remolded specimens should be handled and transported in accordance with the practice for Group B samples.

7.3 *Storage*—Storage of sealed samples should be such that no moisture is lost during storage, that is, no evidence of partial drying of the ends of the samples or shrinkage. Time of storage should be minimized, particularly when the soil or soil moisture is expected to react with the sample tubes.

7.4 *Disturbance*—The quality of consolidation test results diminishes greatly with sample disturbance. No sampling procedure can ensure completely undisturbed samples. Therefore, careful examination of the sample is essential in selection of specimens for testing.

NOTE 11—Examination for sample disturbance, stones, or other inclusions, and selection of specimen location is greatly facilitated by x-ray radiography of the samples (see Methods D4452).

8. Calibration

8.1 *Apparatus Deformation*—The measured axial deformations shall be corrected for apparatus compressibility whenever the equipment deformation exceeds 0.1 % of the initial specimen height or when using paper filter screens. If the correction is warranted at any point during the test, then a correction should be applied using the calibration data to all measurements throughout the test.

8.1.1 Assemble the consolidometer with a copper, aluminum, or hard steel disk of approximately the same height as the test specimen and at least 1 mm [0.04 in.] smaller in diameter than the ring, but no more than 5 mm smaller in diameter than the ring, in place of the specimen. Moisten the porous disks. If paper filter screens are to be used (see 6.3), they should be moistened and sufficient time (a minimum of 2 min.) allowed for the moisture to be squeezed from them during each increment of the calibration process.

8.1.2 Load and unload the consolidometer as in the test and measure the deformation for each load applied. When using paper filter screens, it is imperative that calibration be performed following the exact loading and unloading schedule to be used in the test. This is due to the inelastic deformation characteristics of filter paper. Recalibration should be done on an annual basis, or after replacement and reassembly of apparatus components.

8.1.3 At each load applied, plot or tabulate the apparatus deformations (corrections) to be applied to the measured deformation of the test specimen. The metal disk will also deform; however, modification of the apparatus deformation due to this deformation will be negligible for all but extremely large stress levels. If necessary, the compression of the metal disk can be computed and added to the corrections.

8.1.4 When using nylon filter screens it may be possible to represent the corrections with a mathematical equation.

8.2 *Miscellaneous Loading Elements*—Determine the cumulative mass (to the nearest 0.001 kg) of the top porous disk plus any other apparatus components that rest on the specimen and are not counterbalanced by the load frame, M_a.

8.3 *Apparatus Constants*—The following measurements must be made on an annual schedule or after replacement or alteration.

8.3.1 Determine the height of the ring, H_r, to the nearest 0.01 mm [0.0005 in], the diameter of the ring, D_r, to the nearest 0.01 mm [0.0005 in], and the mass of the ring, M_r, to the nearest 0.01 gm.

8.3.2 Determine the thickness of the filter screen, H_{fs}, to the nearest 0.01 mm [0.0005 in].

8.3.3 Determine the thickness of the step in the recess spacer(s), H_{rs}, to the nearest 0.01 mm [0.0005 in].

9. Specimen Preparation

9.1 Reduce as much as practical any disturbance of the soil or changes in moisture and density during specimen preparation. Avoid vibration, distortion, and compression.

9.2 Prepare test specimens in an environment where soil moisture change during preparation is minimized.

NOTE 12—A high humidity environment is often used for this purpose.

9.3 Trim the specimen and insert it into the consolidation ring. The specimen must fit tightly in the ring without any perimeter gaps. When specimens come from intact soil collected using sample tubes, the inside diameter of the tube shall be at least 5 mm [0.25 in.] greater than the inside diameter of the consolidation ring, except as noted in 9.4 and 9.5. It is recommended that either a trimming turntable or cylindrical cutting ring be used to cut the soil to the proper diameter. When using a trimming turntable, make a complete perimeter cut, reducing the specimen diameter to the inside diameter of the consolidation ring. Carefully insert the specimen into the consolidation ring, by the width of the cut, with a minimum of force. Repeat until the specimen protrudes from the bottom of the ring. When using a cylindrical cutting ring, trim the soil to a gentle taper in front of the cutting edge. After the taper is formed, advance the cutter a small distance to form the final diameter. Repeat the process until the specimen protrudes from the ring.

9.4 Fibrous soils, such as peat, and those soils that are easily damaged by trimming, may be transferred directly from the sampling tube to the ring, provided that the ring has the same or slightly smaller inside diameter as the sample tube.

9.5 Specimens obtained using a ring-lined sampler may be used without prior trimming, provided they comply with the requirements of Practice D3550 and the rigidity requirement of 6.2.4.

9.6 Trim the specimen flush with the plane ends of the ring. For soft to medium soils, a wire saw should be used for trimming the top and bottom of the specimen to minimize smearing. A straightedge with a sharp cutting edge may be used for the final trim after the excess soil has first been removed with a wire saw. For stiff soils, a sharpened straightedge alone should be used for trimming the top and bottom. If a small particle is encountered in any surface being trimmed, it should be removed and the resulting void filled with soil from the trimmings.

NOTE 13—If large particles are found in the material during trimming or in the specimen after testing, include in the report this visual observation or the results of a particle size analysis in accordance with Method D422 (except the minimum sample size requirement shall be waived).

9.6.1 Unless the consolidometer provides a means to center the porous disks, the specimen must be recessed slightly below the top of the ring and also the bottom of the ring when using a floating ring geometry. This is to facilitate centering of the top (and bottom) porous disk. After trimming the top surface flush with the ring cover the specimen surface with the filter screen and then use the recess spacer to partially extrude the specimen from the bottom of the ring. Trim the bottom surface flush with the bottom of the ring. If using a floating ring configuration, cover the surface with the second filter screen and use the recess space with the smaller dimension to push the specimen back into the ring.

NOTE 14—If, at any stage of the test, the specimen swells beyond its initial height, the requirement of lateral restraint of the soil dictates the use of a recessed specimen or the use of a specimen ring equipped with an extension collar of the same inner diameter as the specimen ring. At no time during the test should the specimen extend beyond the specimen ring or extension collar.

9.7 Determine the initial wet mass of the specimen, M_{To}, to the nearest 0.01 g, in the consolidation ring by measuring the mass of the ring with specimen and subtracting the tare mass of the ring, M_r.

9.8 Determine the initial height of the specimen, H_o, to the nearest 0.01 mm [0.001 in.] using one of the following techniques.

9.8.1 Take the average of at least four evenly spaced measurements over the top (and bottom) surface(s) of the specimen using a dial comparator or other suitable measuring device. Subtract the thickness of the filter screens when appropriate.

9.8.2 Calculate the height based on the thickness of the specimen ring, H_r, minus the thickness of the recess spacer(s), H_{rs} and the filter screen(s), Hfs, as appropriate.

9.9 Compute the initial volume of the specimen, V_o, to the nearest 0.01 cm^3 [0.01 in.^{3}] from the diameter of the ring and the initial specimen height.

9.10 If sufficient material is available, obtain at least two natural water content determinations of the soil in accordance with Method D2216 from material trimmed adjacent to the test specimen.

9.11 When index properties are specified by the requesting agency, store the remaining trimmings taken from around the specimen and determined to be similar material in a sealed container for determination as described in Section 10.

10. Soil Index Property Determinations

10.1 The determination of index properties is an important adjunct to but not a requirement of the consolidation test. These determinations when specified by the requesting agency shall be made on the most representative material possible. When testing uniform materials, all index tests may be performed on adjacent trimmings collected in 9.11. When samples are heterogeneous or trimmings are in short supply, index tests should be performed on material from the test specimen as obtained in 11.6, plus representative trimmings collected in 9.11.

10.2 *Specific Gravity*—The specific gravity shall be determined in accordance with Test Method D854 on material from the sample as specified in 10.1. The specific gravity from another sample judged to be similar to that of the test specimen may be used for calculation in 12.2.4 whenever an accurate void ratio is not needed.

10.3 *Atterberg Limits*—The liquid limit, plastic limit and plasticity index shall be determined in accordance with Test Method D4318 using material from the sample as specified in 10.1. Determination of the Atterberg limits are necessary for proper material classification but are not a requirement of this test method.

10.4 *Particle Size Distribution*—The particle size distribution shall be determined in accordance with Method D422 (except the minimum sample size requirement shall be waived) on a portion of the test specimen as obtained in 11.6. A particle size analysis may be helpful when visual inspection indicates that the specimen contains a substantial fraction of coarse grained material but is not a requirement of this test method.

11. Procedure

11.1 Preparation of the porous disks and other apparatus will depend on the material being tested. The consolidometer must be assembled in such a manner as to prevent a change in water content or swelling of the specimen. Dry porous disks and filters must be used with dry, highly expansive soils and may be used for all other soils. Damp disks may be used for partially saturated soils. Saturated disks may be used only when the specimen is saturated and known to have a low affinity for water. The disks should be prepared using the test water. Assemble the ring with specimen, porous disks, filter screens (when needed) in the consolidometer. If the specimen will not be inundated shortly after application of the seating load (see 11.2), enclose the consolidometer in a loose fitting plastic or rubber membrane to prevent change in specimen volume due to evaporation.

NOTE 15—In order to meet the stated objectives of this test method, the specimen must not be allowed to swell in excess of its initial height prior to being loaded beyond its preconsolidation stress. Detailed procedures for the determination of one-dimensional swell or settlement potential of cohesive soils is covered by Test Method D4546.

11.2 Place the consolidometer in the loading device and apply a seating load that results in a total axial stress of about 5 kPa [100 lbf/ft^2]. Immediately after application of the seating load, adjust the deformation indicator and record the initial deformation reading, d_o. If necessary, add additional load to keep the specimen from swelling. Conversely, if it is anticipated that a total axial stress of 5 kPa [100 lbf/ft^2] will cause significant consolidation of the specimen, reduce the seating load to produce a total axial stress of about 3 kPa [50 lbf/ft^2] or less. If necessary, allow time for the consolidometer temperature to reach the test temperature range (± 2 °C).

11.3 If the test is performed on an intact specimen that was either saturated under field conditions or obtained below the water table, inundate with the test water shortly after application of the seating load. As inundation and specimen wetting occur, quickly increase the load as required to prevent swelling. Record the applied load required to prevent swelling and the resulting deformation reading. If specimen inundation is to be delayed to simulate specific conditions, then inundation must occur at a total axial stress that is sufficiently large to prevent swell. In such cases, apply the required load and inundate the specimen. Take deformation readings during the inundation period as specified in 11.5. In such cases, note in the test report the total axial stress at inundation and the resulting axial deformation.

NOTE 16—Inundation is necessary to eliminate the air water interface at the soil boundary which can cause negative pore pressures to exist in the pore space. Inundation will not significantly increase the degree of saturation of the test specimen and should not be used as the basis to claim a specimen is fully saturated.

11.4 The specimen is to be subjected to load increments of constant total axial stress. The duration of each load increment shall conform to guidelines specified in 11.5. The specific loading schedule will depend on the purpose of the test, but should conform to the following guidelines.

11.4.1 The standard loading schedule shall consist of a load increment ratio (LIR) of one which is obtained by approximately doubling the total axial stress on the soil to obtain values of about 12, 25, 50, 100, 200, etc. kPa [250, 500, 1000, 2000, 4000, etc. lbf/ft ^{2}].

11.4.2 If the slope and the shape of the virgin compression curve or determination of the preconsolidation stress is required, the maximum total axial stress shall be sufficiently high to provide either a) three points which define a straight line when plotted in log stress space, b) three points which define a concave up curve when plotted in log stress space or c) a stress level which is eight times the estimated preconsolidation stress. In other circumstances, the maximum total axial stress should be agreed on with the requesting agency.

11.4.3 The standard unloading (or rebound) schedule should be selected by approximately halving the total axial stress on the soil (that is, use the same stress levels as 11.4.1, but in reverse order). However, if desired, each successive stress level can be only one-fourth as large as the preceding stress level, that is, skip every other stress level.

11.4.4 In the case of overconsolidated clays, a better evaluation of recompression parameters may be obtained by imposing an unload-reload cycle once the preconsolidation stress has been exceeded. Specification of the stress level and the magnitude of an unload-reload cycle is the option of the agency requesting the test (see 1.3), however, unloading shall always include at least two decrements of total axial stress.

11.4.5 An alternative loading, unloading, or reloading schedule may be employed that reproduces the construction stress changes or allows better definition of some part of the stress-strain (compression) curve, or aids in interpreting the field behavior of the soil, or is specified by the requesting agency.

NOTE 17—Small increments may be desirable on highly compressible soils or when it is desirable to determine the preconsolidation stress with more precision. It should be cautioned, however, that load increment ratios less than 0.7 and load increments very close to the preconsolidation stress may preclude evaluation for the coefficient of consolidation, c_v, and the end-of-primary consolidation as discussed in Section 12.

11.5 Before each load increment is applied, record the height or change in height, d_f, of the specimen. Two alternative procedures are available that specify the time sequence of readings during the load increment and the required minimum load increment duration. Longer durations are often required during specific load increments to define the slope of the characteristic straight line secondary compression portion of the axial deformation versus log of time graph. For such increments, sufficient readings should be taken near the end of the load increment to define this straight line portion. It is not necessary to increase the duration of other load increments during the test.

11.5.1 *Test Method A*—The standard load increment duration shall be approximately 24 h. For at least two load increments, including at least one load increment after the preconsolidation stress has been exceeded, record the axial deformation, *d*, at time intervals of approximately 0.1, 0.25, 0.5, 1, 2, 4, 8, 15 and 30 min, and 1, 2, 4, 8 and 24 h (or 0.09, 0.25, 0.49, 1, 4, 9 min etc. if using 12.5.2 to present time-deformation data), measured from the time of each load increment application. Take sufficient readings near the end of the load increment duration to verify the completion of primary consolidation. For some soils, a period of more than 24 h may be required to reach the end-of-primary consolidation (as determined in 12.5.1.1 or 12.5.2.3). In such cases, load increment durations greater than 24 h are required. The load increment duration for these tests is usually taken at some multiple of 24 h and should be the standard duration for all load increments of the test. The decision to use a load increment duration greater than 24 h is usually based on experience with particular types of soils. If, however, there is a question as to whether a 24 h period is adequate, a record of axial deformation with time should be made for the initial load increments in order to verify the adequacy of a 24 h period. Load increment durations other than 24 h shall be noted in the report. For load increments where time versus deformation data are not required, leave the load on the specimen for about the same length of time as when time versus deformation readings are taken.

11.5.2 *Test Method B*—For each increment, record the axial deformation, *d*, at time intervals of approximately 0.1, 0.25, 0.5, 1, 2, 4, 8, 15, 30 min, and 1, 2, 4, 8 and 24 h (or 0.09, 0.25, 0.49, 1, 4, 9, min, etc. if using 12.5.2 to present time deformation data), measured from the time of each load increment application. The standard load increment duration shall exceed the time required for completion of primary consolidation as determined by 12.5.1.1, 12.5.2.3, or a criterion set by the requesting agency. For any load increment where it is impossible to verify the end of primary consolidation (for example, low LIR, high overconsolidation during recompression increments, or rapid consolidation), the load increment duration shall be constant and exceed the time required for primary consolidation of an increment applied after the preconsolidation stress and along the virgin compression curve. Where secondary compression must be evaluated, increase the load increment duration as necessary to define the rate of secondary compression.

NOTE 18—The suggested time intervals for recording the axial deformation are for typical soils and load increments. It is often desirable to change the reading frequency to improve interpretation of the data. More rapid consolidation will require more frequent readings. For most soils, primary consolidation during the first load decrements will be complete in less time (typically one-tenth) than would be required for a load increment along the virgin compression curve. However, at very low stresses the rebound time can be longer.

11.6 To minimize swell during disassembly, rebound the specimen back to the seating load (corresponding to a total axial stress of about 5 kPa). Once the change in axial deformation has reduced to less than 0.2 % per hour (usually overnight), record the end-of-test axial deformation, d_{et} and remove the consolidometer from the load frame quickly after releasing the final small seating load on the specimen. Remove the specimen and the ring from the consolidometer and wipe any free water from the ring and specimen.

11.7 Measure the height of the specimen H_{et}, to the nearest 0.01 mm [0.001 in.] by taking the average of at least four evenly spaced measurements over the top and bottom surfaces of the specimen using a dial comparator or other suitable measuring device.

11.8 Determine the final total mass of the specimen, M_{T_f} to the nearest 0.01 g, by measuring the soil plus the ring and subtracting the tare mass of the ring.

11.9 The most accurate determination of the specimen dry mass and water content is found by drying the entire specimen at the end of the test in accordance with Method D2216. If the soil sample is homogeneous and sufficient trimmings are available for the specified index testing (see 9.11), then determine the final water content, w_f, and dry mass of solids, M_d, using the entire specimen. If the soil is heterogeneous or more material is required for the specified index testing, then determine the final water content, w_{f_p}, using a small wedge shaped section of the specimen. The remaining undried material should be used for the specified index testing.

12. Calculation

12.1 Calculations as shown are based on the use of SI units. Other units are permissible, provided the appropriate conversion factors are used to maintain consistency of units throughout the calculations. See 1.5.1 for additional comments on the use of inch-pound units.

12.1.1 Equations and graphs are illustrated using a single and dimensionally consistent set of units. Each equation makes use of the most convenient unit (for example, percent or decimal, s or min, kg or g) for each variable in the calculation. The multiplier unit conversion factors are not provided in the equations for simplicity and may be required to provide dimensional consistency between equations. Other units may be used and still be in conformance with these test methods.

12.1.2 Variables used in the equations are specified with a maximum resolution. When working in different units it will be necessary to compute comparable values to achieve the same number of significant digits.

12.2 *Specimen Physical Properties*:

12.2.1 Obtain the dry mass of the total specimen by direct measurement or for the case where part of the specimen is used for index testing, calculate the dry mass as follows:

$$M_d = \frac{M_{T_f}}{1 + w_{f_p}} \tag{1}$$

where:

M_d = dry mass of total specimen, g (nearest 0.01),
M_{Tf} = moist mass of total specimen after test, g (nearest 0.01), and
w_{fp} = water content wedge of specimen taken after test, in decimal form (nearest 0.0001).

12.2.2 Calculate the initial and final water content of the specimen, in percent, as follows:

$$\text{initial water content: } w_0 = \frac{M_{To} - M_d}{M_d} \times 100 \tag{2}$$

$$\text{final water content: } w_f = \frac{M_{T_f} - M_d}{M_d} \times 100 \tag{3}$$

where:

w_o = initial water content, % (nearest 0.01),
w_f = final water content, % (nearest 0.01),
M_d = dry mass of specimen, g, and
M_{To} = moist mass of specimen before test, g.

12.2.3 Calculate the initial dry density of the specimen as follows:

$$\rho_d = \frac{M_d}{V_o} \tag{4}$$

where:

ρ_d = dry density of specimen, g/cm^3 (nearest 0.001), and
V_o = initial volume of specimen, cm^3 (nearest 0.01).

12.2.4 Compute the volume of solids as follows:

$$V_s = \frac{M_d}{G\rho_w} \tag{5}$$

where:

V_s = Volume of solids, cm^3 (nearest 0.01)
G = specific gravity of the solids (nearest 0.001), and
ρ_w = density of water filling the pore space, (nearest 0.0001) g/cm^3.

NOTE 19—Water density depends on salt concentration and temperature. Appropriate values should be obtained from standard tables.

12.2.5 Since the cross-sectional area of the specimen is constant throughout the test, it is convenient for subsequent calculations to introduce the term "equivalent height of solids," defined as follows:

$$H_s = \frac{V_s}{A} \tag{6}$$

where:

H_s = height of solids, cm (nearest 0.001), and
A = specimen area, cm^2.

12.2.6 Calculate initial and final void ratio as follows:

$$\text{initial void ratio: } e_o = \frac{H_o - H_s}{H_s} \tag{7}$$

$$\textit{final void ratio : } e_f = \frac{H_f - H_s}{H_s} \tag{8}$$

where:

e_o = initial void ratio, (nearest 0.01),

e_f = final void ratio (nearest 0.01),

H_o = initial specimen height, cm, and

H_f = final specimen height, cm.

12.2.7 Calculate the initial and final degree of saturation, in percent, as follows:

$$\text{initial degree of saturation: } S_o = \frac{M_{T_o} - M_d}{A\rho_w(H_o - H_s)} \times 100 \quad (9)$$

$$\text{final degree of saturation: } S_f = \frac{M_{T_f} - M_d}{A\rho_w(H_f - H_s)} \times 100 \quad (10)$$

where:

S_o = initial degree of saturation, % (nearest 0.1), and

S_f = final degree of saturation, % (nearest 0.1).

12.3 *Deformation Calculations*:

12.3.1 For each deformation reading, calculate the change in specimen height, in cm, as follows:

$$\Delta H = d - d_o - d_a \quad (11)$$

where:

ΔH = Change in specimen height, cm, (nearest 0.00025),

d = deformation reading at various times in test, cm (nearest 0.00025),

d_o = initial deformation reading, cm (nearest 0.00025), and

d_a = apparatus deformation correction, cm (nearest 0.00025).

NOTE 20—Refer to 8.1 for apparatus compressibility correction requirements.

12.3.2 Represent each deformation measurement in at least one of the following forms.

12.3.2.1 The change in specimen height as computed in 12.3.1.

12.3.2.2 Calculate the specimen height, in cm, as follows:

$$H = H_o - \Delta H \quad (12)$$

12.3.2.3 Calculate the void ratio as follows:

$$e = \frac{H - H_s}{H_s} \quad (13)$$

12.3.2.4 Calculate the axial strain, in percent, as follows:

$$\varepsilon = \frac{\Delta H}{H_0} \times 100 \quad (14)$$

12.3.2.5 Calculate the final height differential as follows:

$$H_d = H_f - H_{et} \quad (15)$$

where:

H_d = final height differential, cm, (nearest 0.001),

H_f = computed final height using d_{et}, cm (nearest 0.001), and

H_{et} = measured final height, cm (nearest 0.001).

12.4 Compute the axial total stress, in kPa, as follows:

$$\sigma_a = \left(\frac{P + M_a g}{A}\right) \times 10 \quad (16)$$

where:

σ_a = axial total stress in kPa (nearest 1),

P = applied force in N (nearest 1),

M_a = mass of apparatus resting on specimen, kg (nearest 0.01)

A = specimen area, cm^2, (nearest 0.01), and

g = acceleration due to gravity, 9.81 m/s^2.

12.5 *Time-Deformation Properties*—From those load increments where time-deformation readings are obtained, two alternative procedures (see 12.5.1 or 12.5.2) are provided to present the data, determine the end-of-primary consolidation and compute the rate of consolidation. Alternative techniques may be used when agreed to by the requesting agency and still be in conformance with these test methods. The deformation readings may be presented as measured deformation, specimen height, or axial strain (see 12.6). The following text and figures are presented in terms of axial strain. The bold letters in parentheses within the following text are linked to the associated figures.

12.5.1 *Alternative Interpretation Procedure 1*—Referring to Fig. 1, plot the axial strain, ε, versus the log time (typically in minutes) for each applicable load increment.

12.5.1.1 Draw a straight line through the points representing the late time readings which exhibit a straight line trend and constant slope **(C)**. Draw a second straight line tangent to the steepest part of the axial strain-log time curve **(D)**. The intersection of these two lines represents the axial strain **(E)**, ε_{100}, and time **(F)**, t_{100}, corresponding to 100 % primary consolidation. Compression in excess of the above estimated 100 % primary consolidation is defined as secondary compression.

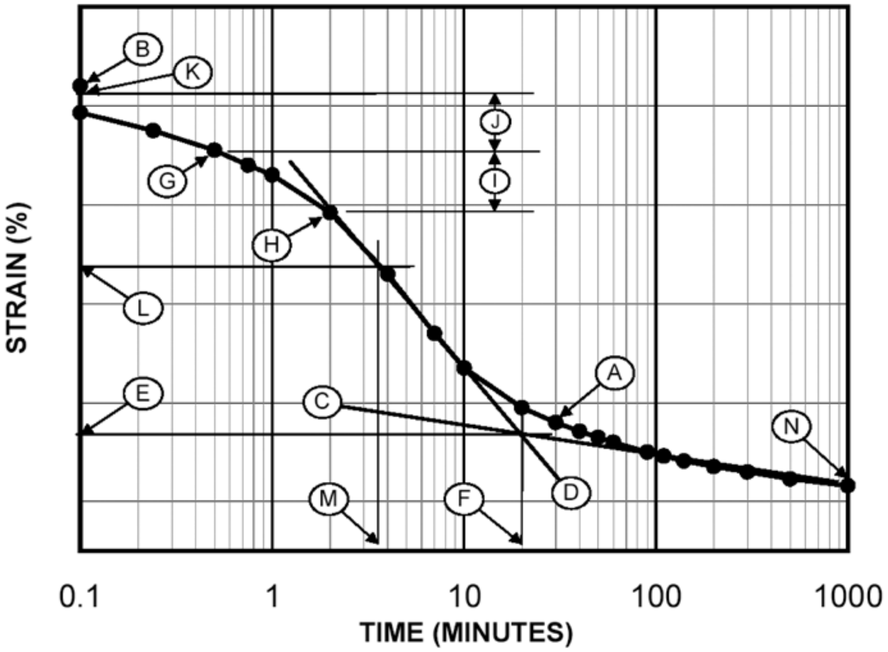
12.5.1.2 Find the axial strain representing 0 % primary consolidation **(K)** by selecting any two points that have a time ratio of 1 to 4 **(points G and H in this example)**. The axial strain increment at the larger of the two times should be greater than ¼ , but less than ½ of the total axial strain increment for the load increment. The axial strain corresponding to 0 % primary consolidation is equal to the axial strain at the smaller time, less the difference in axial strain **(I = J)** between the two selected points.

12.5.1.3 The axial strain **(L)**, ε_{50}, corresponding to 50 % primary consolidation is equal to the average of the axial strains corresponding to the 0 and 100 %. The time **(M)**, t_{50}, required for 50 % consolidation may be found graphically from the axial strain-log time curve by observing the time that corresponds to 50 % of the primary consolidation on the curve.

12.5.2 *Alternative Interpretation Procedure 2*—Referring to Fig. 2, plot the axial strain, ε, versus the square root of time (typically in minutes) for each applicable load increment.

12.5.2.1 Draw a straight line through the points representing the early time readings that exhibit a straight line trend **(A)**. Extrapolate the line back to $t = 0$ and obtain the axial strain ordinate representing 0 % primary consolidation **(B)**.

12.5.2.2 Draw a second straight line through the 0 % ordinate so that the abscissa of this line **(C)** is 1.15 times the abscissa of the first straight line through the data. The intersection of this second line with the axial strain-square root of time data curve gives the axial strain, ε_{90}, **(D)**, and time, t_{90}, **(E)**, corresponding to 90 % primary consolidation.



A – STRAIN-TIME BASED ON DATA POINTS AND INTERPRETED CURVE
B – STRAIN AT TIME = 0 MINUTES
C – LINEAR FIT OF ENDING PORTION OF MEASURED CURVE
D – LINEAR FIT OF STEEPEST PORTION OF MEASURED CURVE
E – STRAIN AT INTERSECTION OF LINES 'C' AND 'D' CORRESPONDING TO 100% CONSOLIDATION
F – TIME AT INTERSECTION OF LINES 'C' AND 'D' CORRESPONDING TO 100% CONSOLIDATION
G – FIRST DATA POINT SELECTED FOR INTERPRETATION OF 0% CONSOLIDATION
H – SECOND INTERPRETATION POINT CORRESPONDING TO FOUR TIMES LATER THAN POINT 'G'
I – INCREMENT OF STRAIN BETWEEN POINTS 'H' AND 'G'
J – INCREMENT OF STRAIN EQUAL TO 'I'
K – INTERPRETED STRAIN AT THE START OF CONSOLIDATION
L – STRAIN AT 50% CONSOLIDATION EQUAL TO MEAN OF 'K' AND 'E'
M – TIME CORRESPONDING TO 50% CONSOLIDATION
N – STRAIN AND TIME FOR LAST READING OF INCREMENT

NOTE—Strain scale omitted intentionally to make plot generic.

FIG. 1 Time-Deformation Curve Using Log Time Method

12.5.2.3 The axial strain at 100 % consolidation **(F)** is ⅑ more than the difference in axial strain between 0 and 90 % consolidation. The time of primary consolidation **(G)**, t_{100}, may be taken at the intersection of the axial strain-square root of time curve and this axial strain ordinate. The axial strain **(H)**, ε_{50}, corresponding to 50 % consolidation is equal to the axial strain at 5⁄9 of the difference between 0 and 90 % consolidation. The time for 50 % consolidation **(I)**, t_{50}, corresponds to the intersection of axial strain-square root time curve and the 50 % strain ordinate.

12.5.3 Compute the coefficient of consolidation for each applicable load increment using the following equation and values appropriate to the chosen method of interpretation:

$$c_v = \frac{T H_{D_{50}}^2}{t} \qquad (17)$$

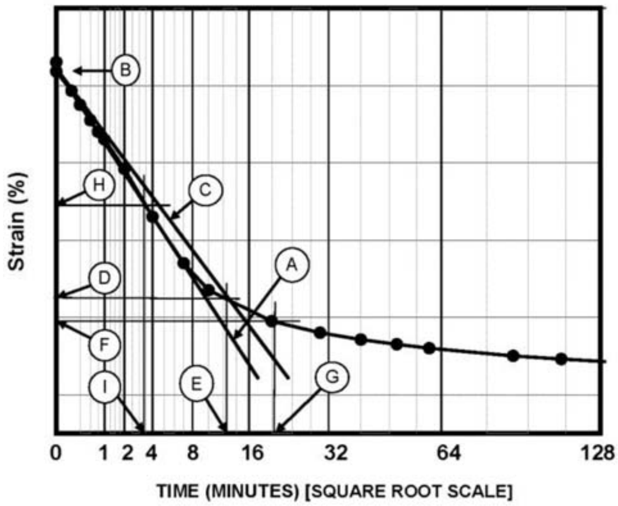
where:

c_v = coefficient of consolidation, cm^2/s (3 significant digits),

T = a dimensionless time factor: for method 12.5.1 use 50 % consolidation with $T = T_{50} = 0.197$, for method 12.5.2 use 90 % consolidation with $T = T_{90} = 0.848$,

t = time corresponding to the particular degree of consolidation, s; for method 12.5.1 use $t = t_{50}$, for method 12.5.2 use $t = t_{90}$, and

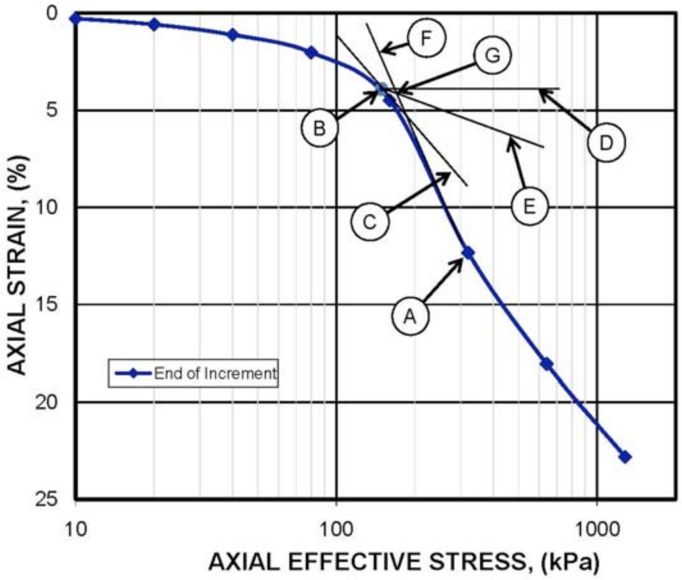
$H_{D_{50}}$ = length of the drainage path at 50 % consolidation, cm, for double-sided drainage $H_{D_{50}}$ is half the specimen height at the appropriate increment and for one-sided drainage $H_{D_{50}}$ is the full specimen height.



A – STRAIGHT LINE FIT THROUGH EARLY TIME DATA
B – EXTENSION OF LINE 'A' TO TIME = 0 MINUTES
C – CONSTRUCTION LINE WITH SLOPE = 1.15 TIMES THAT OF LINE 'A'
D – STRAIN AT INTERSECTION OF CURVE THROUGH DATA AND LINE 'C'
E – TIME AT INTERSECTION OF CURVE THROUGH DATA AND LINE 'C'
F – STRAIN CORRESPONDING TO 100% CONSOLIDATION
G – TIME CORRESPONDING TO 100% CONSOLIDATION
H – STRAIN CORRESPONDING TO 50% CONSOLIDATION
I – TIME CORRESPONDING TO 50% CONSOLIDATION

NOTE—Strain scale omitted intentionally to make plot generic.

FIG. 2 Time-Deformation Curve Using Square Root of Time Method



A – STRESS STRAIN CURVE FROM DATA POINTS
B – POINT OF MAXIMUM CURVATURE
C – TANGENT LINE TO CURVE INTERSECTING AT POINT B
D – HORIZONTAL LINE THROUGH POINT B
E – LINE BISECTING ANGLE MADE BY LINES C AND D
F – TANGENT TO STEEPEST LINEAR PORTION OF DATA CURVE
G – INTERSECTION POINT OF LINES E AND F IS THE PRECONSOLIDATION STRESS

FIG. 3 Evaluation for Preconsolidation Stress From Casagrande Method

12.6 *Load-Deformation Properties*:

12.6.1 Tabulate the deformation or change in deformation, d_f, readings corresponding to the end of each increment and, if using Test Method B, corresponding to the end-of-primary consolidation, d_{100}.

12.6.2 Plot the deformation results (Fig. 3 is in terms of strain) corresponding to the end of each increment and, if using Test Method B, corresponding to the end-of-primary consolidation versus the stress on a log scale.

NOTE 21—In some cases, it may be preferable to present the load-deformation curve in arithmetic scale.

12.6.3 Referring to Fig. 3, determine the value of the preconsolidation stress using the following procedure.

NOTE 22—Any other recognized method of estimating preconsolidation stress (see references) may also be used, provided the method is identified in the report.

12.6.3.1 Draw a smooth curve through the measurements.

12.6.3.2 Estimate the point of maximum curvature on the compression curve **(B)**.

12.6.3.3 Draw the tangent to the compression curve at this point **(C)**, and a horizontal line through the point **(D)**, both extended towards increasing values on the abscissa.

12.6.3.4 Draw the line bisecting the angle between these lines **(E)**.

12.6.3.5 Extend the tangent to the steep, linear portion of the compression curve (virgin compression branch) **(F)** upwards to intersection with the bisector line **(E)**. The stress **(G)** (abscissa) corresponding to this point of intersection is the estimated preconsolidation stress.

12.6.4 Complete evaluation often includes consideration of information not generally available to the laboratory performing the test. For this reason further evaluation of the test is not mandatory. Many recognized methods of evaluation are described in the literature. Some of these are discussed in the Refs. (**1**) through (**9**).[3]

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

13.1 The methodology used to specify how data are recorded on the data sheet(s)/form(s), as given below, is covered in 1.6 and Practice D6026.

13.2 Record as a minimum the following general information (data):

13.2.1 Project name and location, boring number, sample number, and depth.

13.2.2 Test number, starting date, apparatus, and technician.

13.2.3 Description and classification of the soil in accordance with Practice D2488 or Test Method D2487 when Atterberg limit data are available. Specific gravity of solids, Atterberg limits and grain size distribution shall also be reported when available plus the source of such information if other than measurements obtained on test specimen. Also note occurrence and approximate size of isolated large particles.

13.2.4 *Soil Condition*:

13.2.4.1 Average water content of trimmings when available,

13.2.4.2 Initial and final water content of specimen,

---

[3] The boldface numbers in parentheses refer to a list of references at the end of the text.

13.2.4.3 Initial dry density of specimen,

13.2.4.4 Initial and final void ratio of specimen,

13.2.4.5 Initial and final degree of saturation of specimen,

13.2.4.6 Final differential height, and

13.2.4.7 Estimated preconsolidation stress.

13.2.5 *Test Procedure*:

13.2.5.1 Preparation procedure used relative to trimming; state whether the specimen was trimmed using a trimming turntable, trimmed using a cutting shoe, or tested directly in a ring from a ring lined sampler.

13.2.5.2 Condition of test (natural moisture or inundated, stress at inundation, test water).

13.2.5.3 Method of testing (A or B).

13.2.5.4 Interpretation procedure (1 or 2 or both) used to compute coefficient of consolidation.

13.2.5.5 Listing of loading increments, and load increment duration, if differing from 24 h; end of increment deformation results and, for Test Method B, end-of-primary deformation results and coefficient of consolidation (see Table 1).

13.2.5.6 All departures from the procedure outlined, including special loading sequences.

13.2.6 *Graphical Presentations*:

13.2.6.1 Graph of deformation versus log time (see Fig. 1) or square root of time (see Fig. 2) for those load increments where time rate readings were taken.

13.2.6.2 Graph of void ratio versus axial stress (on a log scale) curve or percent compression versus axial stress (on a log scale) curve (see Fig. 3).

13.2.6.3 In cases where time rate of deformation readings have been taken for several load increments, prepare a graph of the log of coefficient of consolidation versus average void ratio or average percent compression for the respective load increments (see Fig. 4). Alternatively, a graph of coefficient of consolidation or log of coefficient of consolidation versus log of average axial stress may be used. If time rate readings were obtained for only two load increments, simply tabulate the values of $c_v$versus the average axial stress for the increment.

NOTE 23—The average stress between two load increments is chosen because it is a convenient coordinate for plotting the result. Unless the rate of pore pressure dissipation is measured, it is not possible to determine the actual effective stress at the time of 50 % consolidation. Furthermore, some ambiguity may arise in cases where the test has been carried through one or more intermediate load-rebound cycles.

14. Precision and Bias

14.1 *Statement of Precision*—Due to the nature of the soil materials tested by this test method it is either not feasible or too costly at this time to produce multiple specimens which have uniform physical properties. Any variation observed in the data is just as likely to be due to specimen variation as to operator or laboratory testing variation. Subcommittee D18.05 welcomes proposals that would allow for development of a valid precision statement.

14.2 *Statement of Bias*—There is no acceptable reference value for this test method, therefore, bias cannot be determined.

15. Keywords

15.1 compressibility; compression curves; consolidation; consolidation coefficient; consolidation test; consolidometer; preconsolidation pressure; preconsolidation stress; primary consolidation; rebound; secondary compression; settlement; swelling

TABLE 1 Example of a Consolidation Test Summary

Load Incr.	Axial Stress σ_a (kPa)	Corrected Deformation ΔH (mm)	Specimen Height H (mm)	Axial Strain ε_a (%)	Void Ratio e (--)	Corrected Deformation ΔH_{50} (mm)	Specimen Height H_{50} (mm)	Axial Strain $\varepsilon_{a,50}$ (%)	Void Ratio e_{50} (--)	Time t_{50} (sec)	Coef. of Consolidation c_v (mm^2/sec)	Time t_{90} (sec)	Coef. of Consolidation c_v (mm^2/sec)
seating	seating	0.0000	19.0500	0.00	1.231					Log Time Method		Root Time Method	
1	5	0.0288	19.0212	0.15	1.228								
2	10	0.0557	18.9943	0.29	1.225								
3	20	0.1133	18.9367	0.59	1.218								
4	40	0.2139	18.8361	1.12	1.206	0.2696	18.7804	1.42	1.200	52	3.34E-01	10	3.34E-01
5	80	0.3867	18.6633	2.03	1.186	0.5355	18.5145	2.81	1.169	144	1.17E-01	30	1.17E-01
6	160	0.8560	18.1940	4.49	1.131	1.5439	17.5061	8.10	1.050	516	2.93E-02	102	2.93E-02
7	320	2.3496	16.7004	12.33	0.956	2.8317	16.2183	14.86	0.900	282	4.59E-02	53	4.59E-02
8	640	3.4392	15.6108	18.05	0.828	3.8223	15.2277	20.06	0.784	156	7.32E-02	31	7.32E-02
9	1280	4.3440	14.7060	22.80	0.722								
10	320	4.2553	14.7947	22.34	0.733								
11	80	3.9300	15.1200	20.63	0.771								
12	20	3.5131	15.5369	18.44	0.820								
13	5	3.0981	15.9519	16.26	0.868								

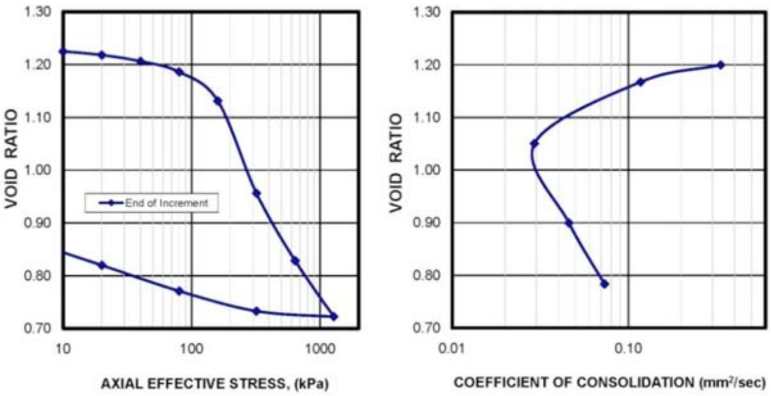


FIG. 4 Example of Consolidation Test Summary Plots

REFERENCES

(**1**) Casagrande, A., "The Determination of the Pre-Consolidation Load and its Practical Significance," Proceedings 1st ICSMFE, III, 1936, p. 60.

(**2**) Taylor, D. W., *Fundamentals of Soil Mechanics*, John Wiley and Sons, New York, NY, 1948.

(**3**) Burmeister, D. M. "The Application of Controlled Test Methods in Consolidation Testing," ASTM STP 126, p. 83, ASTM 1951.

(**4**) Schmertmann, J. H. "The Undisturbed Consolidation Behavior of Clay" Trans. ASCE, 120, pp. 1201 through 1233, 1955.

(**5**) Leonards, G. A. "Engineering Properties of Soils," Chapter 2 in *Foundation Engineering* by Leonards, G. A., ed. McGraw-Hill, New York, NY, 1962.

(**6**) Winterkorn, H. F. and Fang, H. Y. eds. *Foundation Engineering Handbook*, Chapter 4, Von Nostrand Reinhold Co, New York, NY, 1975.

(**7**) Holtz, R. D. and Kovacs, W. D. *An Introduction to Geotechnical Engineering*, Prentice Hall, Englewood Cliffs, NJ, 1981.

(**8**) Yong, R. N. and Townsend, F. C. Eds." Consolidation of Soils: Testing and Evaluation," *ASTM STP 892*, ASTM, 1986.

(**9**) Bishop A.W. and Gibson, R.E., "The Influence of the Provisions for Boundary Drainage on Strength and Consolidation Characteristics of Soils Measured in the Triaxial Apparatus," *Laboratory Shear Testing of Soils*, ASTM STP No 361, pp. 273-328, ASTM 1963.

SUMMARY OF CHANGES

Committee D18 has identified the location of selected changes to these test methods since the last issue, D2435–04, that may impact the use of these test methods. (Approved May 1, 2011)

(*1*) Throughout Standard extensive edits for clarification.
(*2*) Renumbered Notes.
(*3*) Sections 1.1.1 and 1.1.2 added clarification to each method.
(*4*) Section 1.2 and beyond change undisturbed to intact.
(*5*) Section 1.2 added saturation and last sentence.
(*6*) Section 1.3 specify default test conditions.
(*7*) Added Section 1.4 on saturation.
(*8*) Section 1.5 change unit specification.
(*9*) Section 2.1 add reference to D 4753 and D 6027.
(*10*) Section 3.2 add definitions of terms specific to standard.
(*11*) Section 3.2 added all definitions in this section.
(*12*) Section 4.1 and beyond change method to methods.
(*13*) Section 4.1 added discussion relative to saturation.
(*14*) Section 5.4 and 5.5 changed wording relative to requesting agency.
(*15*) Section 5.6 added clarification on inundation.
(*16*) Section 6.1 move note 4 information in standard.
(*17*) Section 6.2 and beyond put dual units in brackets.
(*18*) Section 6.2 and beyond use axial deformation as height measurement.
(*19*) Section 6.2 change in ring specification.
(*20*) Section 6.2.4 change specimen ring specification.
(*21*) Add Note 6.
(*22*) Section 6.3 change porous disk specification.
(*23*) Change note 7.
(*24*) Change note 8.
(*25*) Change note 9.
(*26*) Add Section 6.4, Note 10, and Section 6.7.
(*27*) Section 6.8 change balance specification.
(*28*) Section 6.11 change environment specification.
(*29*) Add Section 6.12 on test water specification.
(*30*) Add Section 6.13.
(*31*) Section 7 insert subsection titles.
(*32*) Section 8.1 change specification of apparatus deformation.
(*33*) Section 8.2 and 8.3 new sections.
(*34*) Add Note 13.
(*35*) Add Section 9.6.1 on providing recess of specimen into ring.
(*36*) Section 9.7 add tolerance on mass measurement
(*37*) Restructured Section 9.8.
(*38*) Section 11.2 add temperature requirement.
(*39*) Add Note 16.

(*40*) Section 11.4 change specifications and restructure subsections.

(*41*) Section 11.4.2 change maximum stress specification.

(*42*) Section 11.4.4 add option to load schedule.

(*43*) Section 11.5.2 add clarification.

(*44*) Section 11.6 change specification.

(*45*) Section 11.7 add section with new requirement.

(*46*) Section 11.8 add specification.

(*47*) Added Section 12.1.1 and Section 12.1.2 for guidance on equations.

(*48*) Section 12.2 changed title.

(*49*) Section 12 added definition of all terms in appropriate subsections.

(*50*) Section 12 added maximum resolution values to terms were appropriate.

(*51*) Section 12 changed example units to one option using SI system.

(*52*) Rearranged several of the subsections with in Section 12.

(*53*) Eliminated old Section 12.2.4 relative to dry unit weight.

(*54*) Section 12.2.4 increased significant digits of water density.

(*55*) Added Note 19.

(*56*) Section 12.3 changed title.

(*57*) Added Section 12.3.1 and 12.3.2 and removed old Section 12.4.

(*58*) Added Section 12.3.2.5 with new calculation.

(*59*) Added Note 20.

(*60*) Section 12.5 examples use strain to represent axial deformation.

(*61*) Section 12.5 separated into two alternative interpretation procedures.

(*62*) Section 12.5.1 and 12.5.2 added letters to better link to figures

(*63*) Section 12.6.2 added title.

(*64*) Added Section 13.2.2.

(*65*) Section 13.2.4 changed requirements.

(*66*) Section 13.2.4.6 new requirement.

(*67*) Renamed Figure 1 to Table 1 and replaced it with a new table.

(*68*) New Log Time and Square Root of Time Figures.

استاندارد آزمایش برش مستقیم

ASTM-D3080-11

Designation: D3080/D3080M – 11

Standard Test Method for
Direct Shear Test of Soils Under Consolidated Drained Conditions[1]

This standard is issued under the fixed designation D3080/D3080M; 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 This test method covers the determination of the consolidated drained shear strength of one specimen of a soil material under direct shear boundary conditions. The specimen is deformed at a controlled rate on or near a single shear plane determined by the configuration of the apparatus.

1.2 Shear stresses and displacements are nonuniformly distributed within the specimen. An appropriate height cannot be defined for calculation of shear strains. Therefore, stress-strain relationships or any associated quantity such as the shear modulus, cannot be determined from this test.

1.3 The determination of strength envelopes and the development of criteria to interpret and evaluate test results are left to the engineer or office requesting the test.

1.4 The results of the test may be affected by the presence of coarse-grained soil or rock particles, or both, (see Section 7).

1.5 Test conditions, including normal stress and moisture environment, should be selected to represent the field conditions being investigated. The rate of shearing must be slow enough to ensure drained conditions.

1.6 Generally, three or more tests are performed on specimens from one soil sample, each under a different normal load, to determine the effects upon shear resistance and displacement. Results from a test series are combined to determine strength properties such as Mohr strength envelopes. Interpretation of multiple tests requires engineering judgment and is beyond the scope of this test method. This test method pertains to the requirements for a single test.

1.7 There may be instances when the gap between the shear box halves should be increased to accommodate sand sized particles greater than the specified gap. Presently there is insufficient information available for specifying the gap dimension based on particle size distribution.

1.8 *Units*—The values stated in either inch-pound units or SI units [given in brackets] are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in non-conformance with the standard.

1.8.1 The gravitational system of inch-pound units is used. In this system, the pound (lbf) represents a unit of force (weight), while the unit for mass is slugs. The slug unit is not given, unless dynamic (F = ma) calculations are involved.

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

1.9.1 The method used to specify how data are collected, calculated, or recorded in this standard is not directly related to the accuracy to which the data can be applied in design or other uses, or both. How one applies the results obtained using this standard is beyond its scope.

1.10 *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]

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))
D1557 Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort (56,000 ft-lbf/ft^3(2,700 kN-m/m^3))
D1587 Practice for Thin-Walled Tube Sampling of Soils for Geotechnical Purposes
D2216 Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass
D2435 Test Methods for One-Dimensional Consolidation Properties of Soils Using Incremental Loading

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

---

[1] This test method is under the jurisdiction of ASTM Committee D18 on Soil and Rock and is the direct responsibility of Subcommittee D18.05 on Strength and Compressibility of Soils.

Current edition approved Nov. 1, 2011. Published January 2012. Originally approved in 1972. Last previous edition approved in 2004 as D3080–04. DOI: 10.1520/D3080_D3080M-11.

[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.

D2487 Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)
D2488 Practice for Description and Identification of Soils (Visual-Manual Procedure)
D3740 Practice for Minimum Requirements for Agencies Engaged in Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction
D4220 Practices for Preserving and Transporting Soil Samples
D4318 Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils
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
D6027 Practice for Calibrating Linear Displacement Transducers for Geotechnical Purposes

3. Terminology

3.1 *Definitions*—For definitions of common technical terms used in this test method, refer to Terminology D653.

3.2 *Description of Terms Specific to This Standard:*

3.2.1 *Failure*—The stress condition at failure for a test specimen. Failure is often taken as the maximum shear stress attained, or in the absence of a peak condition, the shear stress at 10 percent relative lateral displacement. Depending on soil behavior and field application, other suitable criteria may be defined at the direction of the requesting agency.

3.2.2 *Nominal Normal Stress*—In the direct shear test, the applied normal (vertical) force divided by the area of the shear box. The contact area of the specimen on the imposed shear plane decreases during shear and hence the true normal stress is unknown.

3.2.3 *Nominal Shear Stress*—In the direct shear test, the applied shear force divided by the area of the shear box. The contact area of the specimen on the imposed shear plane decreases during shear and hence the true shear stress is unknown.

3.2.4 *Percent Relative Lateral Displacement*—The ratio, in percent, of the relative lateral displacement to the diameter or lateral dimension of the specimen in the direction of shear.

3.2.5 *Preshear*—In strength testing, the stage of a test after the specimen has stabilized under the consolidation loading condition and just prior to starting the shearing phase. It is used as an adjective to modify phase relations or stress conditions.

3.2.6 *Relative Lateral Displacement*—The displacement between the top and bottom shear box halves.

4. Summary of Test Method

4.1 This test method consists of placing the test specimen in the direct shear device, applying a predetermined normal stress, providing for wetting or draining of the test specimen, or both, consolidating the specimen under the normal stress, unlocking the shear box halves that hold the test specimen, and shearing the specimen by displacing one shear box half laterally with respect to the other at a constant rate of shearing deformation while measuring the shearing force, relative lateral displacement, and normal displacement (Fig. 1). The shearing rate must be slow enough to allow nearly complete dissipation of excess pore pressure.

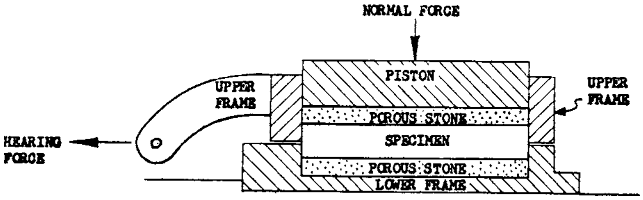


FIG. 1 Test Specimens in Single Shear Apparatus

5. Significance and Use

5.1 The direct shear test is suited to the relatively rapid determination of consolidated drained strength properties because the drainage paths through the test specimen are short, allowing excess pore pressure to dissipate more rapidly than other drained stress tests. The test can be made on any type of soil material. It is applicable for testing intact, remolded, or reconstituted specimens. There is however, a limitation on the maximum particle size (see 6.2).

5.2 The test results are applicable to assessing strength in a field situation where complete consolidation has occurred under the existing normal stresses. Failure is reached slowly under drained conditions so that excess pore pressures are dissipated. The shear rate must meet the requirements of 9.10. The results from several tests may be used to express the relationship between consolidation stress and drained shear strength.

NOTE 1—The equipment specified in this standard method is not appropriate for performing undrained shear tests. Using a fast displacement rate without proper control of the volume of the specimen will result in partial drainage and incorrect measurements of shear parameters.

5.3 During the direct shear test, there is rotation of principal stresses, which may or may not model field conditions. Moreover, failure may not occur on the weakest plane since failure is forced to occur on or near a plane through the middle of the specimen. The fixed location of the plane in the test can be an advantage in determining the shear resistance along recognizable weak planes within the soil material and for testing interfaces between dissimilar materials.

5.4 Shear stresses and displacements are nonuniformly distributed within the specimen, and an appropriate height is not defined for calculating shear strains or any associated engineering quantity. The slow rate of displacement provides for dissipation of excess pore pressures, but it also permits plastic flow of soft cohesive soils.

5.5 The number of tests in a series normal stress level, rate of shearing, and general test conditions should be selected to approximate the specific soil conditions being investigated.

5.6 The area of the shear surface decreases during the test. This area reduction creates uncertainty in the actual value of the shear and normal stress on the shear plane but should not affect the ratio of these stresses.

NOTE 2—Notwithstanding the statement on precision and bias contained in this standard: The precision of this test method is dependent on the competence of the personnel performing the test and the suitability of the equipment and facilities used. Agencies which meet the criteria of

Practice D3740 are generally considered capable of competent and objective testing. Users of this test method are cautioned that compliance with Practice D3740 does not in itself assure reliable testing. Reliable testing depends on several factors; Practice D3740 provides a means of evaluating some of these factors.

6. Apparatus

6.1 *Shear Device*—A device to hold the specimen securely between two porous inserts in such a way that torque is not applied to the specimen. The shear device shall provide a means of applying a normal stress to the faces of the specimen, for measuring change in thickness of the specimen, for permitting drainage of water through the porous inserts at the top and bottom boundaries of the specimen, and for submerging the specimen in water. The device shall be capable of applying a shear force to the specimen along a predetermined shear plane (single shear) parallel to the faces of the specimen. The frames that hold the specimen shall be sufficiently rigid to prevent their distortion during shearing. The various parts of the shear device shall be made of material not subject to corrosion by moisture or substances within the soil, for example, stainless steel, bronze, or aluminum, etc. Dissimilar metals, which may cause galvanic action, are not permitted.

6.2 *Shear Box,* a shear box, either circular or square, made of stainless steel, bronze, or aluminum, with provisions for drainage through the top and bottom. The box is divided by a straight plane into two halves of equal thickness which are fitted together with alignment screws. The shear box is also fitted with gap screws, which create the space (gap) between the top and bottom halves of the shear box prior to shear. The two halves should provide a bearing surface for the specimen along the shear plane during relative lateral displacement.

6.2.1 The minimum specimen diameter for circular specimens, or width for square specimens, shall be 2.0 in. [50 mm], or not less than ten (10) times the maximum particle size diameter, whichever is larger.

6.2.2 The minimum initial specimen thickness shall be 0.5 in. [13 mm], but not less than six (6) times the maximum particle diameter.

6.2.3 The minimum specimen diameter to thickness or width to thickness ratio shall be 2:1.

NOTE 3—A light coating of grease applied to the inside of the shear box may be used to reduce friction between the specimen and shear box. TFE-fluorocarbon coating may also be used on these surfaces instead of grease to reduce friction.

6.3 *Porous Inserts,* Porous inserts function to allow drainage from the soil specimen along the top and bottom boundaries. They also function to transfer shear stress from the insert to the top and bottom boundaries of the specimen. Porous inserts shall consist of silicon carbide, aluminum oxide, or metal which is not subject to corrosion by soil substances or soil moisture. The proper grade of insert depends on the soil being tested. The hydraulic conductivity of the insert should be substantially greater than that of the soil, but should be textured fine enough to prevent excessive intrusion of the soil into the pores of the insert. The diameter or width of the top porous insert or plate shall be 0.01 to 0.02 in. (0.2 to 0.5 mm) less than that of the inside of the shear box. The insert functions to transfer the shear stress to the soil and must be sufficiently coarse to develop interlock. Sandblasting or tooling the insert may help, but the surface of the insert should not be so irregular as to cause substantial stress concentrations in the soil. Porous inserts should be checked for clogging on a regular basis.

NOTE 4—Exact criteria for insert texture and hydraulic conductivity have not been established. For normal soil testing, medium grade inserts with a hydraulic conductivity of about 0.5 to 1.0 × 10^3 ft/yr [5.0 × 10^{-4} to 1.0 × 10^{-3} cm/s] are appropriate for testing silts and clays, and coarse grade inserts with a hydraulic conductivity of about 0.5 to 1.0 × 10^5 ft/yr [0.05 to 0.10 cm/s] are appropriate for sands. It is important that the hydraulic conductivity of the porous insert is not reduced by the collection of soil particles in the pores of the insert. Storing the porous inserts in a water filled container between uses will slow clogging. The inserts can be cleaned by flushing, boiling, or ultrasonic agitation.

6.4 *Loading Devices*:

6.4.1 *Device for Applying the Normal Force*—The normal force is typically applied by dead weights, a lever loading yoke activated by dead weights (masses), a pneumatic force cylinder, or a screw driven actuator. The device shall be capable of maintaining the normal force to within ± 1 percent of the specified force. It should apply the load quickly without significantly exceeding the steady value. Dead weight systems should be checked on a regular schedule. All systems with adjustable force application (e.g. pneumatic regulator or motor driven screw) require a force indicating device such as a proving ring, load cell, or pressure sensor.

6.4.2 *Device for Shearing the Specimen*—The device shall be capable of shearing the specimen at a uniform rate of displacement, with less than ±5 percent deviation. The rate to be applied depends upon the consolidation characteristics of the test material as specified in 9.10. The rate is usually maintained with an electric motor and gear box arrangement and the shear force is determined by a force indicating device such as a proving ring or load cell.

NOTE 5—In order to test a wide range of soils the apparatus should permit adjustment of the rate of displacement from 0.0001 to 0.04 in./min [0.0025 to 1.0 mm/min].

NOTE 6—Shearing the test specimen at a rate greater than specified may produce partially drained shear results that will differ from the drained strength of the material. The specimen must be sheared slowly enough to allow pore pressures to dissipate.

6.4.3 *Top Half of Shear Box*—The weight of the top half of shear box supported by the specimen shall be less than 1 percent of the applied normal force during shear: this will most likely require that the top shear box be supported by a counter force, the equipment modified or the specimen sheared under a greater applied normal force.

6.5 *Normal Force Measurement Device*—A proving ring or load cell (or calibrated pressure sensor when using a pneumatic loading system) accurate to 0.5 lbf [2.5 N], or 1 percent of the normal force during shear, whichever is greater, is required when using anything but dead weights to apply the normal force.

6.6 *Shear Force Measurement Device*—A proving ring or load cell accurate to 0.5 lbf (2.5 *N*), or 1 percent of the shear force at failure, whichever is greater.

6.7 *Deformation Indicators*—Either dial gauges or displacement transducers capable of measuring the change in thickness (normal displacement) of the specimen, with a readability of at least 0.0001 in. [0.002 mm] and to measure relative lateral displacement with readability of at least 0.001 in. [0.02 mm]. D6027 provides details on the evaluation of displacement transducers.

6.8 *Shear Box Bowl*—A metallic box which supports the shear box and provides either a reaction against which one half of the shear box is restrained, or a solid base with provisions for aligning one half of the shear box, which is free to move coincident with applied shear force along a plane. The bowl also serves as the container for the test water used to submerge the specimen.

6.9 *Controlled High Humidity Environment*—if required, for preparing specimens, such that water content gain or loss during specimen preparation is minimized.

6.10 *Test Water*—Water is necessary to saturate the porous stones and fill the submersion reservoir. Ideally, this water would be similar in composition to the specimen pore fluid. Options include extracted pore water from the field, potable tap water, demineralized water, or saline water. The requesting agency should specify the water option. In the absence of a specification, the test should be performed with potable tap water.

6.11 *Trimmer or Cutting Ring,* for trimming oversized samples to the inside dimensions of the shear box with a minimum of disturbance. An exterior jig may be needed to maintain the shear box alignment.

6.12 *Balances*—a balance or scale conforming to the requirements of Specification D4753 readable (with no estimate) to 0.1% or better.

6.13 *Apparatus for Determination of Water Content*—as specified in Test Method D2216.

6.14 *Equipment for Compacting Specimens*—if applicable, as specified in Test Methods D698 or D1557.

6.15 *Miscellaneous Equipment*—including timing device with a second hand, distilled or demineralized water, spatulas, knives, straightedge, wire saws, etc., used in preparing the specimen.

7. Test Specimen Preparation

7.1 *Intact Specimens*—Prepare intact specimens from large intact samples or from samples secured in accordance with Practice D1587, or other intact tube sampling procedures. Intact samples shall be preserved and transported as outlined for Group C or D samples in Practice D4220. Handle specimens carefully to minimize disturbance, changes in cross section, or loss of water content. If compression or any type of noticeable disturbance would be caused by the extrusion device, split the sample tube lengthwise or cut off a small section to facilitate removal of the sample with minimum disturbance. Prepare trimmed specimens, whenever possible, in an environment which will minimize the gain or loss of specimen moisture.

7.1.1 The sample selected for testing should be sufficiently large so that a minimum of three specimens can be prepared from similar material. While this standard test method applies to the measurements on one specimen, the requesting agency will typically specify a series of tests which cover a range of stress levels. The series should be performed on similar material.

7.1.2 Extreme care shall be taken in preparing intact specimens of sensitive soils to prevent disturbance to the natural soil structure.

7.1.3 Assemble the shear box halves and determine the mass of the empty box. Trim the lateral dimensions of the specimen to fit snuggly into the shear box using either a shape cutting shoe or a miter box. With the specimen in the shear box, trim the top and bottom surface of the specimen to be flat and parallel.

7.1.4 Determine and record the initial mass of the box plus specimen and height of the wet specimen for use in calculating the initial water content and total mass density of the material.

NOTE 7—If large particles are found in the soil after testing, a particle size analysis should be performed in accordance with Method D422 to confirm the visual observations, and the result should be provided with the test report.

NOTE 8—A controlled high-humidity room or laboratory glove box provides an appropriate atmosphere for trimming the specimen.

7.2 *Laboratory Fabricated Specimens*—Test specimens can be fabricated by reconstitution (7.3) or compaction (7.4). Acquire enough material to conduct the required series of tests. Blend the material to produce a uniform batch and if necessary divide into appropriate quantities for each required water content. Mix the soil with sufficient water to produce the desired water content. Allow the moist material to stand prior to specimen preparation in accordance with the following guide:

USCS Classification (D2487)	Minimum Standing Time, h
SW, SP	No Requirement
SW-SM, SP_SM, SM (>5% fines)	3
SC, ML, CL, SP-SC	18
MH, CH	36

7.3 *Reconstituted Specimens*—Specimens shall be prepared using the compaction method, water content, and mass density prescribed by the individual assigning the test. Specimens may be molded by either kneading or tamping each layer until the accumulative mass of the soil placed in the shear box is compacted/reconstituted to a known volume, or by adjusting the number of layers, the number of tamps per layer, and the force per tamp. The top of each layer shall be scarified prior to the addition of material for the next layer. The compacted layer boundaries shall be positioned so they are not coincident with the shear plane defined by the shear box halves, unless this is the stated purpose for a particular test. The tamper used to compact the material shall have an area in contact with the soil equal to or less than ½ the area of the shear box.

7.3.1 Secure the halves of the shear box together and assemble in the bowl. Place a moist porous insert in the bottom of the shear box. Determine the mass of wet soil required for a single layer and place it in the shear box. Distribute the material uniformly and compact the soil to achieve the desired condition. Continue placing and compacting soil in additional layers until the entire specimen is reconstituted.

NOTE 9—The required thickness of the compacted lift may be determined by directly measuring the thickness of the lift, or from the marks on the tamping rod which correspond to the thickness of the lift being placed.

7.3.2 Determine and record the height and initial mass of the test specimen.

7.3.3 Place the top moist porous insert on top of the specimen.

7.4 *Compacted Specimens*—Test specimens may also be prepared by compacting soil using the procedures and equipment used to determine moisture-density relationships of soils (Test Methods D698 or D1557), and then trimming the direct shear test specimen from the larger compaction specimen as though it were an intact sample. The shear plane of the direct shear specimen should not be aligned with any of the compaction lift interfaces.

8. Calibration

8.1 Calibration is required to determine the deformation of the apparatus when subjected to the consolidation load, so that for each normal consolidation load the apparatus deflection may be subtracted from the observed deformations. Therefore, only deformation due to specimen consolidation will be reported for completed tests. Calibration for the equipment load-deformation characteristics need to be performed on the apparatus when first placed in service, or when apparatus parts are changed. The following series of steps provide one method of calibrating the apparatus. Other methods of proven accuracy for calibrating the apparatus are acceptable.

8.2 Assemble the direct shear device with a metal calibration disk or plate of a thickness approximately equal to the typical test specimen and a diameter or width that is slightly less than the direct shear box.

8.3 Assemble the normal force loading yoke and apply a small normal load equivalent to about 1 lbf/in^2 [5 kPa].

8.4 Position the normal displacement indicator. Adjust this indicator so that it can be used to measure either consolidation or swell from the calibration disk or plate reading. Record the zero or "no load" reading.

8.5 Apply increments of normal force up to the equipment limitations, and record the normal displacement indicator reading and normal force. Remove the applied normal force in reverse sequence of the applied force, and record the normal displacement indicator readings and normal force. Average the values and plot the load deformation of the apparatus as a function of normal load. Retain the results for future reference in determining the thickness of the test specimen and compression within the test apparatus itself.

8.6 If the apparatus deformation correction exceeds 0.1 % of the initial specimen thickness at any load level during a test, the correction must be applied to every measurement of the test.

9. Procedure

9.1 Assemble the shear box and shear box bowl in the load frame.

9.1.1 *Intact Specimen*—Place moist porous inserts over the exposed surfaces of the specimen in the shear box, place the shear box with the intact specimen and porous inserts into the shear box bowl and align the bowl in the load frame.

NOTE 10—The decision to dampen the porous inserts or use dry inserts depends on the problem under study. For intact samples obtained below the water table, the porous inserts are usually dampened. For swelling soils, the sequence of consolidation, wetting, and shearing should prevent swelling until the specimen is equilibrated under the final normal stress.

9.1.2 *Reconstituted Specimen*—Place and align the assembled shear box, specimen, porous inserts and bowl into the load frame.

NOTE 11—For some apparatus, the top half of the shear box is held in place by a notched rod which fits into a receptacle in the top half of the shear box. The bottom half of the shear box is held in place in the shear box bowl retaining bolts. For some apparatus, the top half of the shear box is held in placed by an anchor plate.

9.2 Connect and adjust the position of the shear force loading system so that no force is imposed on the shear load measuring device. Record the zero value of the shear load measuring device.

9.3 Position and adjust the shear displacement measurement device. Obtain an initial reading or set the measurement device to indicate zero displacement.

9.4 Place the load transfer plate and moment break on top of the porous insert.

9.5 Place the normal force loading yoke into position and adjust it so the loading bar is aligned. For dead weight lever loading systems, level the lever. For pneumatic or motor drive loading systems, adjust the yoke until it sits snugly against the recess in the load transfer plate, or place a ball bearing on the load transfer plate and adjust the yoke until the contact is snug.

9.6 Apply a small seating normal load to the specimen. Verify that the components of the normal loading system are seated and aligned. The top porous insert and load transfer plate must be aligned so that the movement of the load transfer plate into the shear box is not inhibited. The specimen should not undergo significant compression under this seating load.

NOTE 12—The seating normal load applied to the specimen should be sufficient to assure all the components are in contact and alignment but not so large as to cause compression of the specimen. For most applications, a load resulting in approximately 1 lbf/in.^{2} [5 kPa] will be adequate but other values meeting the objective are acceptable.

9.7 Attach and adjust the normal displacement measurement device. Obtain an initial reading for the normal displacement measurement device along with a reading of the normal load (either weights or measurement device).

9.8 *Consolidation*—The final consolidation normal load may be applied in one increment or in several intermediate increments depending on the type of material, the stiffness of the specimen, and the magnitude of the final stress. Load increments must be small enough to prevent extrusion of the material from around the porous inserts. For stiff cohesive or coarse grained material a single increment is normally acceptable. For soft materials, it may be necessary to limit the load increment ratio to unity as described in Test Method D2435 (11.4) and apply a number of intermediate load increments. Based on the above considerations and instructions of the requesting agency, calculate and record the normal force required to achieve each intermediate normal stress level progressing the specimen from the seating load to the final consolidation normal stress.

9.8.1 Apply the first load increment and, if required, fill the shear box bowl with test water, and keep it full for the duration of the test. In the absence of specification, the bowl should be filled with potable water.

Note 13—Flooding the specimen with water eliminates negative pore pressure due to surface tension and also prevents evaporative drying during the test. If and when to inundate the specimen as well as the water chemistry is part of the test specification which should be provided by the requesting agency.

9.8.2 For each intermediate stress level, apply the load as quickly as practical. Maintain each load level until primary consolidation is essentially complete based on either a) interpretation of time versus normal deformation, b) experience with the material or c) a default value of 24 h. Record the normal deformation at the end of each increment and the increment duration.

9.8.3 For the maximum normal stress level and for the final normal stress level, apply the normal load to the specimen as quickly as practical and immediately begin recording the normal deformation readings against elapsed time. Test Method D2435 provides details of the loading procedure and suggestions for appropriate time recording schedules. For these load increments, verify completion of primary consolidation before proceeding to the next stage of the test by interpreting either the plot of normal displacement versus log of time or square root of time (in min). Test Method D2435 provides interpretation details of both methods.

9.8.4 If the test specification requires consolidation to a specific stress and then rebounding to a lower stress prior to shearing, then the maximum stress should be maintained for at least one cycle of secondary compression.

9.8.5 If the material exhibits a tendency to swell under the maximum normal stress, the soil must be inundated with water and must be permitted to achieve equilibrium (essentially stop swelling) under this normal stress before continuing on to the next stage of the test.

9.9 Just before shearing and after consolidation of the final increment is completed, record the preshear normal displacement and then remove the alignment screws or pins from the shear box. Use the gap screws to separate the shear box halves to approximately the diameter of the maximum sized particle in the test specimen or 0.025 in. [0.64 mm] as a minimum default value for fine grained materials. Back out the gap screws after creating the gap.

Note 14—The gap screws in most equipment raise the upper box half relative to the lower box half by prying apart the halves. Creating the gap in this manner will apply a tensile stress increment along the potential failure surface. This can unintentionally weaken the material. The top cap should not move upwards while creating the gap.

9.10 *Determine Shearing Rate*—The specimen must be sheared at a relatively slow rate so that insignificant excess pore pressure exists at failure. Determination of the appropriate rate of displacement requires an estimate of the time required for pore pressure dissipation and amount of deformation required to reach failure. These two factors depend on the type of material and the stress history. The following procedures should be used to compute the required shear rate. 9.10.1 and 9.10.2 may be used to compute times to failure when the maximum consolidation increment yields well defined normal deformation versus time curves and the material has a low overconsolidation ratio. 9.10.3 provides default values to be used in all other situations.

9.10.1 When data for the maximum consolidation increment yield a well defined normal deformation versus log time curve which extends into secondary compression, the curve should be interpreted as in Test Method D2435 and the time to failure should be computed using the following equation:

$$t_f = 50t_{50} \tag{1}$$

where:

t_f = total estimated elapsed time to failure, min,
t_{50} = time required for the specimen to achieve 50 percent consolidation under the maximum normal stress increment, min.

9.10.2 When data for the maximum consolidation increment do not satisfy the requirements of 9.10.1 but yield a well defined normal deformation versus root time curve, the curve should be interpreted as in Test Method D2435 and the time to failure should be computed using the following equation:

$$t_f = 11.6t_{90} \tag{2}$$

where:

t_{90} = time required for the specimen to achieve 90 percent consolidation under the maximum normal stress (increment), min.

9.10.3 When data for the maximum consolidation increment do not satisfy the requirements of 9.10.1 or 9.10.2 or when the specimen is significantly overconsolidated (OCR greater than about 2) under the maximum consolidation stress, default values for the time to failure should be computed based on a normally consolidated coefficient of consolidation for the soil. In the absence of soil specific consolidation data the time should be based on the soil type. The following table provides these default values.

USCS Classification (D2487)	Minimum Time to Failure, t_f
SW, SP (<5% fines)	10 min
SW-SM, SP_SM, SM (>5% fines)	60 min
SC, ML, CL, SP-SC	200 min
MH, CH	24 h

Note 15—The tabulated times are based on estimates of typical normally consolidated coefficient of consolidation values for each soil type and a 1 cm drainage path. A particular soil can vary considerably from these typical values. Square root of time interpretations can yield erroneously fast rates of consolidation for partly saturated or very stiff materials. Shearing overconsolidated specimens will soften the material in the shear zone causing a reduction in the coefficient of consolidation. Consequently, the calculation of t_f based on deformation vs. time curves may produce an inappropriate estimate of the time required to fail the specimen under drained conditions. For overconsolidated clays which are tested under normal stresses less than the soil's pre-consolidation pressure, it is suggested that a time to failure be estimated using a value of t_{50} based on the coefficient of consolidation in the normally consolidated range for the soil. Care should be exercised if the time curve interpretation yields considerably shorter times than the tabulated values.

9.10.4 Estimate the relative lateral displacement required to fail the specimen. This displacement will depend on many factors including the type of material and the stress history. In the absence of specific experience relative to the test conditions, as a guide, use d_f = 0.5 in. [10 mm] if the material is normally or lightly over consolidated fine-grained soil, otherwise use d_f = 0.2 in. [5 mm].

9.10.5 Determine the appropriate maximum displacement rate from the following equation:

$$R_d = \frac{d_f}{t_f} \tag{3}$$

where:

R_d = displacement rate, in./min [mm/min], and

d_f = estimated relative lateral displacement at failure, in. [mm].

9.11 *Drained Shearing*—For some types of apparatus, the displacement rate is achieved using combinations of gear wheels and gear lever positions. For other types of equipment the displacement rate is achieved by adjusting the motor speed. Select and record a displacement rate that is equal to or slower than the value computed in 9.10.5.

9.11.1 Record the initial time, normal and relative lateral displacements, and normal and shear forces.

9.11.2 Start the apparatus and initiate shear.

9.11.3 Obtain data readings of time, normal and relative lateral displacement, and shear force at the desired interval of displacement or time. Data readings should be taken often enough to accurately define a shear stress-displacement curve. At a minimum, data should be recorded at relative lateral displacements of about 0.1, 0.2, 0.3, 0.4, 0.5, 1, 1.5, 2, 2.5, 3, and then every 2 percent relative lateral displacement until test completion.

NOTE 16—Additional readings may be helpful especially at the beginning of the test in identifying trends in behavior and the value of the peak shear stress of over consolidated or brittle material.

9.11.4 It may be necessary to stop the test and re-gap the shear box halves to maintain clearance between the shear box halves. The test should be checked periodically to confirm that a gap persists throughout the shearing phase of the test.

9.11.5 The specimen should be sheared to at least 10 percent relative lateral displacement unless specific termination criteria are provided by the specifying agency. Stop the motor drive to terminate shearing.

NOTE 17—The shape of the shear force versus displacement curve will depend on the soil type and stress history. The curve may have a well defined peak or may increase monotonically throughout the test. In general, it is better to continue the test to large deformation rather than terminate based on shear force variation.

9.11.6 Remove the normal force from the specimen and disassemble the loading apparatus.

9.12 For cohesive test specimens, separate the shear box halves with a sliding motion along the failure plane and in the direction of shearing. Do not pull the shear box halves apart perpendicularly to the failure surface, since this motion would damage the specimen. Photograph, sketch, or describe in writing the failure surface. This step in the procedure is not applicable to cohesionless specimens.

9.13 Remove the specimen from the shear box and determine the water content and dry mass according to Test Method D2216. If applicable, collect the extruded material in a separate container and determine the dry mass.

10. Calculation

10.1 *General*—Typical units are shown for both IP and SI systems and SD stands for significant digits. Furthermore, the prefix used for each variable has been chosen based on current practice. Other prefixes are permissible and will require different numerical values for the Unit Conversion Factors. Other units are permissible, provided consistency of units is maintained throughout the calculations. See 1.8 for additional comments on the use of inch-pound units.

10.2 Calculate the following for each reading during shear:

10.2.1 Nominal shear stress, acting on the specimen is:

$$\tau = \frac{F_s}{A} \tag{4}$$

where:

τ = nominal shear stress, lbf/in.^{2} [kPa] (3 SD),

F_s = shear force, lbf [kN] (3 SD), and

A = area of the shear box, in.^{2} [m^2] (3 SD).

10.2.2 Nominal normal stress acting on the specimen is,

$$\sigma_n = \frac{F_n}{A} \tag{5}$$

where:

σ_n = nominal normal stress, lbf/in.^{2} [kPa] (3 SD), and

F_n = normal force acting on the specimen, lbf [kN] (3 SD).

NOTE 18—Factors which incorporate assumptions regarding the actual specimen surface area over which the shear and normal forces are measured can be applied to the calculated values of shear or normal stress, or both. If a correction(s) is made, the factor(s) and rationale for using the correction should be explained with the test results.

10.2.3 *Displacement Rate*—The average displacement rate along the shear surface is:

$$R_d = \frac{d_h}{t_e} \tag{6}$$

where:

R_d = displacement rate, in./min [mm/min] (3 SD),

d_h = relative lateral displacement, in. [mm] (3 SD),

t_e = elapsed time of test, min (3 SD).

10.2.4 *Percent Relative Lateral Displacement*—The percent relative lateral displacement along the shear surface is:

$$P_d = 100 \cdot \frac{d_h}{D} \tag{7}$$

where:

P_d = percent relative lateral displacement, % (3 SD), and

D = specimen diameter or lateral dimension in direction of shear, in. [mm] (3 SD).

10.3 Compute the initial void ratio, initial dry density, initial water content, and initial degree of saturation based on the specific gravity, initial wet mass, final dry mass, and initial volume of the total specimen. Specimen volume is determined by measurements of the shear box lengths or diameter and the measured thickness of the specimen.

10.4 Compute the preshear void ratio, dry density, and water content based on the values used in 10.3 plus the measured normal deformation.

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

11.1 The methodology used to specify how data are recorded on the data sheet(s)/form(s), as given below is covered in 1.9 and Guide D6026.

11.2 Record as a minimum the following general information (data):

11.2.1 Sample identification, project and location.

11.2.2 Test number, date, apparatus identification, and technician.

11.2.3 Description of type of shear device used in test.

11.2.4 Description of appearance of the specimen, based on Practice D2488 (Test Method D2487 may be used as an alternative), Atterberg limits (Test Method D4318), and grain size data (Method D422), if obtained (see 7.2).

11.2.5 Description of soil structure, that is whether the specimen is intact, remolded, reconstituted, or otherwise prepared.

11.2.6 Initial thickness and diameter (width for square shear boxes).

11.2.7 Dry mass of test specimen.

11.2.8 Initial and pre-shear water content.

11.2.9 Initial and pre-shear wet density, see Note 19.

11.2.10 Initial and pre-shear dry density and void ratio, see Note 19.

11.2.11 Initial and pre-shear degree of saturation, see Note 19.

11.2.12 Table of normal stress, final normal displacement, and duration of load increment during consolidation.

11.2.13 Table of nominal normal stress, nominal shear stress, relative lateral displacement or percent relative lateral displacement, normal displacement, and rate of deformation during shear.

11.2.14 Plot of deformation versus log of time or square root of time for those load increments used to determine the shear rate.

11.2.15 Plot of nominal shear stress versus lateral displacement or percent relative lateral displacement.

11.2.16 Plot of normal displacement versus lateral displacement or percent relative lateral displacement.

11.2.17 For cohesive material, observations made relative to the shear surface.

11.2.18 Departure from the procedure outlines, such as special loading sequences or special wetting requirements.

NOTE 19—In most cases, there is significant soil loss during shear and the specimen shape is such that the final phase relations (density, water content, and saturation) cannot be determined with any degree of reliability. Therefore these values are not required but may be included in the test report.

12. Precision and Bias

12.1 *Precision*—Test data on precision are not presented due to the nature of the soil or rock, or both materials tested by this standard. It is either not feasible or too costly at this time to have ten or more laboratories participate in a round-robin testing program. In addition, it is either not feasible or too costly to produce multiple specimens that have uniform physical properties. Any variation observed in the data is just as likely to be due to specimen variation as to operator or laboratory testing variation.

12.2 Subcommittee D18.05 is seeking any pertinent data from users of these test methods that might be used to make a limited statement on precision.

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

13. Keywords

13.1 compacted specimens; consolidated; direct-shear test; drained test conditions; intact; Mohr strength envelope; reconstituted specimens; shear strength

SUMMARY OF CHANGES

Committee D18 has identified the location of selected changes to this test method since the last issue, D3080–04, that may impact the use of this test method. (Approved November 1, 2011)

(*1*) Extensive editorial changes to clarify text and renumber sections to accommodate more substantial changes. The following items are only the substantial changes. Section and note numbers are referenced to this revision. Summary of changes do not state specific relocations of section material or notes.
(*2*) Changed standard number and modifications to make dual units.
(*3*) Section 1.1 to clarify the Method covers only one test.
(*4*) Added section 1.6 on test series.
(*5*) Added section 1.8 on Units.
(*6*) Add reference in Section 2.
(*7*) Added definitions 3.2.2, 3.2.4, 3.2.5, and 3.2.6.
(*8*) Modified section 4.1 relative to strain rate.
(*9*) Section 5.2 added statement on shear rate.
(*10*) Added Note 1 relative to fast tests.
(*11*) Section 5.5 added requirement.
(*12*) Added section 5.6 on contact area changes.
(*13*) Section 6.2 added requirement to shear box.
(*14*) Section 6.3 new requirement to check stones.
(*15*) Note 4 (and throughout) change permeability to hydraulic conductivity.
(*16*) Note 4 added guidance on stone care.
(*17*) Section 6.4.1 added option to use screw driven load frame for normal force.
(*18*) Section 6.4.2 moved shear rate requirement to suggestion in Note 5
(*19*) Added guidance to Note 6.
(*20*) Section 6.4.3 added title.
(*21*) Added Section 6.5 specifying normal force measurement.
(*22*) Section 6.7 changed SI resolution.
(*23*) Section 6.8 added function.
(*24*) Added section 6.10 for specification of test water.

(*25*) Section 7 changed title and reorganized some of the sections.
(*26*) Section 7 separated into Intact, Reconstituted and Compacted sections.
(*27*) Section 7.1 changed undisturbed to intact throughout standard.
(*28*) Section 7.1 clarified that standard is for one test but sample should be large enough for test series.
(*29*) Section 7.1 added method to trim specimens.
(*30*) Section 7.2 added method to process material and changed USCS symbols.
(*31*) Section 7.3 clarified method to form specimen.
(*32*) Section 7.4 added requirement.
(*33*) Section 8.1 added some flexibility to method which was previously in note.
(*34*) Section 8.2 changed specification on calibration disk.
(*35*) Added section 8.3 and renumbered subsequent sections.
(*36*) Added section 8.6 specifying when correction is necessary.
(*37*) Section 9.1 altered method to be consistent with section 7.
(*38*) Added clarification to Note 10.
(*39*) Section 9.2 added requirement.
(*40*) Section 9.4 added moment break.
(*41*) Section 9.6 added clarification to seating load.
(*42*) Note 12 added clarification.
(*43*) Section 9.7 added requirement.
(*44*) Section 9.8 added clarification and reference to D2435.
(*45*) Section 9.8.1 new procedural step.
(*46*) Added Note 13 for clarification.
(*47*) Added Section 9.8.2 for intermediate consolidation increments.
(*48*) Section 9.8.3 added requirements for time deformation data.
(*49*) Section 9.8.4 new requirement for overconsolidated tests
(*50*) Section 9.8.5 moved information from prior note.
(*51*) Section 9.9 changed gap specification.
(*52*) Added Note 14 identifying potential problem.
(*53*) Section 9.10 completely reorganized and added some discussion to clarify method of interpretation. Added numbering of equations.
(*54*) Section 9.10.1 specification for the log time method.
(*55*) Section 9.10.2 specification for the root time method and changed equation 2.
(*56*) Section 9.10.3 added default time based on material type and high OCR specimen.
(*57*) Added Note 15 with rationale and clarification.
(*58*) Added section 9.10.4 which was mandatory material in a note.
(*59*) Section 9.10.5 new terms in same equation.
(*60*) Section 9.11 reorganized for shearing and add specification of shear rate.
(*61*) Section 9.11.3 increase rate of data collection.
(*62*) Add section 9.11.4 which was information in a note and is now required.
(*63*) Section 9.11.5 change termination requirement.
(*64*) Added note 17 for clarification.
(*65*) Section 9.12 add clarification.
(*66*) Section 9.13 add requirement.
(*67*) Add Section 10.1 for clarification.
(*68*) Section 10.2 clarify units and significant digits.
(*69*) Equation 5 fix equation symbol.
(*70*) Equation 6 change symbol for displacement rate.
(*71*) Section 10.2.4 change equation and symbols.
(*72*) Section 10.4 add requirement,
(*73*) Section 11 change reporting requirements in several locations.
(*74*) Section 12 change to standard precision caveat.
(*75*) Change title of Figure 1.

استاندارد آزمایش برش سه محوری

ASTM-D2850-03

Designation: D 2850 – 03a

Standard Test Method for Unconsolidated-Undrained Triaxial Compression Test on Cohesive Soils[1]

This standard is issued under the fixed designation D 2850; 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 This test method covers determination of the strength and stress-strain relationships of a cylindrical specimen of either undisturbed or remolded cohesive soil. Specimens are subjected to a confining fluid pressure in a triaxial chamber. No drainage of the specimen is permitted during the test. The specimen is sheared in compression without drainage at a constant rate of axial deformation (strain controlled).

1.2 This test method provides data for determining undrained strength properties and stress-strain relations for soils. This test method provides for the measurement of the total stresses applied to the specimen, that is, the stresses are not corrected for pore-water pressure.

NOTE 1—The determination of the unconfined compressive strength of cohesive soils is covered by Test Method D 2166.

NOTE 2—The determination of the consolidated, undrained strength of cohesive soils with pore pressure measurement is covered by Test Method D 4767.

1.3 All observed and calculated values shall conform to the guidelines for significant digits and rounding established in Practice D 6026.

1.3.1 The method used to specify how data are collected, calculated, or recorded in this standard is not directly related to the accuracy to which the data can be applied in design or other uses, or both. How one applies the results obtained using this standard is beyond its scope.

1.4 The values stated in SI units are to be regarded as the standard. The values stated in inch-pound units and given in parentheses are approximate.

1.5 *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]

D 422 Method for Particle-Size Analysis of Soils
D 653 Terminology Relating to Soil, Rock, and Contained Fluids
D 854 Test Method for Specific Gravity of Soils
D 1587 Method for Thin-Walled Tube Sampling of Soils
D 2166 Test Methods for Unconfined Compressive Strength of Cohesive Soil
D 2216 Test Method for Laboratory Determination of Water (Moisture) Content of Soil and Rock
D 2487 Classification of Soils for Engineering Purposes
D 2488 Practice for Description and Identification of Soils (Visual-Manual Procedure)
D 3740 Practice for Evaluation of Agencies Engaged in the Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction
D 4220 Practices for Preserving and Transporting Soil Samples
D 4318 Test Method for Liquid Limit, Plastic Limit, and Plasticity Index of Soils
D 4753 Specification for Evaluating, Selecting, and Specifying Balances and Scales for Use in Testing Soil and Rock, and Related Construction Materials
D 4767 Test Method for Consolidated-Undrained Triaxial Compression Test on Cohesive Soils[2]
D 6026 Practice for Using Significant Digits in Geotechnical Data

3. Terminology

3.1 Definitions—The definitions of terms used in this test method shall be in accordance with Terminology D 653.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *failure*—the stress condition at failure for a test specimen. Failure is often taken to correspond to the maximum principal stress difference (deviator stress) attained or the

---

[1] This test method is under the jurisdiction of ASTM Committee D18 on Soil and Rock and is the direct responsibility of Subcommittee D18.05 on Structural Properties of Soils.

Current edition approved Nov. 1, 2003. Published December 2003. Originally approved in 1970. Last previous edition approved in 2003 as D 2850 – 03.

[2] For referenced ASTM Standards, visit the ASTM website, www.astm.org, or contact 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.**

principal stress difference (deviator stress) at 15 % axial strain, whichever is obtained first during the performance of a test.

3.2.2 *unconsolidated-undrained compressive strength*—the value of the principal stress difference (deviator stress) at failure.

4. Significance and Use

4.1 In this test method, the compressive strength of a soil is determined in terms of the total stress, therefore, the resulting strength depends on the pressure developed in the pore fluid during loading. In this test method, fluid flow is not permitted from or into the soil specimen as the load is applied, therefore the resulting pore pressure, and hence strength, differs from that developed in the case where drainage can occur.

4.2 If the test specimens are 100 % saturated, consolidation cannot occur when the confining pressure is applied nor during the shear portion of the test since drainage is not permitted. Therefore, if several specimens of the same material are tested, and if they are all at approximately the same water content and void ratio when they are tested, they will have approximately the same undrained shear strength. The Mohr failure envelope will usually be a horizontal straight line over the entire range of confining stresses applied to the specimens if the specimens are fully saturated.

4.3 If the test specimens are partially saturated or compacted specimens, where the degree of saturation is less than 100 %, consolidation may occur when the confining pressure is applied and during shear, even though drainage is not permitted. Therefore, if several partially saturated specimens of the same material are tested at different confining stresses, they will not have the same undrained shear strength. Thus, the Mohr failure envelope for unconsolidated undrained triaxial tests on partially saturated soils is usually curved.

4.4 The unconsolidated undrained triaxial strength is applicable to situations where the loads are assumed to take place so rapidly that there is insufficient time for the induced pore-water pressure to dissipate and for consolidation to occur during the loading period (that is, drainage does not occur).

4.5 Compressive strengths determined using this procedure may not apply in cases where the loading conditions in the field differ significantly from those used in this test method.

NOTE 3—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 facilities used. Agencies which meet the criteria of Practice D 3740 are generally considered capable of competent testing. Users of this test method are cautioned that compliance with Practice D 3740 does not ensure reliable testing. Reliable testing depends on several factors; Practice D 3740 provides a means of evaluating some of those factors.

5. Apparatus

5.1 *Axial Loading Device*—The axial loading device shall be screw jack driven by an electric motor through a geared transmission, a hydraulic loading device, or any other compression device with sufficient capacity and control to provide the rate of loading prescribed in 7.5. The rate of advance of the loading device shall not deviate by more than ±5 % from the selected value. Vibrations due to the operation of the loading device shall be sufficiently small to not cause dimensional changes in the specimen.

NOTE 4—A loading device may be said to provide sufficiently small vibrations if there are no visible ripples in a glass of water placed on the loading platen when the device is operating at the speed at which the test is performed.

5.2 *Axial Load-Measuring Device*—The axial load-measuring device shall be a load ring, electronic load cell, hydraulic load cell, or any other load-measuring device capable of measuring the axial load to an accuracy of 1 % of the axial load at failure and may be a part of the axial loading device.

5.3 *Triaxial Compression Chamber*—The triaxial chamber shall consist of a top plate and a baseplate separated by a cylinder. The cylinder shall be constructed of any material capable of withstanding the applied pressure. It is desirable to use a transparent material or have a cylinder provided with viewing ports so the behavior of the specimen may be observed. The top plate shall have a vent valve such that air can be forced out of the chamber as it is filled. The base plate shall have an inlet through which the pressure liquid is supplied to the chamber.

5.4 *Axial Load Piston*—The piston passing through the top of the chamber and its seal must be designed so the variation in axial load due to friction does not exceed 0.1 % of the axial load at failure as measured in 8.4.1.3 and so there is negligible lateral bending of the piston during loading.

NOTE 5—The use of two linear ball bushings to guide the piston is recommended to minimize friction and maintain alignment.

NOTE 6—A minimum piston diameter of one sixth the specimen diameter has been used successfully in many laboratories to minimize lateral bending.

5.5 *Pressure Control Device*—The chamber pressure control device shall be capable of applying and controlling the chamber pressure to within ±2 kPa (0.25 psi) for pressures less than 200 kPa (28 psi) and to within ±1 % for pressures greater than 200 kPa (28 psi). This device may consist of a reservoir connected to the triaxial chamber and partially filled with the chamber fluid (usually water), with the upper part of the reservoir connected to a compressed gas supply; the gas pressure being controlled by a pressure regulator and measured by a pressure gage, electronic pressure transducer, or any other device capable of measuring to the prescribed tolerance. However, a hydraulic system pressurized by deadweight acting on a piston or any other pressure-maintaining and measurement device capable of applying and controlling the chamber pressure to the tolerance prescribed in this section may be used.

5.6 *Specimen Cap and Base*—An impermeable rigid cap and base shall be used to prevent drainage of the specimen. The specimen cap and base shall be constructed of a noncorrosive impermeable material, and each shall have a circular plane surface of contact with the specimen and a circular cross section. The weight of the specimen cap shall produce an axial stress on the specimen of less than 1 kN/m^2. The diameter of the cap and base shall be equal to the initial diameter of the specimen. The specimen base shall be connected to the triaxial compression chamber to prevent lateral motion or tilting and the specimen cap shall be designed such that eccentricity of the piston to cap contact relative to the vertical axis of the specimen does not exceed 1.3 mm (0.05 in.). The end of the piston and specimen cap contact area shall be designed so that tilting of the specimen cap during the test is minimal. The cylindrical surface of the specimen base and cap that contacts the membrane to form a seal shall be smooth and free of scratches.

5.7 *Deformation Indicator*—The vertical deformation of the specimen shall be measured with an accuracy of at least 0.03 % of the specimen height. The deformation indicator shall have a range of at least 20 % of the height of the specimen, and may be a dial indicator, linear variable differential transformer (LVDT), extensiometer or other measuring device meeting the requirements for accuracy and range.

5.8 *Rubber Membrane*—The rubber membrane used to encase the specimen shall provide reliable protection against leakage. Membranes shall be carefully inspected prior to use, and if any flaws or pinholes are evident, the membrane shall be discarded. To offer minimum restraint to the specimen, the unstretched membrane diameter shall be between 90 and 95 % of that of the specimen. The membrane thickness shall not exceed 1 % of the diameter of the specimen. The membrane shall be sealed to the specimen base and cap with rubber O-rings for which the unstressed inside diameter is between 75 and 85 % of the diameter of the cap and base or by any method that will produce a positive seal. An equation for correcting the principal stress difference (deviator stress) for the effect of the stiffness of the membrane is given in 8.7.

5.9 *Sample Extruder*—The sample extruder shall be capable of extruding the soil core from the sampling tube in the same direction of travel in which the sample entered the tube and with minimum disturbance of the sample. If the soil core is not extruded vertically, care should be taken to avoid bending stresses on the core due to gravity. Conditions at the time of sample removal may dictate the direction of removal, but the principal concern is to keep the degree of disturbance minimal.

5.10 *Specimen Size Measurement Devices*— Devices used to measure the height and diameter of the specimen shall be capable of measuring the desired dimension to within 0.1 % of its actual length and shall be constructed such that their use will not disturb the specimen.

NOTE 7—Circumferential measuring tapes are recommended over calipers for measuring the diameter.

5.11 *Timer*—A timing device indicating the elapsed testing time to the nearest 1 s shall be used for establishing the rate of strain application prescribed in 7.5.

5.12 *Balances*—A balance or scale conforming to the requirements of Specification D 4753 readable (with no estimation) to 0.1 % of the test mass, or better.

5.13 *Miscellaneous Apparatus*—Specimen trimming and carving tools including a wire saw, steel straightedge, miter box and vertical trimming lathe, apparatus for preparing compacted specimens, remolding apparatus, water content cans, and data sheets shall be provided as required.

6. Test Specimens

6.1 *Specimen Size*—Specimens shall be cylindrical and have a minimum diameter of 3.3 cm (1.3 in.). The height-to-diameter ratio shall be between 2 and 2.5. The largest particle size shall be smaller than one sixth the specimen diameter. If, after completion of a test, it is found based on visual observation that oversize particles are present, indicate this information in the report of test data (see 9.2.12).

NOTE 8—If oversize particles are found in the specimen after testing, a particle-size analysis may be performed in accordance with Test Method D 422 to confirm the visual observation and the results provided with the test report (see 9.2.4).

6.2 *Undisturbed Specimens*—Prepare undisturbed specimens from large undisturbed samples or from samples secured in accordance with Practice D 1587 or other acceptable undisturbed tube sampling procedures. Samples shall be preserved and transported in accordance with the practices for Group C samples in Practices D 4220. Specimens obtained by tube sampling may be tested without trimming except for cutting the end surfaces plane and perpendicular to the longitudinal axis of the specimen, provided soil characteristics are such that no significant disturbance results from sampling. Handle specimens carefully to minimize disturbance, changes in cross section, or change in water content. If compression or any type of noticeable disturbance would be caused by the extrusion device, split the sample tube lengthwise or cut the tube in suitable sections to facilitate removal of the specimen with minimum disturbance. Prepare trimmed specimens, in an environment such as a controlled high-humidity room where soil water content change is minimized. Where removal of pebbles or crumbling resulting from trimming causes voids on the surface of the specimen, carefully fill the voids with remolded soil obtained from the trimmings. When the sample condition permits, a vertical trimming lathe may be used to reduce the specimen to the required diameter. After obtaining the required diameter, place the specimen in a miter box and cut the specimen to the final height with a wire saw or other suitable device. Trim the surfaces with the steel straightedge. Perform one or more water content determinations on material trimmed from the specimen in accordance with Test Method D 2216. Determine the mass and dimensions of the specimen using the devices described in 5.11 and 5.9. A minimum of three height measurements (120° apart) and at least three diameter measurements at the quarter points of the height shall be made to determine the average height and diameter of the specimen.

6.3 *Compacted Specimens*—Soil required for compacted specimens shall be thoroughly mixed with sufficient water to produce the desired water content. If water is added to the soil, store the material in a covered container for at least 16 h prior to compaction. Compacted specimens may be prepared by compacting material in at least six layers using a split mold of circular cross section having dimensions meeting the requirements enumerated in 6.1. Specimens may be compacted to the desired density by either: (*1*) kneading or tamping each layer until the accumulative mass of the soil placed in the mold is compacted to a known volume; or (*2*) by adjusting the number of layers, the number of tamps per layer, and the force per tamp. The top of each layer shall be sacrified prior to the addition of material for the next layer. The tamper used to compact the material shall have diameter equal to or less than one half the diameter of the mold. After a specimen is formed, with the ends perpendicular to the longitudinal axis, remove the mold and determine the mass and dimensions of the specimen using the devices described in 5.11 and 5.9. Perform one or more water content determinations on excess material used to prepare the specimen in accordance with Test Method D 2216.

NOTE 9—It is common for the unit weight of the specimen after removal from the mold to be less than the value based on the volume of the mold. This occurs as a result of the specimen swelling after removal of the lateral confinement due to the mold.

7. Procedure

7.1 Place the membrane on the membrane expander or, if it is to be rolled onto the specimen, place the membrane onto the cap or base. Place the specimen on the base. Place the rubber membrane around the specimen and seal it at the cap and base with O-rings or other positive seals at each end. A thin coating of silicon grease on the vertical surfaces of the cap or base will aid in sealing the membrane.

7.2 With the specimen encased in the rubber membrane, which is sealed to the specimen cap and base and positioned in the chamber, assemble the triaxial chamber. Bring the axial load piston into contact with the specimen cap several times to permit proper seating and alignment of the piston with the cap. When the piston is brought into contact the final time, record the reading on the deformation indicator to three significant digits. During this procedure, take care not to apply an axial stress to the specimen exceeding approximately 0.5 % of the estimated compressive strength. If the weight of the piston is sufficient to apply an axial stress exceeding approximately 0.5 % of the estimated compressive strength, lock the piston in place above the specimen cap after checking the seating and alignment and keep locked until application of the chamber pressure.

7.3 Place the chamber in position in the axial loading device. Be careful to align the axial loading device, the axial load-measuring device, and the triaxial chamber to prevent the application of a lateral force to the piston during testing. Attach the pressure-maintaining and measurement device and fill the chamber with the confining liquid. Adjust the pressure-maintaining and measurement device to the desired chamber pressure and apply the pressure to the chamber fluid. Wait approximately 10 min after the application of chamber pressure to allow the specimen to stabilize under the chamber pressure prior to application of the axial load.

NOTE 10—In some cases the chamber will be filled and the chamber pressure applied before placement in the axial loading device.

NOTE 11—Make sure the piston is locked or held in place by the axial loading device before applying the chamber pressure.

NOTE 12—The waiting period may need to be increased for soft or partically saturated soils.

7.4 If the axial load-measuring device is located outside of the triaxial chamber, the chamber pressure will produce an upward force on the piston that will react against the axial loading device. In this case, start the test with the piston slightly above the specimen cap, and before the piston comes in contact with the specimen cap, either: (*1*) measure and record the initial piston friction to three significant digits and upward thrust of the piston produced by the chamber pressure and later correct the measured axial load, or (*2*) adjust the axial load-measuring device to compensate for the friction and thrust. If the axial load-measuring device is located inside the chamber, it will not be necessary to correct or compensate for the uplift force acting on the axial loading device or for piston friction. In both cases record the initial reading on the deformation indicator when the piston contacts the specimen cap.

7.5 Apply the axial load to produce axial strain at a rate of approximately 1 %/min for plastic materials and 0.3 %/min for brittle materials that achieve maximum deviator stress at approximately 3 to 6 % strain. At these rates, the elapsed time to reach maximum deviator stress will be approximately 15 to 20 min. Continue the loading to 15 % axial strain, except loading may be stopped when the deviator stress has peaked then dropped 20 % or the axial strain has reached 5 % beyond the strain at which the peak in deviator stress occurred.

7.6 Record load and deformation values to three significant digits at about 0.1, 0.2, 0.3, 0.4, and 0.5 % strain; then at increments of about 0.5 % strain to 3 %; and, thereafter at every 1 %. Take sufficient readings to define the stress-strain curve; hence, more frequent readings may be required in the early stages of the test and as failure is approached.

NOTE 13—Alternate intervals for the readings may be used provided sufficient points are obtained to define the stress-strain curve.

7.7 After completion of the test, remove the test specimen from the chamber. Determine the water content of the test specimen in accordance with Test Method D 2216 using the entire specimen, if possible.

7.8 Prior to placing the specimen (or portion thereof) in the oven to dry, sketch a picture or take a photograph of the specimen showing the mode of failure (shear plane, bulging, etc.).

8. Calculation

8.1 Meaurements and calculations shall contain three significant digits.

8.2 Calculate the axial strain, ϵ (expressed as a decimal), for a given applied axial load, as follows:

$$\epsilon = \Delta H/H_o \tag{1}$$

where:

ΔH = change in height of specimen as read from deformation indicator, and

H_o = initial height of test specimen minus any change in length prior to loading.

8.3 Calculate the average cross-sectional area, A, for a given applied axial load as follows:

$$A = A_o/(1 - \epsilon) \tag{2}$$

where:

A_o = initial average cross-sectional area of the specimen, and

ϵ = axial strain for the given axial load (expressed as a decimal).

NOTE 14—In the event that the application of the chamber pressure results in a change in the specimen length, A_o, should be corrected to reflect this change in volume. Frequently, this is done by assuming that lateral strains are equal to vertical strains. The diameter after volume change would be given by $D = D_o(1 - \Delta H/H)$.

8.4 Calculate the principal stress difference (deviator stress), $\sigma_1 - \sigma_3$, for a given applied axial load as follows:

$$\sigma_1 - \sigma_3 = P/A \tag{3}$$

where:

P = measured applied axial load (corrected for uplift and piston friction, if required see 7.4), and

A = corresponding average cross-sectional area.

8.5 *Stress-Strain Curve*—Prepare a graph showing the relationship between principal stress difference (deviator stress) and axial strain, plotting deviator stress as ordinate and axial strain (in percent) as abscissa. Select the compressive strength and axial strain at failure in accordance with the definitions in 3.2.1 and 3.2.2.

8.6 *Correction for Rubber Membrane*— Assuming units are consistent, the following equation shall be used to correct the principal stress difference or deviator stress for the effect of the rubber membrane if the error in principal stress difference due to the stiffness of the membrane exceeds 5 %:

$$\Delta(\sigma_1 - \sigma_3) = 4E_m t_m \epsilon_1 / D \tag{4}$$

where:

$\Delta(\sigma_1 - \sigma_3)$ = correction to be subtracted from the measured principal stress difference,

D = $\sqrt{4A/\pi}$ = diameter of specimen,

E_m = Young's modulus for the membrane material,

t_m = thickness of the membrane, and

ϵ_1 = axial strain.

8.6.1 The Young's modulus of the membrane material may be determined by hanging a 10.0-mm wide strip of membrane over a thin rod, placing another rod along the bottom of the hanging membrane, and measuring the force per unit strain obtained by stretching the membrane. The modulus value may be computed using the following equation assuming units are consistent:

$$E_m = FL/A_m \Delta L \tag{5}$$

where:

E_m = Young's modulus of the membrane material,

F = force applied to stretch the membrane,

A_m = twice the initial thickness of the membrane multiplied by the width of the membrane strip,

L = unstretched length of the membrane, and

ΔL = change in length of the membrane due to application of F.

A typical value of E_m for latex membrane is 1400 kN/m^2.

NOTE 15—The effect of the stiffness of the membrane on the lateral stress is usually assumed to be negligible.

NOTE 16—The correction for rubber membranes is based on simplified assumptions concerning their behavior during shear. Their actual behavior is complex and there is not a consensus on more exact corrections.

8.7 Calculate the major and minor principal total stresses at failure as follows:

σ_3 = *minor principal total stress* = *chamber pressure, and*

σ_1 = *major principal total stress*
= *deviator stress at failure plus chamber pressure.*

8.8 Calculate the initial degree of saturation of the test specimen using the initial mass and dimensions.

NOTE 17—The specific gravity determined in accordance with Test Method D 854 is required for calculation of the saturation. An assumed specific gravity may be used provided it is noted in the test report that an assumed value was used.

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

9.1 The methodology used to specify how data are recorded on the data sheet(s)/form(s, as given below, is covered in 1.3.

9.2 Record as a minimum the following general information (data):

9.2.1 Identification data and visual description (Practice D 2488 or, if the information is available, Practice D 2487) of specimen including soil classification and whether the specimen is undisturbed, compacted, or otherwise prepared,

9.2.2 Values of plastic limit and liquid limit, if determined, in accordance with Test Method D 4318,

9.2.3 Value of specific gravity of solids and notation if the value was determined in accordance with Test Method D 854 or assumed,

9.2.4 Particle-size analysis, if determined, in accordance with Test Method D 422,

9.2.5 Initial height and diameter of the specimen.

9.2.6 Initial specimen dry unit weight, void ratio, water content, and saturation. (Specify if the water content was obtained from cuttings, excess material, or the entire specimen.),

9.2.7 Rate of axial strain, percent per minute,

9.2.8 Axial strain at failure, percent,

9.2.9 The value of the compressive strength and the values of the minor and major principal stresses at failure, (Indicate when values have been corrected for membrane effects),

9.2.10 Stress-strain curve as described in 8.5,

9.2.11 Failure sketch or photograph of the specimen, and

9.2.12 Remarks and notations regarding any unusual conditions such as slickensides, stratification, shells, pebbles, roots, etc., or other information necessary to properly interpret the results obtained including any departures from the procedure outlined.

10. Precision and Bias

10.1 *Precision*—Test data on precision is not presented due to the nature of the soil materials tested by this procedure. It is either not feasible or too costly at this time to have ten or more laboratories participate in a round-robin testing program. Subcommittee D18.05 is seeking any data from users of this test method that might be used to make a limited statement on precision.

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

11. Keywords

11.1 cohesive soil; lateral confinement; strain-controlled loading; stress-strain relationships; total stresses; unconsolidated undrained strength

SUMMARY OF CHANGES

In accordance with Committee D18 policy, this section identifies the location of changes to this standard since the last edition (D2850–03) that may impact the use of this standard.

(1) D 2487and D 2488 were added to the Referenced Documents Section.

(2) Reference to D 2487 and D 2488 were added to Section 9.2.1.

استاندارد آزمایش هم ارز ماسه

ASTM-D2419-14

Designation: D2419 – 14

Standard Test Method for Sand Equivalent Value of Soils and Fine Aggregate[1]

This standard is issued under the fixed designation D2419; 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 is intended to serve as a rapid field-correlation test. The purpose of this test method is to indicate, under standard conditions, the relative proportions of clay-size or plastic fines and dust in granular soils and fine aggregates that pass the 4.75-mm (No. 4) sieve. The term "sand equivalent" expresses the concept that most granular soils and some fine aggregates are mixtures of desirable coarse particles, sand-size particles, and generally undesirable clay or plastic fines and dust.

NOTE 1—For fine aggregates containing clean dust of fracture (clay-size particles that are not clay minerals), test results will depend on the amount of fines present in the material. In this case other tests such as Methylene Blue Value (AASHTO T330) or X-Ray Diffraction (XRD) may be needed to determine if the fines are deleterious.

NOTE 2—Some agencies perform the test on material with a top size smaller than the 4.75-mm (No. 4) sieve. This is done to avoid trapping the clay-size or plastic fines and dust below flaky shaped 4.75 to 2.36 mm (No. 4 to 8) sized particles. Testing smaller top sized material may lower the numerical results of the test.

1.2 The values stated in inch-pound units are to be regarded as standard. The values given in parentheses are mathematical conversions to SI units that are provided for information only and are not considered standard.

1.2.1 Regarding sieves, per Specification E11 Section 1.2, "the values stated in SI units shall be considered standard for the dimensions of the wire cloth openings and the diameter of the wires used in the wire cloth. The values stated in inchpound units shall be considered standard with regard to the sieve frames." When sieve mesh sizes are referenced, the alternate inch-pound designations are provided for information purposes and enclosed in parentheses.

1.3 *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]

C670 Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials
C702 Practice for Reducing Samples of Aggregate to Testing Size
D8 Terminology Relating to Materials for Roads and Pavements
D75 Practice for Sampling Aggregates
D653 Terminology Relating to Soil, Rock, and Contained Fluids
D3666 Specification for Minimum Requirements for Agencies Testing and Inspecting Road and Paving Materials
E11 Specification for Woven Wire Test Sieve Cloth and Test Sieves

2.2 *AASHTO Standard:*

T 176 Standard Method of Test for Plastic Fines in Graded Aggregates and Soils by Use of Sand Equivalent Test[3]

3. Terminology

3.1 *Definitions:*

3.1.1 *clay size*—that portion of the soil or aggregate finer than 0.002 mm (0.005 mm in some cases) (see Terminology D653).

3.1.2 *fine aggregate*—aggregate passing the 9.5-mm (⅜-in.) sieve and almost entirely passing the 4.75-mm (No. 4) sieve and predominantly retained on the 75-µm (No. 200) sieve (see Terminology D8).

3.1.3 *sand*—particles of rock that will pass the 4.75 mm (No. 4) sieve and be retained on the 0.075 mm (No. 200) sieve (see Terminology D653).

3.1.4 *sand equivalent*—a measure of the amount of silt, clay contamination, or clay-size aggregate particles in the fine aggregate (or soil) as determined by test (see Terminology D653). (For further explanation, see Section 4 and Section 5.)

---

[1] This test method is under the jurisdiction of ASTM Committee D04 on Road and Paving Materials and is the direct responsibility of Subcommittee D04.51 on Aggregate Tests.

Current edition approved June 1, 2014. Published September 2014. Originally approved in 1965. Last previous edition approved in 2009 as D2419 – 09. DOI: 10.1520/D2419-14.

[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.

3.1.5 *soil*—sediments or other unconsolidated accumulations of solid particles produced by the physical and chemical disintegration of rocks which may or may not contain organic matter (see Terminology D653).

4. Summary of Test Method

4.1 A measured volume of soil or fine aggregate and a small quantity of flocculating solution are poured into a graduated plastic cylinder and are agitated to loosen the claylike coatings or clay size particles from the sand particles in the test specimen. The specimen is then "irrigated" using additional flocculating solution forcing the claylike or clay size material into suspension above the sand. After a prescribed sedimentation period, the height of flocculated material is read and the height of sand in the cylinder is determined. The sand equivalent is the ratio of the height of sand to the height of flocculated material times 100.

5. Significance and Use

5.1 This test method assigns an empirical value to the relative amount, fineness, and character of claylike material present in the test specimen.

5.2 A minimum sand equivalent value may be specified to limit the permissible quantity of claylike or clay size fines in an aggregate.

5.3 This test method provides a rapid field method for determining changes in the quality of aggregates during production or placement.

NOTE 3—The quality of the results produced by this standard are dependant upon the competence of the personnel performing the procedure and the capability, calibration, and the maintenance of the equipment used. Agencies that meet the criteria of Practice D3666 are generally considered capable of competent and objective testing/sampling/inspection/etc. Users of this standard are cautioned that compliance with Practice D3666 alone does not completely assure reliable results. Reliable results depend on many factors: following the suggestions of Practice D3666 or similar acceptable guideline provides a means of evaluating and controlling some of those factors.

6. Interferences

6.1 Maintain the temperature of the working solution at 72 ± 5°F (22 ± 3°C) during the performance of this test.

NOTE 4—If field conditions preclude the maintenance of the temperature range, frequent referee samples should be submitted to a laboratory where proper temperature control is possible. It is also possible to establish temperature correction curves for each material being tested where proper temperature control is not possible. However, no general correction should be utilized for several materials even within a narrow range of sand equivalent values. Samples that meet the minimum sand equivalent requirement at a working solution temperature below the recommended range need not be subject to referee testing.

6.2 Perform the test at a location free from vibration. Excessive vibration may cause the suspended material to settle at a greater rate than normal.

6.3 Do not expose the plastic cylinders to direct sunlight any more than is necessary.

6.4 Occasionally it may be necessary to remove a fungus growth from the working calcium chloride solution container and from the inside of the flexible tubing and irrigator tube. This fungus can easily be seen as a slimy substance in the solution, or as a mold growing on the inside of the container.

6.4.1 To remove this growth, prepare a cleaning solvent by diluting sodium hypochlorite solution (household chlorine bleach) with an equal quantity of water.

6.4.2 After discarding the contaminated solution, fill the solution container with the prepared cleaning solvent: allow about 1 L of the cleaning solvent to flow through the siphon assembly and irrigator tube, then place the pinch clamp on the end of the tubing to cut off the flow of solvent and to hold the solvent in the tube. Refill the container and allow to stand overnight.

6.4.3 After soaking, allow the cleaning solvent to flow out through the siphon assembly and irrigator tube.

6.4.4 Remove the siphon assembly from the solution container and rinse both with clear water. The irrigator tube and siphon assembly can be rinsed easily by attaching a hose between the tip of the irrigator tube and water faucet and backwashing fresh water through the tube.

6.5 Occasionally the holes in the tip of the irrigator tube may become clogged by a particle of sand. If the obstruction cannot be freed by any other method, use a pin or other sharp object to force it out using extreme care not to enlarge the size of the opening.

6.6 Working solution which is more than two weeks old shall be discarded.

6.7 Mixing and storage container(s) for solutions shall be thoroughly rinsed prior to mixing a fresh batch of solution.

6.8 Fresh solution shall not be added to old solution regardless of age.

7. Apparatus

7.1 A graduated transparent acrylic plastic cylinder, rubber stopper, irrigator tube, weighted foot assembly and siphon assembly all conforming to the respective specifications and dimensions shown in Fig. 1. See Annex A1 for alternative apparatus.

7.2 *Measuring Tin*—A cylindrical tin approximately 2¼ in. (57 mm) in diameter having a capacity of 85 ± 5 mL.

7.3 *4.75-mm (No. 4) Sieve,* conforming to the requirements of Specification E11.

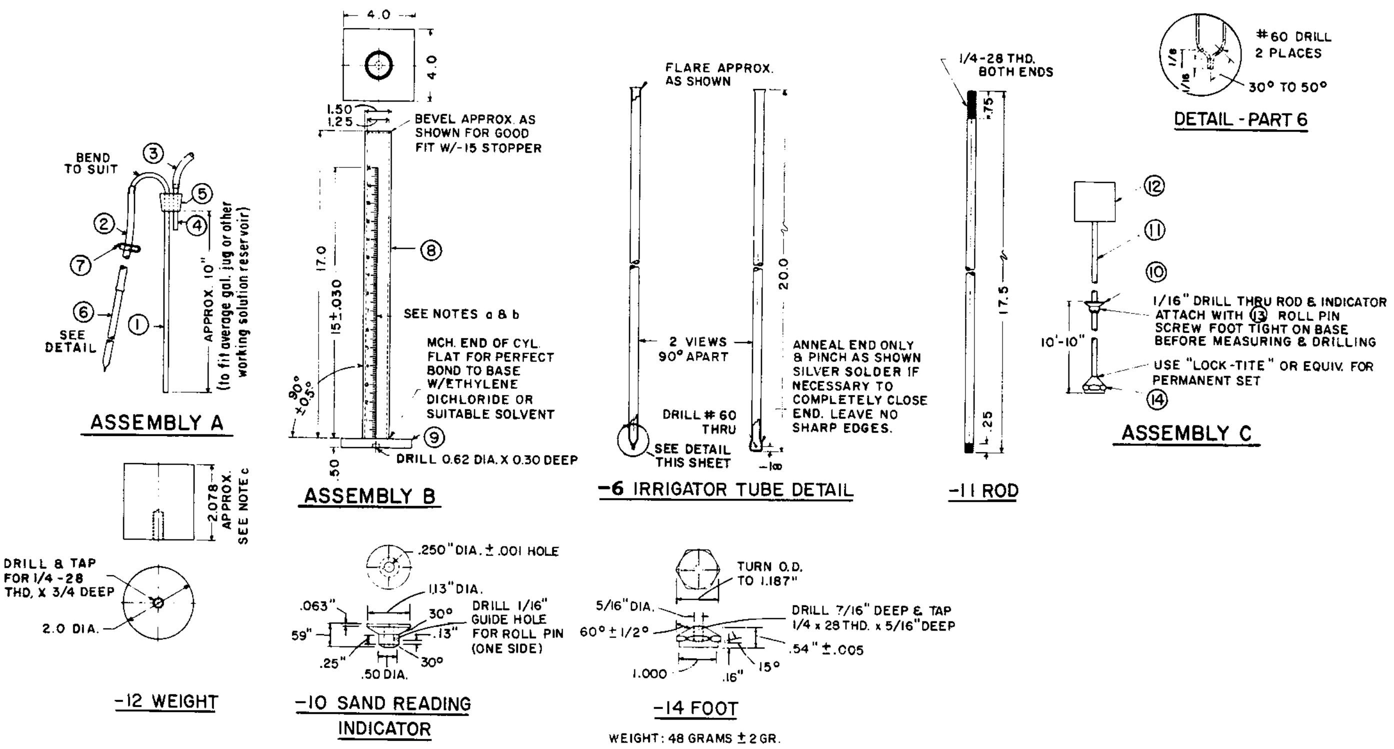
7.4 *Funnel,* wide-mouth, for transferring test specimens into the graduated cylinder.

7.5 *Bottles,* two 1.0-gal (3.8-L) to store stock solution and working solution.

7.6 *Flat Pan,* for mixing.

7.7 *Clock or Watch,* reading in minutes and seconds.

7.8 *Mechanical Sand Equivalent Shaker,* designed to hold the required graduated plastic cylinder in a horizontal position while subjecting it to a reciprocating motion parallel to its length and having a throw of 8 ± 0.04 in. (203.2 ± 1.0 mm) and operating at 175 ± 2 cpm. A typical apparatus is shown in Fig. 2. The shaker shall be securely fastened to a firm and level mount.



List of Material

Assembly	Part No.	Description	Stock Size, In.	Material
A		*Siphon Assembly:*		
	1	siphon tube	¼ diameter by 16	copper tube (may be plated)
	2	siphon hose	3⁄16 ID by 48	rubber tube, pure gum or equivalent
	3	blow hose	3⁄16 ID by 2	rubber tube, pure gum or equivalent
	4	blow tube	¼ diameter by 2	copper tube (may be plated)
	5	2-hole stopper	No. 6	rubber
	6	irrigator tube	¼ OD 0.035 wall by 20 SS tube, Type 316	
	7	clamp	Pinchcock, Day, BKH No. 21730 or equivalent	
B[A,B]		*Graduate Assembly:*		
	8	tube	1.50 OD by 17	transparent acrylic plastic
	9	base	¼ by 4 by 4	transparent acrylic plastic
C[C]		*Weighted Foot Assembly:*		
	10	sand reading indicator	1¼ diameter by 0.59	nylon 101 type 66 annealed
	11	rod	¼ diameter by 17½	brass (may be plated)
	12	weight	2 diameter by 2.078	C. R. steel (may be plated)
	13	roll pin	1⁄16 diameter by ½	corrosion-resistant metal
	14	foot	11⁄16 hex by 0.54	brass (may be plated)
	15	solid stopper	No. 7	rubber

[A] *Assembly B*—Accuracy of scale should be± 0.010 in. per tenth of an inch. Error at any point on scale should be± 0.030 in. of true distance to zero.

[B] *Assembly B*—Graduations on graduate should be in tenths of an inch. Inch marks should be numerically designated as shown. The inch and half-inch division lines should be approximately ¼ in. long. All division lines should be 0.015 in. deep with width across top 0.030 in.

[C] *Assembly C*—Weighted foot assembly should weigh 1000 ± 5 g.

Metric Equivalents

in.	mm	in.	mm	in.	mm	in.	mm
0.001	0.025	0.13	3.30	0.62	15.75	2	50.80
0.005	0.127	3⁄16	4.76	0.63	16.00	2.078	52.78
0.010	0.254	0.25	6.35	0.75	19.05	4	101.60
0.015	0.381	¼	6.35	¾	19.05	10.10	256.54
0.020	0.508	0.30	7.62	1	25.4	15	381.00
0.030	0.762	5⁄16	7.94	11⁄16	26.99	16	406.40
0.035	0.889	⅜	9.51	1.24	31.50	17	431.80
1⁄16	1.59	0.50	12.70	1¼	31.75	17.5	444.50
0.100	2.54	0.54	13.72	1.50	38.10	20	508.00
⅛	3.17	0.59	14.99	1½	38.10	48	1219.2

NOTE 1—The sand reading indicator and foot specified by ASTM Method D2419 – 69. Fig. 1, may be used where this equipment is previously available.

FIG. 1 Sand Equivalent Test Apparatus

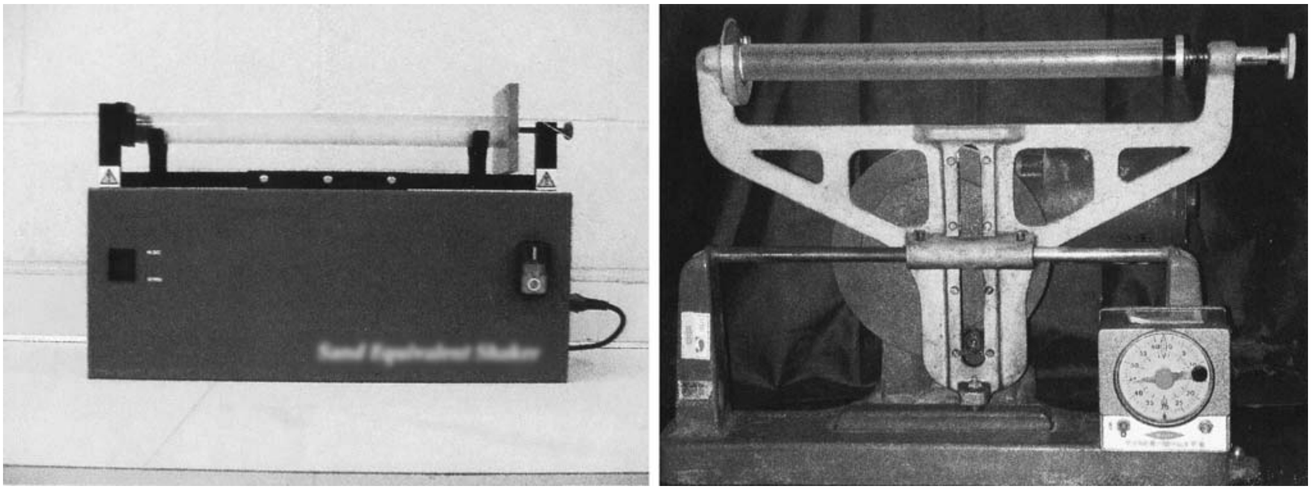


FIG. 2 Mechanized Shakers

NOTE 5—Moving parts of the mechanical shaker should be provided with a safety guard for protection of the operator.

7.9 *Manually Operated Sand Equivalent Shaker*—(optional), as shown in Fig. 3, or equivalent, capable of producing an oscillating motion at a rate of 100 complete cycles in 45 ± 5 s, with a hand-assisted half stroke length of 5 ± 0.2 in. (12.7 ± 0.5 cm). The device shall be designed to hold the required graduated cylinder in a horizontal position while subjecting it to a reciprocating motion parallel to its length. The shaker shall be fastened securely to a firm and level mount. If only a few tests are to be run the shaker may be held by hand on a firm level mount.

7.10 *Oven,* of sufficient size, and capable of maintaining a temperature of 230 ± 9°F (110 ± 5°C).

7.11 *Filter Paper,* Watman No. 2V or equivalent.

8. Reagents and Materials

8.1 *Stock Solution*—The materials listed in 8.1.1, 8.1.2 or 8.1.3 may be used to prepare the stock solution. If the use of formaldehyde as the biocide is of concern, the materials in 8.1.2 or 8.1.3 should be used. A fourth alternative is not to use any biocide provided the time of storage of stock solution is not sufficient to promote the growth of fungi.

8.1.1 Stock solution with formaldehyde.

8.1.1.1 *Anhydrous Calcium Chloride,* 454 g of technical grade.

8.1.1.2 *USP Glycerin,* 2050 g (1640 mL).

8.1.1.3 *Formaldehyde,* (40 volume % solution) 47 g (45 mL).

8.1.1.4 Dissolve the 454 g of calcium chloride in ½ gal (1.89 L) of distilled water. Cool and filter through ready pleated rapid filtering paper. Add the 2050 g of glycerin and the 47 g of formaldehyde to the filtered solution, mix well, and dilute to 3.78 L (1 gal).

8.1.2 Stock solution with glutaraldehyde.

8.1.2.1 *Calcium Chloride Dihydrate,* 577 g of A. C. S. grade.

NOTE 6—ACS grade calcium chloride dihydrate is specified for the stock solution prepared with glutaraldehyde because tests indicate that impurities in the technical grade anhydrous calcium chloride may react with the glutaraldehyde resulting in an unknown precipitate.

8.1.2.2 *USP Glycerin,* 2050 g (1640 mL).

8.1.2.3 *1,5-Pentanedial (Glutaraldehyde),* 50 % solution in water 59 g (53 mL).

8.1.2.4 Dissolve the 577 g of calcium chloride dihydrate in ½ gal (1.89 L) of distilled water. Cool and add the 2050 g of glycerin and the 59 g of glutaraldehyde to the solution, mix well, and dilute to 1 gal (3.78 L).

NOTE 7—1,5-pentanedial, also known as glutaraldehyde, glutaric dialdehyde, and trade name UCARCIDE 250, may be obtained as "Glutaraldehyde Solution 50 %."[4]

8.1.3 Stock solution with Kathon CG/ICP.

8.1.3.1 *Calcium Chloride Dihydrate,* 577 g of A. C. S. grade.

8.1.3.2 *USP Glycerin,* 2050 g (1640 mL).

8.1.3.3 *Kathon CG/ICP*[5], 63 g (53 mL).

8.1.3.4 Dissolve the 577 g of calcium chloride dihydrate in ½ gal (1.89 L) of distilled water. Cool and add the 2050 g of glycerin and the 63 g of Kathon CG/ICP to the solution, mix well, and dilute to 1 gal (3.78 L).

8.2 *Working Calcium Chloride Solution*—Prepare the working calcium chloride solution by diluting one measuring tin (85 ± 5 mL) full of the stock calcium chloride solution to 1.0 gal (3.8 L) with water. Use distilled or demineralized water for the normal preparation of the working solution. However, if it is determined that the local tap water is of such purity that it does not affect the test results, it is permissible to use it instead of distilled or demineralized water except in the event of dispute.

NOTE 8—The effect of local tap water on sand equivalent test results may be determined by comparing the results of three sand equivalent tests using distilled water with the results of three sand equivalent tests using

---

[4] Available from Aldrich Chemical Company, P. O. Box 2060, Milwaukee, WI 53201 or Fisher Scientific, 711 Forbes Ave., Pittsburg, PA 15219.

[5] The sole source of supply of Kathon CG/ICP known to the committee at this time is Rohm and Hass Chemical Company, Independence Mall West, Philadelphia, PA 19105. If you are aware of alternative suppliers, please provide this information to ASTM International Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee,[1] which you may attend.

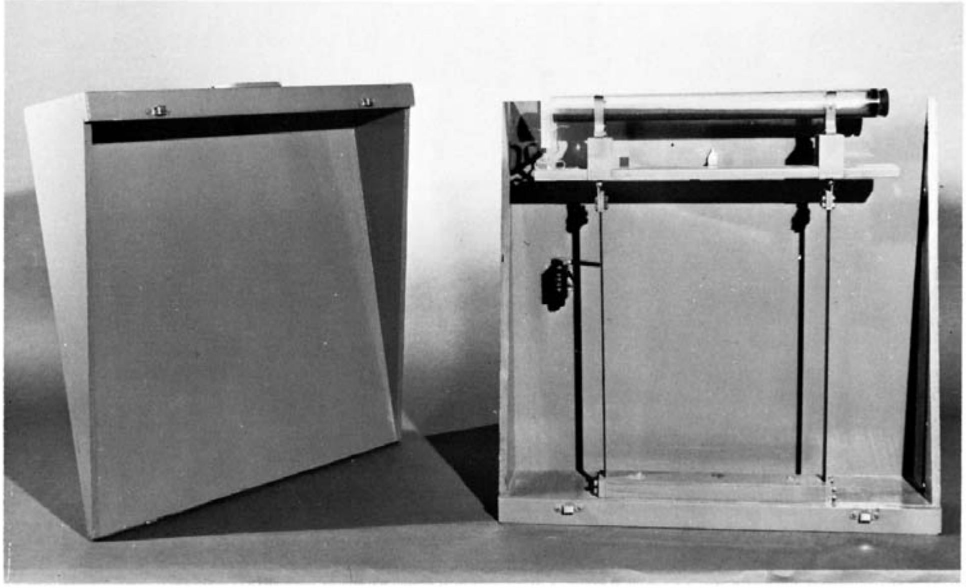


FIG. 3 Manually Operated Shaker

the local tap water. The six test specimens required for this comparison shall be prepared from the sample of material and oven-dried as prescribed in this test method.

9. Sample Preparation

9.1 Sample the material to be tested in accordance with Practice D75.

9.2 Thoroughly mix the sample and reduce it as necessary using the applicable procedures in Practice C702.

9.3 Obtain at least 1500 g of material passing the 4.75-mm (No. 4) sieve in the following manner:

9.3.1 Separate the sample on the 4.75-mm (No. 4) sieve by means of a lateral and vertical motion of the sieve, accompanied by a jarring action so as to keep the sample moving continuously over the surface of the sieve. Continue the sieving until not more than 1 weight % of the residue passes the sieve during 1 min. Perform the sieving operation either by hand or by a mechanical apparatus. When thoroughness of mechanical sieving is being determined, test by the hand method described above using a single layer of material on the sieve.

9.3.2 Break down any lumps of material in the coarse fraction to pass the 4.75-mm (No. 4) sieve. Use a mortar and rubber-covered pestle or any other means that will not cause appreciable degradation of the aggregate.

9.3.3 Remove any coatings of fines adhering to the coarse aggregate. These fines may be removed by surface-drying the coarse aggregate, then rubbing between the hands over a flat pan.

9.3.4 Add the material passing the sieve obtained in 9.3.2 and 9.3.3 to the separated fine portion of the sample.

9.4 Prepare test specimens from the material passing the 4.75-mm (No. 4) sieve portion of the sample by either the procedure described in 9.4.1 or 9.4.2.

NOTE 9—Experiments show that as the amount of material being reduced by splitting or quartering is decreased, the accuracy of providing representative portions is decreased. For this reason, it is imperative that extreme care be exercised when preparing the test specimens.

9.4.1 *Test Specimen Preparation, Procedure A:*

9.4.1.1 If it appears necessary, dampen the material to avoid segregation or loss of fines during the splitting or quartering operations. Use care in adding moisture to the sample to retain a free-flowing condition of the material.

9.4.1.2 Using the measuring tin, dip out four of these measures from the sample. Each time a measure full of the material is dipped from the sample, tap the bottom edge of the measure on a work table or other hard surface at least four times and jog it slightly to produce a measure of consolidated material level-full or slightly rounded above the brim.

9.4.1.3 Determine and record the amount of material contained in these four measures either by weight or by volume in a dry plastic cylinder.

9.4.1.4 Return this material back to the sample and proceed to split or quarter the sample, using the applicable procedures in Practice C702 and making the necessary adjustments to obtain the predetermined weight or volume. When this weight or volume is obtained, two successive splitting or quartering operations without adjustment should provide the proper amount of material to fill the measure, and therefore provide one test specimen.

9.4.1.5 Dry the test specimen to constant weight at 230 ± 9°F (110 ± 5°C) and cool to room temperature before testing.

NOTE 10—Sand equivalent results on test specimens that have not been dried will generally be lower than the results obtained on identical test specimens that have been dried. As a time-saving expedient, it is permissible to test most materials without drying when the sand equivalent value is used to determine compliance with a specification giving a minimum acceptable test value. If the resulting test value is lower than that specified, however, it will be necessary to rerun the test on a dried test specimen. If the sand equivalent determined from a test on one dried test specimen, is below the minimum specification limit, it will be necessary to perform two additional tests on dried test specimens from the same sample. The sand equivalent for a sample shall be determined in accordance with the calculation section.

9.4.2 *Test Specimen Preparation, Procedure B:*

9.4.2.1 Maintaining a free-flowing condition, dampen the material sufficiently to prevent segregation or loss of fines.

9.4.2.2 Split or quarter out 1000 to 1500 g of the material. Mix thoroughly with a hand trowel in a circular pan by scooping toward the middle of the pan while rotating it horizontally. Mixing or remixing should be continued for at least 1 min to achieve uniformity. Check the material for the necessary moisture condition by tightly squeezing a small portion of the thoroughly mixed sample in the palm of the hand. If a cast is formed that permits careful handling without breaking, the correct moisture range has been obtained. If the material is too dry, the cast will crumble and it will be necessary to add water and remix and retest until the material forms a cast. If the material shows any free water it is too wet to test and must be drained and air-dried, mixing it frequently to ensure uniformity. This overly wet material will form a good cast when checked initially, so the drying process should continue until a squeeze check on the drying material gives a cast which is more fragile and delicate to handle than the original. If the "as received" moisture content is within the limits described above, the sample may be run immediately. If the moisture content is altered to meet these limits, the sample should be put in the pan, covered with a lid or with a damp towel that does not touch the material, and allowed to stand for a minimum of 15 min.

9.4.2.3 After the minimum curing time, remix for 1 min without water. When thoroughly mixed, form the material into a cone with a trowel.

9.4.2.4 Take the tin measure in one hand and push it directly through the base of the pile while holding the free hand firmly against the pile opposite the measure.

9.4.2.5 As the can travels through the pile and emerges, hold enough hand pressure to cause the material to fill the can to overflowing. Press firmly with the palm of the hand, compacting the material until it consolidates in the can. The excess material should be struck off level with the top of the can, moving the edge of the trowel in a sawing motion across the brim.

9.4.2.6 To obtain additional test specimens, repeat the procedures in 9.4.2.3 through 9.4.2.5.

10. Preparation of Apparatus

10.1 Fit the siphon assembly to a 1.0-gal (3.8-L) bottle of working calcium chloride solution. Place the bottle on a shelf 36 ± 2 in. (90 ± 5 cm) above the working surface, (see Fig. 4).

NOTE 11—Instead of the 1.0-gal (3.8-L) bottle, a glass or plastic vat having a larger capacity may be used provided the liquid level of the working solution is maintained between 36 and 48 in. (90 and 120 cm) above the work surface.

10.2 Start the siphon by blowing into the top of the solution bottle through a short piece of tubing while the pinch clamp is open.

11. Procedure

11.1 Siphon 4 ± 0.1 in. (102 ± 3 mm) (indicated on the graduated cylinder) of working calcium chloride solution into the plastic cylinder.

FIG. 4 Graduated Cylinder, Irrigator Tube, Weighted Foot Assembly, and Siphon

11.2 Pour one of the test specimens into the plastic cylinder using the funnel to avoid spillage (see Fig. 5).

11.3 Tap the bottom of the cylinder sharply on the heel of the hand several times to release air bubbles and to promote thorough wetting of the specimen.

11.4 Allow the wetted specimen and cylinder to stand undisturbed for 10 ± 1 min.

11.5 At the end of the 10-min soaking period, stopper the cylinder, then loosen the material from the bottom by partially inverting the cylinder and shaking it simultaneously.

11.6 After loosening the material from the bottom of the cylinder, shake the cylinder and contents by any of the following three methods:

11.6.1 *Mechanical Shaker Method*—Place the stoppered cylinder in the mechanical sand equivalent shaker, set the time, and allow the machine to shake the cylinder and the contents for 45 ± 1 s.

11.6.2 *Manual Shaker Method:*

11.6.2.1 Secure the stoppered cylinder in the three spring clamps of the carriage of the hand-operated sand equivalent shaker and reset the stroke counter to zero.

NOTE 12—To prevent spillage, be sure the stopper is firmly seated in the cylinder before placing in the manual shaker.

11.6.2.2 Stand directly in front of the shaker and force the pointer to the stroke limit marker painted on the backboard by applying an abrupt horizontal thrust to the upper portion of the right-hand spring steel strap. Then remove the hand from the strap and allow the spring action of the straps to move the carriage and cylinder in the opposite direction without assistance or hindrance.

11.6.2.3 Apply enough force to the right-hand spring steel strap during the thrust portion of each stroke to move the

FIG. 5 Transfer of Samples from Measuring Tin to Cylinder

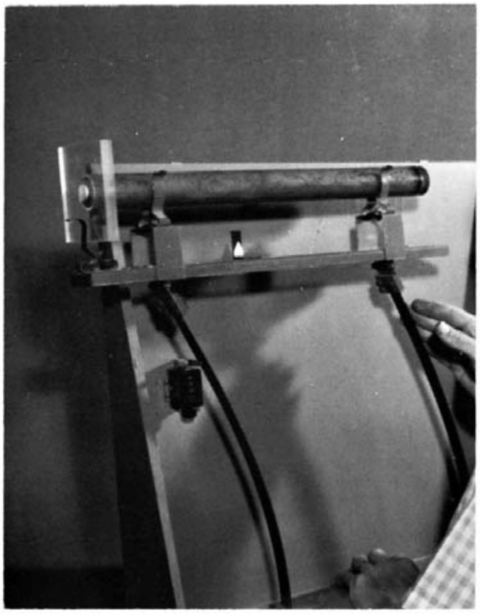


FIG. 6 Use of Manual Shaker

FIG. 7 Using Hand Method of Shaking

pointer to the stroke limit marker by pushing against the strap with the ends of the fingers to maintain a smooth oscillating motion (see Fig. 6). The center of the stroke limit marker is positioned to provide the proper stroke length and its width provides the maximum allowable limits of variation. The proper shaking action is accomplished only when the tip of the pointer reverses direction within the marker limits. Proper shaking action can best be maintained by using only the forearm and wrist action to propel the shaker.

11.6.2.4 Continue the shaking action for 100 strokes.

11.6.3 *Hand Method:*

11.6.3.1 Hold the cylinder in a horizontal position as illustrated in Fig. 7 and shake it vigorously in a horizontal linear motion from end to end.

11.6.3.2 Shake the cylinder 90 cycles in approximately 30 s using a throw of 9 ± 1 in. (23 ± 3 cm). A cycle is defined as a complete back and forth motion. To shake the cylinder at this speed properly, it will be necessary for the operator to shake with the forearms only, relaxing the body and shoulders.

11.7 Following the shaking operation, set the cylinder upright on the work table and remove the stopper.

11.8 *Irrigation Procedure:*

11.8.1 During the irrigation procedure, keep the cylinder vertical and the base in contact with the work surface. Insert the irrigator tube in the top of the cylinder, remove the spring clamp from the hose, and rinse the material from the cylinder walls as the irrigator is lowered. Force the irrigator through the material to the bottom of the cylinder by applying a gentle stabbing and twisting action while the working solution flows from the irrigator tip. This flushes the fine material into suspension above the coarser sand particles (see Fig. 8).

11.8.2 Continue to apply a stabbing and twisting action while flushing the fines upward until the cylinder is filled to the 15-in. (38.0 cm) graduation. Then raise the irrigator tube slowly without shutting off the flow so that the liquid level is maintained at about the 15-in. (38.0-cm) graduation while the irrigator tube is being withdrawn. Regulate the flow just before the irrigator tube is entirely withdrawn and adjust the final level to the 15-in. (38.0-cm) graduation.

11.9 Allow the cylinder and contents to stand undisturbed for 20 min ± 15 s. Start the timing immediately after withdrawing the irrigator tube.

11.10 At the end of the 20-min sedimentation period, read and record the level of the top of the suspension as prescribed in 11.12. This is referred to as the "clay reading." If no clear line of demarcation has formed at the end of the specified 20-min sedimentation period, allow the sample to stand undisturbed until a "clay reading" can be obtained; then immediately read and record the level of the top of the suspension and the total sedimentation time. If the total sedimentation time exceeds 30 min, rerun the test using three individual specimens of

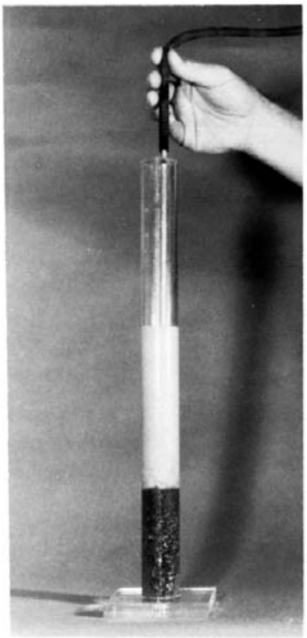


FIG. 8 Irrigation

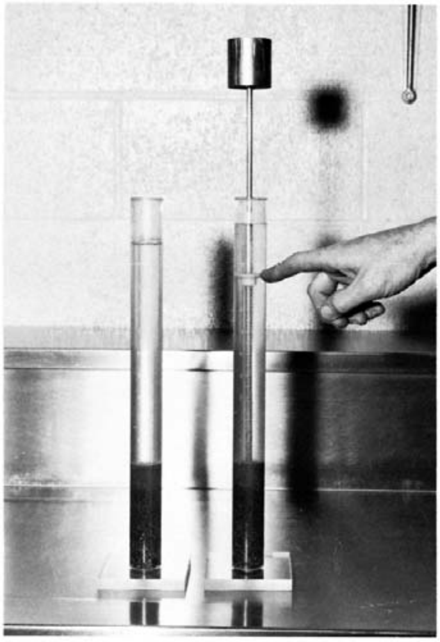


FIG. 9 Sand Reading

the same material. Record the suspension column height for the sample requiring the shortest sedimentation period as the "clay reading."

11.11 *Sand Reading Determination:*

11.11.1 After the suspension reading has been taken, place the weighted foot assembly over the cylinder and gently lower the assembly until it comes to rest on the sand. Do not allow the indicator to hit the mouth of the cylinder as the assembly is being lowered.

11.11.2 As the weighted foot comes to rest on the sand, tip the assembly toward the graduations on the cylinder until the indicator touches the inside of the cylinder. Subtract 10-in. (25.4 cm) from the level indicated by the extreme top edge of the indicator and record this value as the "sand reading" (see Fig. 9).

NOTE 13—See Annex A1 for the use of alternative foot apparatus and measurement procedure.

11.11.3 When taking the sand reading, use care not to press down on the weighted foot assembly since this could give an erroneous reading.

11.12 If the "clay reading" or sand reading falls between 0.1-in. (2.5-mm) graduations, record the level of the higher graduation as the reading.

12. Calculation and Report

12.1 Calculate the sand equivalent to the nearest 0.1 % as follows:

$$SE = (\text{sand reading/clay reading}) \times 100 \qquad (1)$$

where:

SE = sand equivalent.

12.2 If the calculated sand equivalent is not a whole number, report it as the next higher whole number. For example, if the clay level were 8.0 and the sand level were 3.3, the calculated sand equivalent would be:

$$(3.3/8.0) \times 100 = 41.2 \qquad (2)$$

Since this calculated sand equivalent is not a whole number it would be reported as the next higher whole number which is 42.

12.3 If it is desired to average a series of sand equivalent values, average the whole number values determined as described in 12.2. If the average of these values is not a whole number, raise it to the next higher whole number as shown in the following example:

12.3.1 Calculate SE values: 41.2, 43.8, 40.9.

12.3.2 After raising each to the next higher whole number they become 42, 44, 41.

12.3.3 Determine the average of these values as follows:

$$(42+44+41)/3 = 42.3 \qquad (3)$$

12.3.4 Since the average value is not a whole number, it is raised to the next higher whole number, and the sand equivalent value is reported as 43.

13. Precision and Bias

13.1 *Precision*—The following estimates of precision for this test method are based on results from the AASHTO Materials Reference Laboratory (AMRL) Reference Sample program, with testing conducted using this test method and AASHTO Method T 176. There are no significant differences between the two methods. The data are based on the analyses of eight paired test results from 50 to 80 laboratories, with the range of average sand equivalent values for the samples varying from approximately 60 to 90.

13.1.1 *Single Operator Precision*—The single operator standard deviation has been found to be 1.5 for sand equivalent values greater than 80 and 2.9 for values less than 80 (1s).[6] Therefore, results of two properly conducted tests by the same operator on similar material should not differ by more than 4.2 and 8.2, respectively (d2s).

13.1.2 *Multi-laboratory Precision*—The multi-laboratory standard deviation has been found to be 4.4 for sand equivalent values greater than 80 and 8.0 for values less than 80 (1s).[6] Therefore, results of two properly conducted tests from different laboratories on similar material should not differ by more than 12.5 and 22.6,[6] respectively (d2s).

13.1.3 Additional precision data is available from a study done by one state agency involving the circulation of pairs of samples to over 20 laboratories on three separate occasions. The range of average sand equivalent values for these samples varied from approximately 30 to 50; these were materials containing much more fines than the AMRL samples reported on in 13.1.1 and 13.1.2.

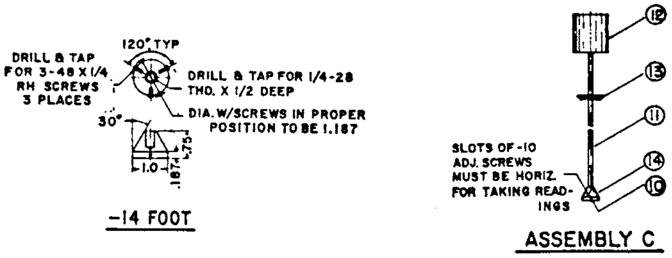
13.1.3.1 The Multi-laboratory standard deviation from these single agency tests was found to be 3.2 (1s). Therefore, within the laboratories of this agency, results of two properly conducted tests from different laboratories on similar material should not differ by more than 9.1 (d2s).

13.2 *Bias*—The procedure in this test method has no bias because the value of sand equivalent is defined only in terms of the test method.

ANNEX

(Mandatory Information)

A1. READING PROCEDURE FOR THE SAND READING WHEN THE 1969 SAND READING INDICATOR AND FOOT CONFORMING TO FIG. OF ASTM D2419 – 69 IS BEING USED



PART NO.	DESCRIPTION	STOCK SIZE	MATERIAL
14	Foot	1 dia by ¾	Bronze
13	Guide	1.50 dia by ¼	Brass
12	Weight	2 dia by 2.078	C.R.SH.
11	Rod	¼ dia by 17½	Brass
10	Adj. Screws	3-48 by ¼ RH	Brass

FIG. A1.1 1969 Weighted Foot Assembly from Test Method D2419 – 69

A1.1 *Differences in 1969 Equipment:*

A1.1.1 See Fig. A1.1 for the 1969 weighted foot (Assembly C) and the details of the 1969 Foot (Item 14).

A1.2 *Sand Reading Procedure*when 1969 foot assembly is used:

A1.2.1 After the clay reading has been taken, place the weighted foot assembly over the cylinder with the guide cap in position on the mouth of the cylinder and gently lower theassembly until it comes to rest on the sand. While the weighted foot is being lowered, keep one of the adj. screws (see Item 10 on Fig. A1.1) in contact with the cylinder wall near the graduations so that it can be seen at all times. When the weighted foot has come to rest on the sand, read and record the level of the horizontal slot of the adj. screw as the "Sand Reading" value.

---

[6] These numbers represent, respectively, the (ls) and (d2s) limits as described in Practice C670.

استاندارد آزمایش تعیین چگالی ویژه توسط آب

ASTM-D854-14

Designation: D854 – 14

Standard Test Methods for
Specific Gravity of Soil Solids by Water Pycnometer[1]

This standard is issued under the fixed designation D854; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the U.S. Department of Defense.

1. Scope*

1.1 These test methods cover the determination of the specific gravity of soil solids that pass the 4.75-mm (No. 4) sieve, by means of a water pycnometer. When the soil contains particles larger than the 4.75-mm sieve, Test Method C127 shall be used for the soil solids retained on the 4.75-mm sieve and these test methods shall be used for the soil solids passing the 4.75-mm sieve.

1.1.1 Soil solids for these test methods do not include solids which can be altered by these methods, contaminated with a substance that prohibits the use of these methods, or are highly organic soil solids, such as fibrous matter which floats in water.

NOTE 1—The use of Test Method D5550 may be used to determine the specific gravity of soil solids having solids which readily dissolve in water or float in water, or where it is impracticable to use water.

1.2 Two methods for performing the specific gravity are provided. The method to be used shall be specified by the requesting authority, except when testing the types of soils listed in 1.2.1

1.2.1 *Method A*—Procedure for Moist Specimens, described in 9.2. This procedure is the preferred method. For organic soils; highly plastic, fine grained soils; tropical soils; and soils containing halloysite, Method A shall be used.

1.2.2 *Method B*—Procedure for Oven-Dry Specimens, described in 9.3.

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

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

1.4 The values stated in SI units are to be regarded as standard. The inch-pound units given in parentheses are mathematical conversions which are provided for information purposes only and are not considered standard.

1.5 *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
D653 Terminology Relating to Soil, Rock, and Contained Fluids
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)
D3740 Practice for Minimum Requirements for Agencies Engaged in Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction
D4753 Guide for Evaluating, Selecting, and Specifying Balances and Standard Masses for Use in Soil, Rock, and Construction Materials Testing
D5550 Test Method for Specific Gravity of Soil Solids by Gas Pycnometer
D6026 Practice for Using Significant Digits in Geotechnical Data
E11 Specification for Woven Wire Test Sieve Cloth and Test Sieves
E177 Practice for Use of the Terms Precision and Bias in

---

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

Current edition approved May 1, 2014. Published May 2014. Originally approved in 1945. Last previous edition approved in 2010 as D854 – 10. DOI: 10.1520/D0854-14.

[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**

ASTM Test Methods
E691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method

3. Terminology

3.1 *Definitions*—For definitions of technical terms used in these test methods, refer to Terminology D653.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *specific gravity of soil solids, G_s, n*—the ratio of the mass of a unit volume of a soil solids to the mass of the same volume of gas-free distilled water at 20°C.

4. Significance and Use

4.1 The specific gravity of a soil solids is used in calculating the phase relationships of soils, such as void ratio and degree of saturation.

4.1.1 The specific gravity of soil solids is used to calculate the density of the soil solids. This is done by multiplying its specific gravity by the density of water (at proper temperature).

4.2 The term soil solids is typically assumed to mean naturally occurring mineral particles or soil like particles that are not readily soluble in water. Therefore, the specific gravity of soil solids containing extraneous matter, such as cement, lime, and the like, water-soluble matter, such as sodium chloride, and soils containing matter with a specific gravity less than one, typically require special treatment (see Note 1) or a qualified definition of their specific gravity.

4.3 The balances, pycnometer sizes, and specimen masses are established to obtain test results with three significant digits.

NOTE 2—The quality of the result produced by these test methods 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/etc. Users of these test methods 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.

5. Apparatus

5.1 *Pycnometer*—The water pycnometer shall be either a stoppered flask, stoppered iodine flask, or volumetric flask with a minimum capacity of 250 mL. The volume of the pycnometer must be 2 to 3 times greater than the volume of the soil-water mixture used during the deairing portion of the test.

5.1.1 The stoppered flask mechanically sets the volume. The stoppered iodine flask has a flared collar that allows the stopper to be placed at an angle during thermal equilibration and prevents water from spilling down the sides of the flask when the stopper is installed. The wetting of the outside of the flask is undesirable because it creates changes in the thermal equilibrium. When using a stopper flask, make sure that the stopper is properly labeled to correspond to the flask.

5.2 *Balance*—A balance meeting the requirements of Guide D4753 for a balance of 0.01 g readability. When using the 250–mL pycnometers, the balance capacity shall be at least 500 g and when using the 500–mL pycnometers, the balance capacity shall be at least 1000 g.

5.3 *Drying Oven*—Thermostatically controlled oven, capable of maintaining a uniform temperature of 110 ± 5°C throughout the drying chamber. These requirements usually require the use of a forced-draft oven.

5.4 *Thermometric Device,* capable of measuring the temperature range within which the test is being performed, having a readability of 0.1°C and a maximum permissible error of 0.5°C. The device must be capable of being immersed in the sample and calibration solutions to a depth ranging between 25 and 80 mm. Full immersion thermometers shall not be used. To ensure the accuracy of the thermometric device, the thermometric device shall be standardized by comparison to a NIST traceable thermometric device. The standardization shall include at least one temperature reading within the range of testing. The thermometric device shall be standardized at least once every twelve months.

5.5 *Desiccator*—A desiccator cabinet or large desiccator jar of suitable size containing silica gel or anhydrous calcium sulfate.

NOTE 3—It is preferable to use a desiccant that changes color to indicate when it needs reconstitution.

5.6 *Entrapped Air Removal Apparatus*—To remove entrapped air (deairing process), use one of the following:

5.6.1 *Hot Plate or Bunsen Burner,* capable of maintaining a temperature adequate to boil water.

5.6.2 *Vacuum System,* a vacuum pump or water aspirator, capable of producing a partial vacuum of 100 mm of mercury (Hg) or less absolute pressure.

NOTE 4—A partial vacuum of 100 mm Hg absolute pressure is approximately equivalent to a 660 mm (26 in.) Hg reading on vacuum gauge at sea level.

5.7 *Insulated Container*—A Styrofoam cooler and cover or equivalent container that can hold between three and six pycnometers plus a beaker (or bottle) of deaired water, and a thermometer. This is required to maintain a controlled temperature environment where changes will be uniform and gradual.

5.8 *Funnel*—A non-corrosive smooth surface funnel with a stem that extends past the calibration mark on the volumetric flask or stoppered seal on the stoppered flasks. The diameter of the stem of the funnel must be large enough that soil solids will easily pass through.

5.9 *Pycnometer Filling Tube with Lateral Vents (optional)*—A device to assist in adding deaired water to the pycnometer without disturbing the soil-water mixture. The device may be fabricated as follows. Plug a 6 to 10-mm (¼ to ⅜ in.) diameter plastic tube at one end and cut two small vents (notches) just above the plug. The vents should be perpendicular to the axis of the tube and diametrically opposed. Connect a valve to the other end of the tube and run a line to the valve from a supply of deaired water.

5.10 *Sieve*—4.75 mm (No. 4) conforming to the requirements of Specification E11.

5.11 *Blender (optional)*—A blender with mixing blades built into the base of the mixing container.

5.12 *Miscellaneous Equipment,* such as a computer or calculator (optional), specimen dishes, and insulated gloves.

6. Reagents

6.1 *Purity of Water*—Distilled water is used in this test method. This water may be purchased and is readily available at most grocery stores; hereafter, distilled water will be referred to as water.

7. Test Specimen

7.1 The test specimen may be moist or oven-dry soil and shall be representative of the soil solids that pass the 4.75-mm (No. 4) sieve in the total sample. Table 1 gives guidelines on recommended dry soil mass versus soil type and pycnometer size.

7.1.1 Two important factors concerning the amount of soil solids being tested are as follows. First, the mass of the soil solids divided by its specific gravity will yield four-significant digits. Secondly, the mixture of soil solids and water is a slurry not a highly viscous fluid (thick paint) during the deairing process.

8. Calibration of Pycnometer

8.1 Determine the mass of the clean and dry pycnometer to the nearest 0.01 g (typically five significant digits). Repeat this determination five times. One balance should be used for all of the mass measurements. Determine and record the average and standard deviation. The standard deviation shall be less than or equal to 0.02 g. If it is greater, attempt additional measurements or use a more stable or precise balance.

8.2 Fill the pycnometer with deaired water to above or below the calibration mark depending on the type of pycnometer and laboratory preference to add or remove water.

8.2.1 It is recommended that water be removed to bring the water level to the calibration mark. The removal method reduces the chances of altering the thermal equilibrium by reducing the number of times the insulated container is opened.

8.2.2 The water must be deaired to ensure that there are no air bubbles in the water. The water may be deaired using either boiling, vacuum, combination of vacuum and heat, or a deairing device. This deaired water should not be used until it has equilibrated to room temperature. Also, this water shall be added to the pycnometer following the guidance given in 9.6.

8.3 Up to six pycnometers can be calibrated concurrently in each insulated container. Put the pycnometer(s) into a covered insulated container along with the thermometric device (or the temperature sensing portion of the thermometric device), a beaker (or bottle) of deaired water, stopper(s) (if a stoppered pycnometer is being used), and either an eyedropper or pipette. Let the pycnometer(s) come to thermal equilibrium (for at least 3 h). The equilibrium temperature should be within 4°C of room temperature and between 15 and 30°C.

TABLE 1 Recommended Mass for Test Specimen

Soil Type	Specimen Dry Mass (g) When Using 250 mL Pycnometer	Specimen Dry Mass (g) When Using 500 mL Pycnometer
SP, SP-SM	60 ± 10	100 ± 10
SP-SC, SM, SC	45 ± 10	75 ± 10
Silt or Clay	35 ± 5	50 ± 10

8.4 Move the insulated container near the balance or vice versa. Open the container and remove one pycnometer. Only the rim of the pycnometer shall be touched as to prevent the heat from handling changing the thermal equilibrium. Either work in the container or place the pycnometer on an insulated block (Styrofoam) while making water level adjustments.

8.4.1 If using a volumetric flask as a pycnometer, adjust the water to the calibration mark, with the bottom of the meniscus level with the mark. If water has to be added, use the thermally equilibrated water from the insulated container. If water has to be removed, use a small suction tube or paper towel. Check for and remove any water beads on the pycnometer stem or on the exterior of the flask. Measure and record the mass of pycnometer and water to the nearest 0.01 g.

8.4.2 If a stoppered flask is used, adjust the water to prevent entrapment of any air bubbles below the stopper during its placement. If water has to be added, use the thermally equilibrated water from the insulated container. Then, place the stopper in the bottle. If water has to be removed, before or after inserting the stopper, use an eyedropper. Dry the rim using a paper towel. Be sure the entire exterior of the flask is dry. Measure and record the mass of pycnometer and water to the nearest 0.01 g.

8.5 Measure and record the temperature of the water to the nearest 0.1°C using the thermometric device that has been thermally equilibrated in the insulated container. Insert the thermometric device (or the temperature sensing portion of the thermometric device) to the appropriate depth of immersion (see 5.4). Return the pycnometer to the insulated container. Repeat the measurements for all pycnometers in the container.

8.6 Readjust the water level in each pycnometer to above or below the calibration line or empty the pycnometer and fill to the above or below the calibration line. Allow the pycnometers to thermally equilibrate (for at least 3 h) in the covered insulated container. Adjust the water level to the calibration line by removing water from the pycnometer or by filling the pycnometer to the calibration mark with the thermally equilibrated deaired water from the insulated container. Measure and record the mass and temperature of the filled pycnometer.

8.6.1 Repeat the procedure in 8.6 until a total of five independent measurements of the mass of the filled pycnometer and temperature readings are obtained. The temperatures do not need to bracket any particular temperature range.

8.7 Using each of these five data points, compute the calibrated volume of each pycnometer, V_p, using the following equation:

$$V_p = \frac{(M_{pw,c} - M_p)}{\rho_{w,c}} \tag{1}$$

where:

$M_{pw,c}$ = the mass of the pycnometer and water at the calibration temperature, g,

M_p = the average mass of the dry pycnometer at calibration, g, and

$\rho_{w,c}$ = the mass density of water at the calibration temperature g/mL, (Table 2).

8.8 Calculate the average and the standard deviation of the five volume determinations. The standard deviation shall be less than or equal to 0.05 mL (rounded to two decimal places). If the standard deviation is greater than 0.05 mL, the calibration procedure has too much variability and will not yield accurate specific gravity determinations. Evaluate areas of possible refinement (adjusting the volume to the calibration mark, achieving temperature equilibrium, measuring temperature, deairing method or changing to the stoppered flasks) and revise the procedure until the standard deviation is less than or equal to 0.05 mL.

9. Procedure

9.1 *Pycnometer Mass*—Using the same balance used to calibrate the pycnometer, verify that the mass of the pycnometer is within 0.06 g of the average calibrated mass. If it is not, re-calibrate the dry mass of the pycnometer.

9.2 *Method A—Procedure for Moist Specimens:*

9.2.1 Determine the water content of a portion of the sample in accordance with Test Method D2216. Using this water content, calculate the range of wet masses for the specific gravity specimen in accordance with 7.1. From the sample, obtain a specimen within this range. Do not sample to obtain an exact predetermined mass.

TABLE 2 Density of Water and Temperature Coefficient (*K*) for Various Temperatures[A,B]

Temperature (°C)	Density (g/mL)[C]	Temperature Coefficient (*K*)	Temperature (°C)	Density (g/mL)[C]	Temperature Coefficient (*K*)	Temperature (°C)	Density (g/mL)[C]	Temperature Coefficient (*K*)	Temperature (°C)	Density (g/mL)[C]	Temperature Coefficient (*K*)
15.0	0.99910	1.00090	16.0	0.99895	1.00074	17.0	0.99878	1.00057	18.0	0.99860	1.00039
.1	0.99909	1.00088	.1	0.99893	1.00072	.1	0.99876	1.00055	.1	0.99858	1.00037
.2	0.99907	1.00087	.2	0.99891	1.00071	.2	0.99874	1.00054	.2	0.99856	1.00035
.3	0.99906	1.00085	.3	0.99890	1.00069	.3	0.99872	1.00052	.3	0.99854	1.00034
.4	0.99904	1.00084	.4	0.99888	1.00067	.4	0.99871	1.00050	.4	0.99852	1.00032
.5	0.99902	1.00082	.5	0.99886	1.00066	.5	0.99869	1.00048	.5	0.99850	1.00030
.6	0.99901	1.00080	.6	0.99885	1.00064	.6	0.99867	1.00047	.6	0.99848	1.00028
.7	0.99899	1.00079	.7	0.99883	1.00062	.7	0.99865	1.00045	.7	0.99847	1.00026
.8	0.99898	1.00077	.8	0.99881	1.00061	.8	0.99863	1.00043	.8	0.99845	1.00024
.9	0.99896	1.00076	.9	0.99879	1.00059	.9	0.99862	1.00041	.9	0.99843	1.00022
19.0	0.99841	1.00020	20.0	0.99821	1.00000	21.0	0.99799	0.99979	22.0	0.99777	0.99957
.1	0.99839	1.00018	.1	0.99819	0.99998	.1	0.99797	0.99977	.1	0.99775	0.99954
.2	0.99837	1.00016	.2	0.99816	0.99996	.2	0.99795	0.99974	.2	0.99773	0.99952
.3	0.99835	1.00014	.3	0.99814	0.99994	.3	0.99793	0.99972	.3	0.99770	0.99950
.4	0.99833	1.00012	.4	0.99812	0.99992	.4	0.99791	0.99970	.4	0.99768	0.99947
.5	0.99831	1.00010	.5	0.99810	0.99990	.5	0.99789	0.99968	.5	0.99766	0.99945
.6	0.99829	1.00008	.6	0.99808	0.99987	.6	0.99786	0.99966	.6	0.99764	0.99943
.7	0.99827	1.00006	.7	0.99806	0.99985	.7	0.99784	0.99963	.7	0.99761	0.99940
.8	0.99825	1.00004	.8	0.99804	0.99983	.8	0.99782	0.99961	.8	0.99759	0.99938
.9	0.99823	1.00002	.9	0.99802	0.99981	.9	0.99780	0.99959	.9	0.99756	0.99936
23.0	0.99754	0.99933	24.0	0.99730	0.99909	25.0	0.99705	0.99884	26.0	0.99679	0.99858
.1	0.99752	0.99931	.1	0.99727	0.99907	.1	0.99702	0.99881	.1	0.99676	0.99855
.2	0.99749	0.99929	.2	0.99725	0.99904	.2	0.99700	0.99879	.2	0.99673	0.99852
.3	0.99747	0.99926	.3	0.99723	0.99902	.3	0.99697	0.99876	.3	0.99671	0.99850
.4	0.99745	0.99924	.4	0.99720	0.99899	.4	0.99694	0.99874	.4	0.99668	0.99847
.5	0.99742	0.99921	.5	0.99717	0.99897	.5	0.99692	0.99871	.5	0.99665	0.99844
.6	0.99740	0.99919	.6	0.99715	0.99894	.6	0.99689	0.99868	.6	0.99663	0.99842
.7	0.99737	0.99917	.7	0.99712	0.99892	.7	0.99687	0.99866	.7	0.99660	0.99839
.8	0.99735	0.99914	.8	0.99710	0.99889	.8	0.99684	0.99863	.8	0.99657	0.99836
.9	0.99732	0.99912	.9	0.99707	0.99887	.9	0.99681	0.99860	.9	0.99654	0.99833
27.0	0.99652	0.99831	28.0	0.99624	0.99803	29.0	0.99595	0.99774	30.0	0.99565	0.99744
.1	0.99649	0.99828	.1	0.99621	0.99800	.1	0.99592	0.99771	.1	0.99562	0.99741
.2	0.99646	0.99825	.2	0.99618	0.99797	.2	0.99589	0.99768	.2	0.99559	0.99738
.3	0.99643	0.99822	.3	0.99615	0.99794	.3	0.99586	0.99765	.3	0.99556	0.99735
.4	0.99641	0.99820	.4	0.99612	0.99791	.4	0.99583	0.99762	.4	0.99553	0.99732
.5	0.99638	0.99817	.5	0.99609	0.99788	.5	0.99580	0.99759	.5	0.99550	0.99729
.6	0.99635	0.99814	.6	0.99607	0.99785	.6	0.99577	0.99756	.6	0.99547	0.99726
.7	0.99632	0.99811	.7	0.99604	0.99783	.7	0.99574	0.99753	.7	0.99544	0.99723
.8	0.99629	0.99808	.8	0.99601	0.99780	.8	0.99571	0.99750	.8	0.99541	0.99720
.9	0.99627	0.99806	.9	0.99598	0.99777	.9	0.99568	0.99747	.9	0.99538	0.99716

[A] Reference: CRC Handbook of Chemistry and Physics, David R. Lide, Editor-in-Chief, 74th Edition, 1993–1994.

[B] $\rho_w = 1.00034038 - (7.77 \times 10^{-6}) \times T - (4.95 \times 10^{-6}) \times T^2$

where:

ρ_w = Density of water in g/mL,
T = the test temperature in °C, and
K = $\rho_w/0.9982063$

[C] mL = cm³.

9.2.2 To disperse the soil put about 100 mL of water into the mixing container of a blender or equivalent device. Add the soil and blend. The minimum volume of slurry that can be prepared by this equipment will typically require using a 500-mL pycnometer.

9.2.3 Using the funnel, pour the slurry into the pycnometer. Rinse any soil particles remaining on the funnel into the pycnometer using a wash/spray squirt bottle.

9.2.4 Proceed as described in 9.4.

9.3 *Method B—Procedure for Oven-Dried Specimens:*

9.3.1 Dry the specimen to a constant mass in an oven maintained at 110 ± 5°C. Break up any clods of soil using a mortar and pestle. If the soil will not easily disperse after drying or has changed composition, use Test Method A. Refer to 1.2.1 for soils that require use of Test Method A.

9.3.2 Place the funnel into the pycnometer. The stem of the funnel must extend past the calibration mark or stopper seal. Spoon the soil solids directly into the funnel. Rinse any soil particles remaining on the funnel into the pycnometer using a wash/spray squirt bottle.

9.4 *Preparing the Soil Slurry*—Add water until the water level is between ⅓ and ½ of the depth of the main body of the pycnometer. Agitate the water until slurry is formed. Rinse any soil adhering to the pycnometer into the slurry.

9.4.1 If slurry is not formed, but a viscous paste, use a pycnometer having a larger volume. See 7.1.1.

NOTE 5—For some soils containing a significant fraction of organic matter, kerosene is a better wetting agent than water and may be used in place of distilled water for oven-dried specimens. If kerosene is used, the entrapped air should only be removed by use of an aspirator. Kerosene is a flammable liquid that must be used with extreme caution.

9.5 *Deairing the Soil Slurry*—Entrapped air in the soil slurry can be removed using either heat (boiling), vacuum or combining heat and vacuum.

9.5.1 When using the heat-only method (boiling), use a duration of at least 2 h after the soil-water mixture comes to a full boil. Use only enough heat to keep the slurry boiling. Agitate the slurry as necessary to prevent any soil from sticking to or drying onto the glass above the slurry surface.

9.5.2 If only a vacuum is used, the pycnometer must be continually agitated under vacuum for at least 2 h. Continually agitated means the silt/clay soil solids will remain in suspension, and the slurry is in constant motion. The vacuum must remain relatively constant and be sufficient to cause bubbling at the beginning of the deairing process.

9.5.3 If a combination of heat and vacuum are used, the pycnometers can be placed in a warm water bath (not more than 40°C) while applying the vacuum. The water level in the bath should be slightly below the water level in the pycnometer, if the pycnometer glass becomes hot, the soil will typically stick to or dry onto the glass. The duration of vacuum and heat must be at least 1 h after the initiation of boiling. During the process, the slurry should be agitated as necessary to maintain boiling and prevent soil from drying onto the pycnometer.

9.6 *Filling the Pycnometer with Water*—Fill the pycnometer with deaired water (see 8.2.2) by introducing the water through a piece of small-diameter flexible tubing with its outlet end kept just below the surface of the slurry in the pycnometer or by using the pycnometer filling tube. If the pycnometer filling tube is used, fill the tube with water, and close the valve. Place the tube such that the drainage holes are just at the surface of the slurry. Open the valve slightly to allow the water to flow over the top of the slurry. As the clear water layer develops, raise the tube and increase the flow rate. If the added water becomes cloudy, do not add water above the calibration mark or into the stopper seal area. Add the remaining water the next day.

9.6.1 If using the stoppered iodine flask, fill the flask, such that the base of the stopper will be submerged in water. Then rest the stopper at an angle on the flared neck to prevent air entrapment under the stopper. If using a volumetric or stoppered flask, fill the flask to above or below the calibration mark depending on preference.

9.7 If heat has been used, allow the specimen to cool to approximately room temperature.

9.8 *Thermal Equilibrium*—Put the pycnometer(s) into a covered insulated container along with the thermometric device (or the temperature sensing portion of the thermometric device), a beaker (or bottle) of deaired water, stopper(s) (if a stoppered pycnometer is being used), and either an eyedropper or pipette. Keep these items in the closed container overnight to achieve thermal equilibrium.

9.9 *Pycnometer Mass Determination*—If the insulated container is not positioned near a balance, move the insulated container near the balance or vice versa. Open the container and remove the pycnometer. Only touch the rim of the pycnometer because the heat from hands can change the thermal equilibrium. Place the pycnometer on an insulated block (Styrofoam or equivalent).

9.9.1 If using a volumetric flask, adjust the water to the calibration mark following the procedure in 8.4.1.

9.9.2 If a stoppered flask is used, adjust the water to prevent entrapment of any air bubbles below the stopper during its placement. If water has to be added, use the thermally equilibrated water from the insulated container. Then, place the stopper in the bottle. If water has to be removed, before or after inserting the stopper, use an eyedropper. Dry the rim using a paper towel. Be sure the entire exterior of the flask is dry.

9.10 Measure and record the mass of pycnometer, soil, and water to the nearest 0.01 g using the same balance used for pycnometer calibration.

9.11 *Pycnometer Temperature Determination*—Measure and record the temperature of the slurry/soil-water mixture to the nearest 0.1°C using the thermometric device and method used during calibration in 8.5. This is the test temperature, T_t.

9.12 *Mass of Dry Soil*—Determine the mass of a tare or pan to the nearest 0.01 g. Transfer the soil slurry to the tare or pan. It is imperative that all of the soil be transferred. Water can be added. Dry the specimen to a constant mass in an oven maintained at 110 ± 5°C and cool it in a desiccator. If the tare can be sealed so that the soil can not absorb moisture during cooling, a desiccator is not required. Measure the dry mass of soil solids plus tare to the nearest 0.01 g using the designated balance. Calculate and record the mass of dry soil solids to the nearest 0.01 g.

NOTE 6—This method has been proven to provide more consistent, repeatable results than determining the dry mass prior to testing. This is most probably due to the loss of soil solids during the de-airing phase of testing.

10. Calculation

10.1 Calculate the mass of the pycnometer and water at the test temperature as follows:

$$M_{\mathrm{pw,t}} = M_{\mathrm{p}} + (V_p \cdot \rho_{w,t}) \tag{2}$$

where:

$M_{\rho w,t}$ = mass of the pycnometer and water at the test temperature (T_t), g,
M_p = the average calibrated mass of the dry pycnometer, g,
V_p = the average calibrated volume of the pycnometer, mL, and
$\rho_{w,t}$ = the density of water at the test temperature (T_t), g/mL from Table 2.

10.2 Calculate the specific gravity of soil solids at the test temperature, G_t as follows:

$$G_t = \frac{\rho_s}{\rho_{w,t}} = \frac{M_s}{\left(M_{\rho_{w,t}} - (M_{\rho ws,t} - M_s)\right)} \tag{3}$$

where:

ρ_s = the density of the soil solids Mg/m^3 or g/cm^3,
$\rho_{w,t}$ = the density of water at the test temperature (T_t), from Table 2, g/mL or g/cm^3.
M_s = the mass of the oven dry soil solids (g), and
$M_{\rho ws,t}$ = the mass of pycnometer, water, and soil solids at the test temperature, (T_t), g.

10.3 Calculate the specific gravity of soil solids at 20°C as follows:

$$G_{20^\circ\mathrm{C}} = K \cdot G_t \tag{4}$$

where:

K = the temperature coefficient given in Table 2.

10.4 For soil solids containing particles greater than the 4.75-mm (No. 4) sieve for which Test Method C127 was used to determine the specific gravity of these particles, calculate an average specific gravity. Test Method C127 requires the test be performed at 23 ± 1.7°C and does not require the specific gravity data to be corrected to 20°C. Use 10.3 to correct this measurement to 20°C. Use the following equation to calculate the average specific gravity:

$$G_{avg@20^\circ\mathrm{C}} = \frac{1}{\dfrac{R}{100 \cdot G_{1@20^\circ C}} + \dfrac{P}{100 \cdot G_{2@20^\circ C}}} \tag{5}$$

where:

R = the percent of soil retained on the 4.75-mm sieve,
P = the percent of soil passing the 4.75-mm sieve,
$G_{1@20^\circ\mathrm{C}}$ = the apparent specific gravity of soils retained on the 4.75-mm sieve as determined by Test Method C127, corrected to 20°C
$G_{2@20^\circ\mathrm{C}}$ = the specific gravity of soil solids passing the 4.75-mm sieve as determined by these test methods (Equation 4).

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

11.1 The method used to specify how data are recorded on the test data sheets or forms, as given below, is the industry standard, and are representative of the significant digits that should be retained. These requirements do not consider in situ material variation, use of 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 commensurate with these considerations. It is beyond the scope of the standard to consider significant digits used in analysis methods for engineering design.

11.2 Record as a minimum the following information (data):

11.2.1 Identification of the soil (material) being tested, such as boring number, sample number, depth, and test number.

11.2.2 Visual classification of the soil being tested (group name and symbol in accordance with Practice D2487).

11.2.3 Percent of soil particles passing the 4.75-mm (No. 4) sieve.

11.2.4 If any soil or material was excluded from the test specimen, describe the excluded material.

11.2.5 Method used (Method A or Method B).

11.2.6 All mass measurements (to the nearest 0.01 g).

11.2.7 Test temperature (to the nearest 0.1°C).

11.2.8 Specific gravity at 20°C (G, G_s, $G_{20^\circ C}$) to the nearest 0.01. If desired, values to the nearest 0.001 may be recorded.

11.2.9 Average specific gravity at 20°C (G_{ave} or $G_{avg@20^\circ C}$) to the nearest 0.01, if applicable. (See 10.4).

12. Precision and Bias

12.1 *Precision*—Criteria for judging the acceptability of test results obtained by these test methods on a range of soil types using Method A (except the soil was air dried) is given in Tables 3 and 4. These estimates of precision are based on the results of the interlaboratory program conducted by the ASTM Reference Soils and Testing Program.[3]

---

[3] Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR: RR:D18-1009.

TABLE 3 Summary of Test Results from Triplicate Test Laboratories (Specific Gravity)

(1) Soil Type	(2) Number of Triplicate Test Labs	(3) Average Value[A]	(4) Standard Deviation[B]	(5) Acceptable Range of Two Results[C]
Single-Operator Results (Within- Laboratory Repeatability):				
CH	14	2.717	0.009	0.03
CL	13	2.670	0.006	0.02
ML	14	2.725	0.006	0.02
SP	14	2.658	0.006	0.02
Multilaboratory Results (Between- Laboratory Reproducibility):				
CH	14	2.717	0.028	0.08
CL	13	2.670	0.022	0.06
ML	14	2.725	0.022	0.06
SP	14	2.658	0.008	0.02

[A] The number of significant digits and decimal places presented are representative of the input data. In accordance with Practice D6026, the standard deviation and acceptable range of results cannot have more decimal places than the input data.

[B] Standard deviation is calculated in accordance with Practice E691 and is referred to as the 1*s* limit.

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

TABLE 4 Summary of Single Test Result from Each Laboratory (Specific Gravity)[A]

(1) Soil Type	(2) Number of Test Laboratories	(3) Average Value	(4) Standard Deviation	(5) Acceptable Range of Two Results
Multilaboratory Results (Single-Test Performed by Each Laboratory):				
CH	18	2.715	0.027	0.08
CL	18	2.673	0.018	0.05
ML	18	2.726	0.022	0.06
SP	18	2.660	0.007	0.02

[A] See footnotes in Table 3.

In this program, some laboratories performed three replicate tests per soil type (triplicate test laboratory), while other laboratories performed a single test per soil type (single test laboratory). A description of the soils tested is given in 12.1.4. The precision estimates may vary with soil type and method used (Method A or B). Judgement is required when applying these estimates to another soil or method.

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

12.1.2 In the ASTM Reference Soils and Testing Program, many of the laboratories performed only a single test. This is common practice in the design and construction industry. The data in Table 4 are based upon the first test result from the triplicate test laboratories and the single test results from the other laboratories. Results of two properly conducted tests performed by two different laboratories with different operators using different equipment and on different days should not vary by more than the d2*s* limits shown in Table 4, Column 5. The results in Tables 3 and 4 are dissimilar because the data sets are different.

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

12.1.4 *Soil Type*—Based on the multilaboratory test results, the soil used in the program is described below in accordance with Practice D2487. In addition, the local name of the soil is given.

CH—Fat clay, CH, 99 % fines, LL=60, PI=39, grayish brown, soil had been air dried and pulverized. Local name—Vicksburg Buckshot Clay

CL—Lean clay, CL, 89 % fines, LL=33, PI=13, gray, soil had been air dried and pulverized. Local name—Annapolis Clay

ML—Silt, ML, 99 % fines, LL=27, PI=4, light brown, soil had been air dried and pulverized. Local name—Vicksburg Silt

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

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

SUMMARY OF CHANGES

In accordance with Committee D18 policy, this section identifies the location of changes to this standard since the last edition (10) that may impact the use of this standard.

(1) Removed mercury caveat from 5.6.2.

استاندارد آزمایش تعیین چگالی ویژه توسط گاز

ASTM-D5550-14

Designation: D5550 − 14

Standard Test Method for
Specific Gravity of Soil Solids by Gas Pycnometer[1]

This standard is issued under the fixed designation D5550; 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 This test method covers the determination of the specific gravity of soil solids by means of a gas pycnometer. Particle size is limited by the dimensions of the specimen container of the particular pycnometer being used.

1.2 Test Method D854 may be used instead of or in conjunction with this test method for performing specific gravity tests on soils. Note that Test Method D854 does not require the specialized test apparatus needed by this test method. However, Test Method D854 may not be used if the specimen contains matter that can readily dissolve in water, whereas this test method does not have that limitation.

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

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

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

1.4 *Units*—The values stated in SI units are to be regarded as standard. The values given in parentheses are mathematical conversions to inch-pound units, which are provided for information only and are not considered standard.

1.4.1 The converted inch-pound units use the gravitational system of units. In this system, the pound (lbf) represents a unit of force (weight), while the unit for mass is slugs. The converted slug unit is not given, unless dynamic (F = ma) calculations are involved.

1.5 *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

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

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

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

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

3. Terminology

3.1 *Definitions:*

3.1.1 For common definitions of terms in this standard, refer to Terminology D653.

4. Summary of Test Method

4.1 This test method is used to determine the specific gravity of soil grains using a gas pycnometer. This test method also contains equations for correcting the initial specific gravity value for dissolved matter within the pore fluid.

---

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

Current edition approved Dec. 15, 2014. Published January 2015. Originally approved in 1994. Last previous edition approved in 2006 as D5550 – 06. DOI: 10.1520/D5550-14.

[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**

5. Significance and Use

5.1 The specific gravity value is used in many phase relation equations to determine relative volumes of particle, water, and gas mixtures.

5.2 The term soil particle typically refers to a naturally occurring mineral grain that is not readily soluble in water. Therefore, the specific gravity of soils that contain extraneous matter (such as cement, lime, and the like) or water-soluble material (such as salt) must be corrected for the precipitate that forms on the specimen after drying. If the precipitate has a specific gravity less than the parent soil grains, the uncorrected test result will be too low. If the precipitate has a higher specific gravity, then the uncorrected test value will be too high.

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 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 *Pycnometer*—The gas pycnometer shall be one of the commercially available models that determines the volume of a solid by one of two methods. One measures the pressure drop that occurs after a gas at a known pressure is allowed to flow into another chamber (typically the first chamber contains the solid material being tested). The amount of pressure drop is related to the volume of soil present. The other type of instrument puts a known volume of gas into a chamber containing the specimen. The increase in pressure is related to the volume of the material. Either type of instrument is acceptable provided that the required accuracy of the instrument produces a volume measurement that is ±0.2 % of the specimen volume.

NOTE 2—Commercially available instruments should be checked using materials with known specific gravities to ensure that they provide acceptable precision and accuracy for the range of soil types to be tested. Some instruments require an operator to manually perform the test (that is, physically move the working components of the apparatus), whereas, other instruments are fully automatic (after the specimen has been loaded) and can produce a digital display of the volume and specific gravity value (the specimen mass has to be input). Some instruments can also send the test results to a separate printer. Obviously, inherent errors are more possible with one type of equipment than another. Furthermore, some instruments are constructed differently than others and can therefore produce more accurate and reproducible results.

6.2 *Balance*—Balance meeting the requirements of Specifications D4753 and readable, without estimation, to at least 0.1 % of the specimen mass.

6.3 *Compressed Gas System*—Typically research grade helium is required by the instruments. A tank capable of storing the required volume of gas and associated pressure regulator(s) required to deliver the gas at the specified pressure.

NOTE 3—Other inert gas may be substituted for helium; refer to manufacturer's suggestions. Helium is often used because it obeys the ideal gas law and is able to penetrate small soil pores. Ordinary air may produce acceptable results for non-reactive specimens in some instruments, however, that practice should be discouraged because of the uncertainty introduced into the test results.

6.4 *Drying Oven*—Thermostatically-controlled oven, capable of maintaining a uniform temperature of 110 ± 5°C (230 ± 9°F) throughout the drying chamber.

6.5 *Desiccator*—A desiccating cabinet or jar with air-tight seal containing silica gel or an anhydrous calcium sulfate desiccant.

NOTE 4—Indicating desiccant changes color when it is no longer able to absorb moisture. However, indicating desiccant is more expensive than the non-indicating variety. To save cost, indicating desiccant can be mixed in with the non-indicating type. A ratio of one part indicating desiccant to approximately four parts non-indicating has proven to be acceptable in many applications.

NOTE 5—Anydrous calcium sulfate can be rejuvenated by heating at 204°C (400°F) for 1 h. Silica gel can be rejuvenated by heating at 149°C (300°F) for 3 h. Indicating desiccant that still has the capacity to absorb moisture will change color back to or close to the original color after heating.

6.6 *Vacuum System*—A vacuum pump or aspirator may be required by some instruments. Refer to the manufacturer's specifications to determine the requirements of the particular apparatus.

NOTE 6—Some pycnometers do not require a vacuum system to remove gas from the chambers, but instead, rely on a series of purges with an inert gas to clear the instrument of reactive gases.

6.7 *Mortar and Pestle,* used to pulverize some dried soil specimens.

6.8 *Miscellaneous Equipment,* specimen dishes or weighing paper and insulated gloves or tongs.

7. Reagents and Materials

7.1 Research grade Helium unless otherwise specified as being acceptable by the manufacturer.

8. Test Specimen

8.1 The test specimen must be oven dried and shall be representative of the total sample. Typically a greater specimen mass used in the instrument will produce a more accurate measured volume. The sample container within the available pycnometers varies in size from 1 to 350 cm^3. Because of the principles involved with instrument function, most manufacturers require that a majority of the specimen cup be filled with soil to produce acceptably accurate volume results. Soil grains of any size are acceptable to test provided that they are easily placed within and do not protrude from the specimen container.

NOTE 7—Using a small sample container may require the use of a more accurate balance with higher precision to attain the specified accuracy required by this test method.

9. Calibration

9.1 The calibration of each type of pycnometer is different. The manufacturer's instructions should be followed. There are generally two common calibration checks. The first one requires the specimen holder cup be checked when empty. The determined volume should be within manufacturer's tolerances of zero. Each pycnometer should also be supplied with an object of known volume (± manufacturer's tolerances) that can be placed in the specimen cup. The measured object's volume should fall within specifications.

9.2 The zero check should be made at the beginning of testing on a daily basis. The calibration volume check should be performed after twenty-five soil specimens are tested. Depending on its configuration, a pycnometer may also require the periodic checking of an internal chamber volume(s). If any calibration check falls outside the tolerances set forth by the manufacturer, the problem must be found and rectified before testing on soil specimens resumes.

NOTE 8—It may be beneficial to have a number of soil specimens that are used as internal laboratory standards that behave more similarly to test samples than the stainless steel spheres often supplied with the instruments. A number of different minerals (or combinations) can be used periodically to check for accuracy or precision, or both. One easily obtained mineral is quartz with a specific gravity of 2.65. One additional benefit of calculating actual mineral grain specific gravity values is that it is also an indirect check on the operation of the balance (there is however an unlikely possibility that compensating errors in both the mass and volume determinations will produce the expected result).

10. Procedure

10.1 Dry the specimen in an oven at 110 ± 5°C (230 ± 9°F) until a constant mass is obtained.

NOTE 9—Heating may diagenetically alter the structure of some clay minerals.[3] Therefore caution should be exercised if the mineral composition of a clay specimen is going to be determined after drying. It is possible to dry the specimen at a lower temperature. However the effect on water content[4] and hence specific gravity should be investigated. In addition, some materials other than clay may be affected by drying at 110°C, such as gypsum, soils containing organics, fly ash containing residual coal, island sands. Test Method D2216 includes recommendations for drying gypsum using a lower temperature, such as 60°C.

10.2 Remove the specimen from the oven and grind it into sand size particles using a mortar and pestle.

NOTE 10—In some instances the specimen may not have to be ground to a finer size, for example, cohesionless coarse grained sand. Multiple tests using pulverized and intact specimens can be performed and results compared. If a difference is obtained, the pulverized procedure is preferred.

10.3 Place the specimen back in the oven until a constant mass is again obtained. Care should be exercised to avoid losing any soil during the transfer process.

10.4 Remove the specimen from the oven and place it into a desiccator for the minimum time required for it to cool to ambient temperature. The temperature at which the soil volume is measured can be reported but is not required by this test method because of the negligible effect of temperature on the volume of soil solids. However, temperature may have a significant effect on performance of the gas pycnometer. Therefore, testing should be conducted within the specified operating temperature range of the apparatus.

NOTE 11—While in the instrument, the soil specimen should not be warmer than room temperature because the operation of many pycnometers is adversely affected by such a specimen temperature change. The specimen should not be exposed to air (even within the desiccator) any longer than is required to reach thermal equilibrium because of the potential for some types of minerals to adsorb moisture, which would change the measured mass and volume. A tight-fitting metal cover placed over metal specimen containers has been successfully used to prevent moisture adsorption during the cooling period.

10.5 Quickly obtain and record the mass of the specimen, M_s, to the nearest 0.01 g.

10.6 Transfer the soil into the test chamber.

10.7 Following the manufacturer's instructions, obtain and record the volume of the specimen, V_s, to the nearest 0.05 cm^3.

10.8 After the test is finished, quickly obtain the mass of the specimen again, M_s^2 to the nearest 0.01 g.

NOTE 12—The comparison of the second mass measurement, M_s^2, to the first value, M_s, is another informal way to check the operation of the instrument. If the two mass values differ by more than the precision of the balance, re-run the test or determine what the cause of the difference is. A gain in mass may indicate that the specimen adsorbed water which would produce a low specific gravity. A loss in mass could indicate that some of the specimen was carried into the instrument by faulty procedure or by equipment malfunction.

11. Calculation

11.1 Determine the specific gravity of the soil, G_s, by using the equation:

$$G_s = \frac{\left(\frac{M_s}{V_s}\right)}{\rho_W} \qquad (1)$$

where:

M_s = mass of the soil specimen determined prior to placement in the pycnometer, g,

V_s = volume of the specimen, cm^3, and

ρ_W = distilled water density at a temperature of 4°C, 1 g/cm^3.

NOTE 13—Grain specific gravity values are typically reported to the nearest 0.01, however the most accurate and precise pycnometers (in conjunction with the appropriate balance) may produce results that would allow reporting to the nearest 0.005 or better.

11.2 If the soil contained salt (or other dissolved matter) in the pore fluid, the G_s value should be corrected for the additional mass and volume that precipitated out during drying. The following equation can be used if the specimen water content has not been corrected for salt content (assume salt represents any kind of dissolved matter):

$$G_{sc1} = \frac{M_s - \left[\left(\frac{S}{1000 - S}\right) W M_s\right]}{\left[V_s - \frac{\left(\frac{S}{1000 - S}\right) W M_s}{\rho_s}\right] \rho_W} \qquad (2)$$

where:

G_{sc1} = grain specific gravity corrected for a particular salinity and salt density using a non-corrected water content,

M_s = mass of pycnometer specimen including salt, g,

V_s = volume of pycnometer specimen including salt, cm^3,

S = salinity of pore fluid, parts per thousand by mass,

W = water content (mass of water without salt loss during drying/mass of solids including salt, determined after drying), not corrected for salinity, decimal form,

---

[3] Carroll, D., *Clay Minerals: A Guide to Their X-Ray Identification*, Geological Society of America Special Paper 126, 1970.

[4] Lambe, T. W., *Soil Testing for Engineers*, Wiley, 1951.

ρ_s = density of dissolved matter (sea salt density is typically 2.18 g/cm^3), and
ρ_W = distilled water density at a temperature of 4°C, 1 g/cm^3.

11.3 The following equation can be used if the specimen water content has been corrected for salt content (assume salt represents any kind of dissolved matter):

$$G_{sc2} = \frac{M_s - \left[\dfrac{W_c\left(\dfrac{S}{1000}\right)M_s}{1+w_c\left(\dfrac{S}{1000}\right)}\right]}{\left\{V_s - \left[\dfrac{W_c\left(\dfrac{S}{1000}\right)M_s}{\left(1+W_c\left(\dfrac{S}{1000}\right)\right)\rho_s}\right]\right\}\rho_w} \quad (3)$$

where:

G_{sc2} = grain specific gravity corrected for a particular salinity and salt density using a salinity-corrected water content,
M_s = mass of pycnometer specimen including salt, g,
V_s = volume of pycnometer specimen including salt, cm^3
S = salinity of pore fluid, parts per thousand by mass,
W_c = water content (mass of water including salt/mass of solids excluding salt), corrected for salinity, decimal form,
ρ_s = density of dissolved matter (sea salt density is typically 2.18 g/cm^3), and
ρ_W = distilled water density at a temperature of 4°C, 1 g/cm^3.

NOTE 14—The following equation can be used to obtain a water content corrected for pore water salinity:

$$W_c = \frac{\left(1+\dfrac{S}{1000-S}\right)M_w}{M_s - \left[\left(\dfrac{S}{1000-S}\right)M_w\right]} \quad (4)$$

where:

W_c = water content corrected for pore water salinity, decimal form,
M_W = mass of water without salt, g,
M_s = mass of specimen including salt, g, and
S = salinity of the pore fluid, by mass, in parts per thousand.

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

12.1 The methodology used to specify how data are recorded on the test data sheet(s)/form(s), as given below is covered in 1.3.

12.2 Report at a minimum the following information in the report or data sheet:

12.2.1 Specimen identifying information, such as project name, sample/core/boring identification, and depth of specimen. This information can be modified if applicable,

12.2.2 Date of test performance and name of individual that performed the test,

12.2.3 Temperature at which the specimen was dried (to the nearest 0.1°C),

12.2.4 Specimen mass, M_s (to the nearest 0.01 g). Specimen mass M_{s2} should also be recorded if measured,

12.2.5 Volume of specimen determined with the pycnometer (to the nearest 0.05 cm^3),

12.2.6 The calculated specimen specific gravity, G_s, to the nearest 0.01,

12.2.7 If salt or other matter was dissolved in the pore fluid, then the corrected or uncorrected water content should be recorded, as mass, to the nearest 0.01 g.

12.2.8 The corrected specific gravity should be calculated using the appropriate equation if necessary and recorded, and

12.2.9 Specimen type, either intact or pulverized using a mortar and pestle.

13. Precision and Bias

13.1 *Precision*[5]—The repeatability standard deviation from a single operator has been determined to be ±0.001 g/cm^3, or ±0.04%.

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

14. Keywords

14.1 desiccant; salinity; soil; specific gravity; water content

---

[5] An interlaboratory study is being organized and a complete precision statement is expected to be available on or before June 2016.

SUMMARY OF CHANGES

In accordance with Committee D18 policy, this section identifies the location of changes to this standard since the 2000 edition that may impact the use of this standard.

(1) Removed comma in 1.3.1 and correction of typo "specifies" to "specified", to improve readability.
(2) Revised 1.4, Units statement, and added new 1.4.1, so as to match approved language.
(3) Added Test Method D2216 to Reference Documents, 2.1.
(4) Revised 3.1.1 to match approved language.
(5) Removed 3.2.1 and original Note 1, and renumbered Notes throughout standard.
(6) Revised Note 1 to match approved language.
(7) Revised Note 2 to improve readability.
(8) Removed original Note 4, along with footnote three, referring specifically to Drierite, with necessary renumbering of Notes.
(9) Revised 7.1 to improve clarity.
(10) Increased sample quantity range up to 350 cm^3 in Section 8.

(11) Revised 9.1 to improve clarity.
(12) Revised Note 9 to reference Test Method D2216 with precautions on drying samples containing water.
(13) Added a portion of Note 1 to 10.4 concerning temperature of soil specimen under analysis.
(14) Revised Note 11 to improve clarity.
(15) Changed "grams" to "g" in 10.5, 10.8, and 12.2.4.
(16) Revised Note 12 removing reference to Lab Manager and skipping of step 10.8.
(17) Revised 11.2 to improve clarity of w, the water loss on drying.
(18) Revised 11.3 to use same symbol in text as in Eq 4 for W_c.
(19) Revised 12.1, 12.2, and 12.2.1 to match approved language.
(20) Added units and tolerance for recording water content in 12.2.7.
(21) Revised 13.1 to include temporary repeatability statement, with added footnote concerning upcoming ILS.
(22) Removed specific reference to Drierite in Keywords.

استاندارد آزمایش بارگذاری صفحه (PLT)– بارگذاری تکراری

ASTM-D1195-09

Designation: D1195/D1195M – 09

Standard Test Method for
Repetitive Static Plate Load Tests of Soils and Flexible Pavement Components, for Use in Evaluation and Design of Airport and Highway Pavements[1]

This standard is issued under the fixed designation D1195/D1195M; 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 This test method covers a procedure for making repetitive static plate load tests on subgrade soils and compacted pavement components, in either the compact condition or the natural state, and provides data for use in the evaluation and design of rigid and flexible-type airport and highway pavements.

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

1.3 *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. Terminology

2.1 *Definitions:*

2.1.1 *deflection*, *n*—the amount of downward vertical movement of a surface due to the application of a load to the surface.

2.1.2 *rebound deflection*, *n*—the amount of vertical rebound of a surface that occurs when a load is removed from the surface.

2.1.3 *residual deflection*, *n*—the difference between original and final elevations of a surface resulting from the application and removal of one or more loads to and from the surface.

3. Significance and Use

3.1 Field, in-place repetitive static plate load tests are used for the evaluation and design of pavement structures. Repetitive static plate load tests are performed on soils and unbound base and subbase materials to determine a measure of the shear strength of pavement components.

4. Apparatus

4.1 *Loading Device*—A truck or trailer or a combination of both a tractor-trailer, an anchored frame, or other structure loaded with sufficient weight to produce the desired reaction on the surface under test. The supporting points (wheels in the case of a truck or trailer) shall be at least 2.4 m [8 ft] from the circumference of the largest diameter bearing plate being used.

4.2 *Hydraulic Jack Assembly*, with a spherical bearing attachment, capable of applying and releasing the load in increments. The jack shall have sufficient capacity for applying the maximum load required, and shall be equipped with an accurately calibrated gauge that will indicate the magnitude of the applied load.

4.3 *Bearing Plates*—A set of circular steel bearing plates not less than 25.4 mm [1 in.] in thickness, machined so that they can be arranged in pyramid fashion to ensure rigidity, and having diameters ranging from 152 to 762 mm [6 to 30 in.]. The diameters of adjacent plates in the pyramid arrangement shall not differ by more than 152 mm [6 in.].

NOTE 1—A minimum of four different plate sizes is recommended for pavement design or evaluation purposes. For evaluation purposes alone, a single plate may be used, provided that its area is equal to the tire-contact area corresponding to what may be considered as the most critical combination of conditions of wheel load and tire pressure. For the purpose of providing data indicative of bearing index (for example, the determination of relative subgrade support throughout a period of a year), a single plate of any selected size may be used.

4.4 *Dial Gauges*, two or more, graduated in units of 0.03 mm [0.001 in.] and capable of recording a maximum deflection of 25 mm [1 in.] or other equivalent deflection-measuring devices.

4.5 *Deflection Beam*—A beam upon which the dial gauges shall be mounted. The beam shall be a 64-mm [2½-in.] standard black pipe or a 76 by 76 by 6-mm [3 by 3 by ¼-in.] steel angle or equivalent. It shall be at least 5.5 m [18 ft] long and shall rest on supports located at least 2.4 m [8 ft] from the

---

[1] This test method is under the jurisdiction of ASTM Committee E17 on Vehicle - Pavement Systems and is the direct responsibility of Subcommittee E17.41 on Pavement Management and Data Needs.

Current edition approved Nov. 1, 2009. Published December 2009. Originally approved in 1952. Last previous edition approved in 2004 as D1195 – 93 (2004). DOI: 10.1520/D1195_D1195M-09.

circumference of the bearing plate or nearest wheel or supporting leg. The entire deflection measuring system shall be adequately shaded from direct rays of the sun.

4.6 *Miscellaneous Tools*, including a spirit level, for preparation of the surface to be tested and for operation of the equipment.

5. Procedure

5.1 Carefully center a bearing plate, of the selected diameter, under the jack assembly. Set the remaining plates of smaller diameter concentric with, and on top of, the bearing plate. Set the bearing plate level in a thin bed of a mixture of sand and plaster of Paris, of plaster of Paris alone, or of fine sand, using the least quantity of materials required for uniform bearing. To prevent loss of moisture from the subgrade during the load test, cover the exposed subgrade to a distance of 1.8 m [6 ft] from the circumference of the bearing plate with a tarpaulin or waterproof paper.

5.2 Where unconfined load tests are to be made at a depth below the surface, remove the surrounding material to provide a clearance equal to one-and-one-half plate diameters from the edge of the bearing plate. For confined tests, the diameter of the excavated circular area shall be just sufficient to accommodate the selected bearing plate.

5.3 Use a sufficient number of dial gauges, so located and fixed in position as to indicate the average vertical movement of the bearing plate. When using two dial gauges, they shall be set near each extremity of a diameter of the bearing plate, 25.4 mm [1 in.] from the circumference. When three gauges are used, they shall be set at an angle of 120° from each other, and equidistant from the circumference of the bearing plate. Each individual set of readings shall be averaged, and this value is recorded as the average settlement reading.

5.4 After the equipment has been properly arranged, and with all of the dead load (jack, plates, and so forth) acting, seat and bearing plate and assembly by the quick application and release of a load sufficient to produce a deflection of not less than 0.25 mm [0.01 in.] nor more than 0.51 mm [0.02 in.] as indicated by the dial gauges. When the dial needles come to rest following the release of this load, reseat the plate by applying one half of the recorded load producing the 0.25- to 0.51-mm [0.01 to 0.02-in.] deflection. When the dial needles have again come to rest, set each dial accurately at its zero mark.

NOTE 2—The use of additional dial gauges, placed on the surface of the material being tested at one half, one, and one and one-half, and so forth, bearing-plate diameters from the edge of the bearing plate, is optional.

5.5 Apply a load giving a deflection of about 1.0 mm [0.04 in.], start a stop watch, and maintain the same load constantly until the rate of deflection is 0.03 mm [0.001 in.] per min or less for 3 min successively. Then completely release the load, and observe the rebound until the rate of recovery is 0.03 mm [0.001 in.] per min or less, for three successive minutes. Apply and release the same load in this manner six times. Record the readings of the dial gauges resting on the bearing plate at the end of each minute; record the readings of the dial gauges set beyond the perimeter of the bearing plate just before the application, and just before the release of load, for each repetition. To ensure good contact between the gauges and the bearing plate or other surface on which they are resting, briefly buzz an electric bell attached to the deflection beam, 10 s before the dial gauges are to be read.

5.6 Increase the load to give a deflection of about 5.1 mm [0.2 in.], and proceed as directed in 5.5.

5.7 Increase the load to give a deflection of about 10.2 mm [0.4 in.], and proceed as directed in 5.5.

5.8 In all cases the standard end point shall be a rate of 0.03 mm [0.001 in.]/min or less for 3 min successively.

5.9 From a thermometer suspended near the bearing plate, read and record the air temperature at ½-h intervals.

6. Record of Tests

6.1 In addition to the continuous listing of all load, deflection, and temperature data, as prescribed in Section 5, a record shall also be made of all associated conditions and observations pertaining to the test, including the following:

6.1.1 Date,
6.1.2 Time of beginning and completion of test,
6.1.3 List of personnel,
6.1.4 Weather conditions,
6.1.5 Any irregularity in routine procedure,
6.1.6 Any unusual conditions observed at the test site, and
6.1.7 Any unusual observations made during the test.

7. Calculation and Plotting of Load-Deflection Relationships

7.1 For each repetition of each load, determine the deflection at which the rate of deflection is exactly 0.03 mm [0.001 in.]/min. This is termed end point deflection and can be determined with sufficient accuracy from visual inspection of the deflection data for each repetition of load recorded.

7.2 Correct the recorded loads, as read from the pressure gauge of each hydraulic jack used, by means of the calibration curve for each jack and pressure gauge used.

7.3 Determine graphically the zero point corrections for both applied load and deflection. This requires taking into account the weight of the hydraulic jack, that of the pyramid of bearing plates, and so forth, and that of the corrected jack loads at which the dial gauges were set to zero at the beginning of the test.

7.4 Plot the corrected deflection at which the rate of deflection is exactly 0.03 mm [0.001 in.]/min *versus* the number of repetitions of each corrected load. Similar graphs may be prepared in which corrected residual deflection and rebound deflection are plotted *versus* the number of repetitions of each corrected load.

8. Precision and Bias

8.1 The precision and bias of this test method for making repetitive static plate load tests on subgrade soils and flexible pavement components has not been determined. Soils and flexible pavement components at the same location may exhibit significantly different load-deflection relationships. No method presently exists to evaluate the precision of a group of repetitive plate load tests on soils and flexible pavement components because of the variability of these materials. The subcommittee is seeking pertinent data from users of this method that may be used to develop meaningful statements of precision and bias.

9. Keywords

9.1 bearing plate; deflection; pavements

استاندارد آزمایش بارگذاری صفحه (PLT)– بارگذاری غیرتکراری

ASTM-D1196-12

Standard Test Method for Nonrepetitive Static Plate Load Tests of Soils and Flexible Pavement Components, for Use in Evaluation and Design of Airport and Highway Pavements[1]

This standard is issued under the fixed designation D1196/D1196M; 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 This test method covers the making of nonrepetitive static plate load tests on subgrade soils and pavement components, in either the compacted condition or the natural state, and provides data for use in the evaluation and design of rigid and flexible-type airport and highway pavements.

1.2 *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; therefore, each system shall be used independently of the other. Combining values from the two systems may result in nonconformance with the standard.

1.3 *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. Terminology

2.1 *Definitions:*

2.1.1 *deflection*, *n*—amount of downward vertical movement of a surface as a result of the application of a load to the surface.

2.1.2 *rebound deflection*, *n*—amount of vertical rebound of a surface that occurs when a load is removed from the surface.

2.1.3 *residual deflection*, *n*—difference between original and final elevations of a surface resulting from the application and removal of one or more loads to and from the surface.

3. Significance and Use

3.1 Field, in-place nonrepetitive static load tests are used for the evaluation and design of pavement structures. Nonrepetitive static plate load tests are performed on soils and unbound base and subbase materials to determine the modulus of subgrade reaction or a measure of the shear strength of pavement components.

4. Apparatus

4.1 *Loading Device*—A truck or trailer or a combination of both a tractor-trailer, an anchored frame, or other structure loaded with sufficient weight to produce the desired reaction on the surface under test. The supporting points (wheels in the case of a truck or trailer) shall be at least 2.4 m [8 ft] from the circumference of the largest diameter bearing plate being used.

4.2 *Hydraulic Jack Assembly*, with a spherical bearing attachment, capable of applying and releasing the load in increments. The jack shall have sufficient capacity for applying the maximum load required, and shall be equipped with an accurately calibrated gage that will indicate the magnitude of the applied load.

4.3 *Bearing Plates*—A set of circular steel bearing plates not less than 25.4 mm [1 in.] in thickness, machined so that they can be arranged in pyramid fashion to ensure rigidity, and having diameters ranging from 152 to 762 mm [6 to 30 in.]. The diameters of adjacent plates in the pyramid arrangement shall not differ by more than 152 mm [6 in.]

NOTE 1—A minimum of four different plate sizes is recommended for pavement design or evaluation purposes. For evaluation purposes alone, a single plate may be used, provided that its area is equal to the tire-contact area corresponding to what may be considered as the most critical combination of conditions of wheel load and tire pressure. For the purpose of providing data indicative of bearing index (for example, the determination of relative subgrade support throughout a period of a year), a single plate of any selected size may be used.

4.4 *Dial Gages*, two or more, graduated in units of 0.01 mm [or 0.001 in.] and capable of recording a maximum deflection of 25.4 mm [1 in.] or other equivalent deflection-measuring devices.

4.5 *Deflection Beam*, upon which the dial gages shall be mounted. The beam shall be a 64 mm [2 ½-in.] standard black pipe or a 76 by 76 by 6-mm [3 by 3 by ¼-in.] steel angle, or equivalent. It shall be at least 5.5 m [18 ft] long and shall rest on supports located at least 2.4 m [8 ft] from the circumference of the bearing plate or nearest wheel or supporting leg. The entire deflection measuring system shall be adequately shaded from direct rays of the sun.

4.6 *Miscellaneous Tools*, including a spirit level, for preparation of the surface to be tested and for operation of the equipment.

---

[1] This test method is under the jurisdiction of ASTM Committee E17 on Vehicle - Pavement Systems and is the direct responsibility of Subcommittee E17.41 on Pavement Testing and Evaluation.

Current edition approved Jan. 1, 2012. Published January 2012. Originally approved in 1952. Replaces D1196 – 57. Last previous edition approved in 2004 as D1196 – 93 (2004). DOI: 10.1520/D1196-12.

5. Procedure

5.1 Carefully center a bearing plate of the selected diameter under the jack assembly. Set the remaining plates of smaller diameter concentric with, and on top of, the bearing plate. Set the bearing plate level in a thin bed of a mixture of sand and plaster of paris, of plaster of paris alone, or of fine sand, using the least quantity of materials required for uniform bearing. To prevent loss of moisture from the subgrade during the load test, cover the exposed subgrade to a distance of 1.8 m [6 ft] from the circumference of the bearing plate with a tarpaulin or waterproof paper.

5.2 Where unconfined load tests are to be made at a depth below the surface, remove the surrounding material to provide a clearance equal to one and one-half bearing plate diameters from the edge of the bearing plate. For confined tests the diameter of the excavated circular area shall be just sufficient to accommodate the selected bearing plate.

5.3 Use a sufficient number of dial gages, so located and fixed in position as to indicate the average deflection of the bearing plate. When using two dial gages, they shall be set near each extremity of a diameter of the bearing plate, 25.4 mm [1 in.] from the circumference. When three gages are used, they shall be set at an angle of 120° from each other, and equidistant from the circumference of the bearing plate. Each individual set of readings shall be averaged, and this value is recorded as the average settlement reading.

5.4 After the equipment has been properly arranged, with all of the dead load (jack, plates, and so forth) acting, seat the bearing plate and assembly by the quick application and release of a load sufficient to produce a deflection of not less than 0.25 mm [0.01 in.] nor more than 0.51 mm [0.02 in.], as indicated by the dials. When the dial needles come to rest following release of this load, reseat the plate by applying one half of the recorded load producing the 0.25–to–0.51–mm [0.01 to 0.02-in.] deflection. When the dial needles have then again come to rest, set each dial accurately at its zero mark.

5.5 Apply loads at a moderately rapid rate in uniform increments. The magnitude of each load increment shall be small enough to permit the recording of a sufficient number of load-deflection points to produce an accurate load-deflection curve (not less than six). After each increment of load has been applied, maintain the load until a rate of deflection of not more than 0.03 mm [0.001 in.]/min occurs for 3 min consecutively. Record load and deflection readings for each load increment. Continue this procedure until the selected total deflection has been obtained, or until the load capacity of the apparatus has been reached, whichever occurs first. At this point, maintain the load until an increased deflection of not more than 0.03 mm [0.001 in.]/min for 3 min consecutively occurs. Record the total deflection, after which release the load to load at which the dial gages were set at zero, and maintain this zero-setting load until the rate of recovery does not exceed 0.03 mm [0.001 in.] for 3 min consecutively. Record the deflection at the zero-setting load.

5.6 From a thermometer suspended near the bearing plate, read and record the air temperature at ½ h intervals.

6. Record of Tests

6.1 In addition to the continuous listing of all load, deflection, and temperature data, as prescribed in Section 4, a record shall also be made of all associated conditions and observations pertaining to the test, including the following:

6.1.1 Date,

6.1.2 Time of beginning and completion of test,

6.1.3 List of personnel,

6.1.4 Weather conditions,

6.1.5 Any irregularity in routine procedure,

6.1.6 Any unusual conditions observed at the test site, and

6.1.7 Any unusual observations made during the test.

7. Calculation and Plotting of Load-Deflection Relationships

7.1 From the data obtained by the procedure described under 4.5, plot the total or unit load in Newtons [pounds-force] for each increment against the corresponding settlement in millimeters [inches]. Also plot the recovery after full release of load. Correction should be made for the zero deflection point, taking into account the dead weight of the equipment and the seating load. From this graph, the relation of load and total deflection for that load, and the relation of rebound and residual deflection for the maximum load used, may be obtained.

8. Precision and Bias

8.1 The precision and bias of this test method for making nonrepetitive static plate load tests on subgrade soils and flexible pavement components has not been determined. Soils and flexible pavement components at the same location may exhibit significantly different load deflection relationships. No method presently exists to evaluate the precision of a group of nonrepetitive plate load tests on soils and flexible pavement components because of the variability of these materials. The subcommittee is seeking pertinent data from users of this test method that may be used to develop meaningful statements of precision and bias.

9. Keywords

9.1 bearing plate; deflection; pavements

استاندارد آزمایش چگالی ماکزیمم

γ_{max}

ASTM-D4253-14

Designation: D4253 – 14

Standard Test Methods for Maximum Index Density and Unit Weight of Soils Using a Vibratory Table[1]

This standard is issued under the fixed designation D4253; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the U.S. Department of Defense.

1. Scope*

1.1 These test methods cover the determination of the maximum-index dry density/unit weight of cohesionless, free-draining soils using a vertically vibrating table. The adjective “dry before density or unit weight is omitted in the title and remaining portions of this standard to be consistent with the applicable definition given in Section 3 on Terminology.

1.2 *Systems of Units:*

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

1.2.2 It is common practice in the engineering profession to concurrently use pounds to represent both a unit of mass (lbm) and a unit of force (lbf). This implicitly combines two separate systems of units; that is, the absolute system and the gravitational system. It is scientifically undesirable to combine the use of two separate sets of inch-pound units within a single standard. This 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, balances or scales measure mass; and weight must be calculated. In the inch-pound system, it is common to assume that 1 lbf is equal to 1 lbm. While reporting density is not regarded as nonconformance with this standard, unit weights should be calculated and reported since the results may be used to determine force or stress.

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

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

1.3.1 *Method 1A*—Using oven-dried soil and an electromagnetic, vertically vibrating table.

1.3.2 *Method 1B*—Using wet soil and an electromagnetic, vertically vibrating table.

1.3.3 *Method 2A*—Using oven-dried soil and an eccentric or cam-driven, vertically vibrating table.

1.3.4 *Method 2B*—Using wet soil and an eccentric or cam-driven vertically vibrating table.

1.4 The method to be used should be specified by the individual assigning the test.

1.4.1 The type of table to be used (Method 1 or 2) is likely to be decided based upon available equipment.

NOTE 1—There is evidence to show that electromagnetic tables yield slightly higher values of maximum index density/unit weight than the eccentric or cam-driven tables.

1.4.2 It is recommended that both the dry and wet methods (Methods 1A and 1B or 2A and 2B) be performed when beginning a new job or encountering a change in soil types, as the wet method can yield significantly higher values of maximum index density/unit weight for some soils. Such a higher maximum index density, when considered along with the minimum index density/unit weight, Test Methods D4254, will be found to significantly affect the value of the relative density (3.2.8) calculated for a soil encountered in the field. While the dry method is often preferred because results can usually be obtained more quickly, as a general rule the wet method should be used if it is established that it produces maximum index densities/unit weights that would significantly affect the use/application of the value of relative density.

1.5 These test methods are applicable to soils that may contain up to 15 %, by dry mass, of soil particles passing a No. 200 (75-µm) sieve, provided they still have cohesionless, free-draining characteristics (nominal sieve dimensions are in accordance with Specification E11). Further, these test methods are applicable to soils in which 100 %, by dry mass, of soil particles pass a 3-in. (75-mm) sieve.

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

---

[1] This standard is 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.

Current edition approved Dec. 15, 2014. Published January 2015. Originally approved in 1983. Last previous edition approved in 2006 as D4253 – 00(2006). DOI: 10.1520/D4253-14.

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

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

1.6 These test methods will typically produce a higher maximum dry density/unit weight for cohesionless, free-draining soils than that obtained by impact compaction in which a well-defined moisture-density relationship is not apparent. However, for some soils containing between 5 and 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 These test methods will typically produce a lower maximum dry density/unit weight than that obtained by vibrating hammer using Test Method D7382.

1.8 For many types of free-draining, cohesionless soils, these test methods cause a moderate amount of degradation (particle breakdown) of the soil. When degradation occurs, typically there is an increase in the maximum index density/unit weight obtained, and comparable test results may not be obtained when different size molds are used to test a given soil.

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

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

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

1.10 *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

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

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)

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

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

D4753 Guide for Evaluating, Selecting, and Specifying Balances and Standard Masses for Use in Soil, Rock, and Construction Materials Testing

D6026 Practice for Using Significant Digits in Geotechnical Data

D6913 Test Methods for Particle-Size Distribution (Gradation) of Soils Using Sieve Analysis

D7382 Test Methods for Determination of Maximum Dry Unit Weight and Water Content Range for Effective Compaction of Granular Soils Using a Vibrating Hammer

E11 Specification for Woven Wire Test Sieve Cloth and Test Sieves

E177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods

E691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method

3. Terminology

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

3.2 *Definitions of Terms:*

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

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

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

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

3.2.5 *minimum index density/unit weight, ρ_{dmin} or γ_{dmin}, n*—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, which 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.

---

[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.

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

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

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

or, in terms of corresponding dry densities

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

in terms of corresponding or dry unit weights

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

3.2.8 *percent compaction or relative compaction, R_c, n*—the ratio, expressed as a percentage, of the dry density/unit weight of a given soil to its maximum index density/unit weight.

3.2.8.1 *Discussion*—The equation for percent compaction or relative compaction is:

$$R_c = \frac{\rho_d}{\rho_{dmax}} \times 100 \quad (4)$$

or

$$R_c = \frac{\gamma_d}{\gamma_{dmax}} \times 100 \quad (5)$$

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

3.2.9.1 *Discussion*—The equation for density index is:

$$I_d = \frac{\rho_d - \rho_{dmin}}{\rho_{dmax} - \rho_{dmin}} \times 100 \quad (6)$$

or

$$I_d = \frac{\gamma_d - \gamma_{dmin}}{\gamma_{dmax} - \gamma_{dmin}} \quad (7)$$

4. Summary of Test Method

4.1 The maximum index density/unit weight of a given free-draining soil is determined by placing either oven-dried or wet soil in a mold, applying a 2-lb/in.^{2} (14-kPa) surcharge (dead weight) to the surface of the soil, and then vertically vibrating the mold, soil, and surcharge. Use either an electromagnetic, eccentric, or cam-driven vibrating table having a sinusoid-like time-vertical displacement relationship at a double amplitude of vertical vibration (peak-to-peak) of about 0.013 ± 0.002 in. (0.33 ± 0.05 mm) at a frequency of 60 Hz for 8.00 ± 0.25 minutes or 0.019 ± 0.003 in. (0.48 ± 0.08 mm) at 50 Hz for 10.00 ±0.25 minutes. The maximum index density/unit weight is calculated by dividing the oven-dried mass of the densified soil by its volume (average height of densified soil times area of mold).

5. Significance and Use

5.1 For many cohesionless, free-draining soils, the maximum index density/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 placed during construction.

5.1.1 Relative density and percent compaction are commonly used for evaluating the state of compactness of a given soil mass. Density/unit weight index is also sometimes used. See Section 3 for descriptions of terms.

5.2 It is generally recognized that either relative density or 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.

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

NOTE 2—In addition, there are published data to indicate that these test methods have a high degree of variability.[3] 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.

NOTE 3—The quality of the result produced by this standard is dependent on the competence of the personnel performing it, and the suitability of the equipment and facilities used. Agencies that meet the criteria of Practice D3740, generally, are considered capable of competent and objective testing/sampling/inspection/etc. Users of this standard are cautioned that compliance with Practice D3740 does not in itself ensure reliable results. Reliable results depend on many factors; Practice D3740 provides a means of evaluating some of those factors.

5.4 The double amplitude of vertical vibration has been found to have a significant effect on the density obtained.[3] For a particular vibrating table and mold assembly, the maximum index density/unit weight of a given material may be obtained at a double amplitude of vibration other than the double amplitude of 0.013 ± 0.002 in. (0.33 ± 0.05 mm) at a frequency of 60 Hz or 0.019 ± 0.003 in. (0.48 ± 0.08 mm) at 50 Hz required in this method; that is, dry density/unit weight may initially increase with increasing double amplitude of vibration, reach a peak, and then decrease with further increases in double amplitude of vibration. Furthermore, the relationship between the peak density/unit weight and optimum double amplitude of vibration (double amplitude of vibration where peak density/unit weight occurrs) can vary with various soil types and gradations.

5.5 The use of the standard molds (6.1.1) has been found to be satisfactory for most soils requiring maximum index-density/unit weight testing. Special molds (6.1.2) shall only be used when the test results are to be applied in conjunction with design or special studies and there is not enough soil to use the standard molds. Such test results should be applied with caution as maximum index densities/unit weights obtained with the special molds may not agree with those that would be obtained using the standard molds.

---

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

6. Apparatus

6.1 *Mold Assembly*—An example of a typical mold assembly is shown in Fig. 1. Individual components and accessories shall be as follows:

6.1.1 *Standard Molds*—Cylindrical metal molds having nominal volumes of 0.100 ft^3 (2830 cm^3) and 0.500 ft^3 (14 200 cm^3). The molds shall conform to the requirements shown in Fig. 2. The actual volume of the molds shall be within ±1.5 % of the specified nominal volume.

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

6.1.3 *Guide Sleeves*—One guide sleeve with clamp assembly, or other suitable attachment devices [see Fig. 4(a)], for each size mold. For easy centering of the guide sleeve above the mold, two of the three setscrews on the clamp assembly should be provided with lock nuts.

6.1.4 *Surcharge Base Plates*—One surcharge base plate for each standard size mold, conforming to the requirements of Fig. 5.

6.1.5 *Surcharge Weights*—One surcharge weight for each size mold. See Fig. 5 for tolerances related to the 0.100 ft^3 (2830 cm^3) and 0.500 ft^3 (14 200 cm^3) molds. For special molds, similar tolerances should be maintained. The total mass of the surcharge base plate and surcharge weight shall be equivalent to a surcharge stress of 2.00 ± 0.02 lb/$in.^2$ (13.8 ± 0.1 kPa) for the mold being used. For special molds, the surcharge base plate and weight can be composed of a single solid mass of metal.

6.1.6 *Surcharge Base-Plate Handle*—A device used to initially place and then to remove the surcharge base plate upon completion of densification. An example of such a handle is given in Fig. 4(b); however, any convenient hooking device may be used.

6.2 *Dial-Indicator Gauge Holder and Dial Indicator*—A device used, in conjunction with the guide brackets, to measure the difference in elevation between the top surfaces of the mold and surcharge base plate after densification [Fig. 4(c)]. The dial indicator shall have a 2-in. (50-mm) or greater travel, with 0.001-in. (0.025-mm) graduations and mounted so that the dial stem is parallel with the vertical axis of the mold. The dial indicator may be digital, analog clockwise-movement type where the dial pointer reads zero when the stem is extended, or counterclockwise type where the dial pointer reads zero when the stem is all the way in.

6.3 *Balance(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 %. Examples of balances capable of satisfying these requirements for most conditions have specifications as follows:

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

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

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

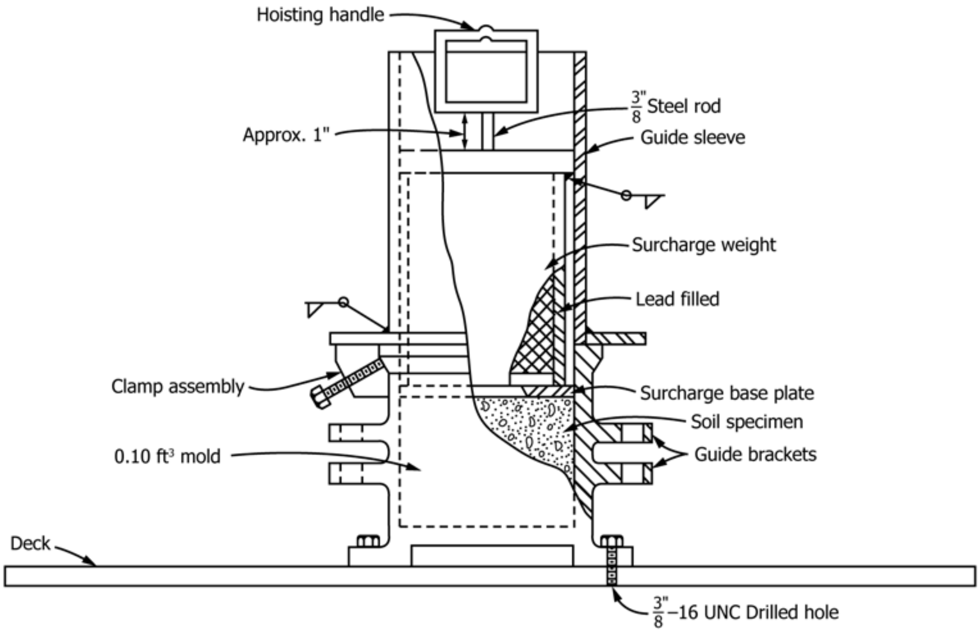
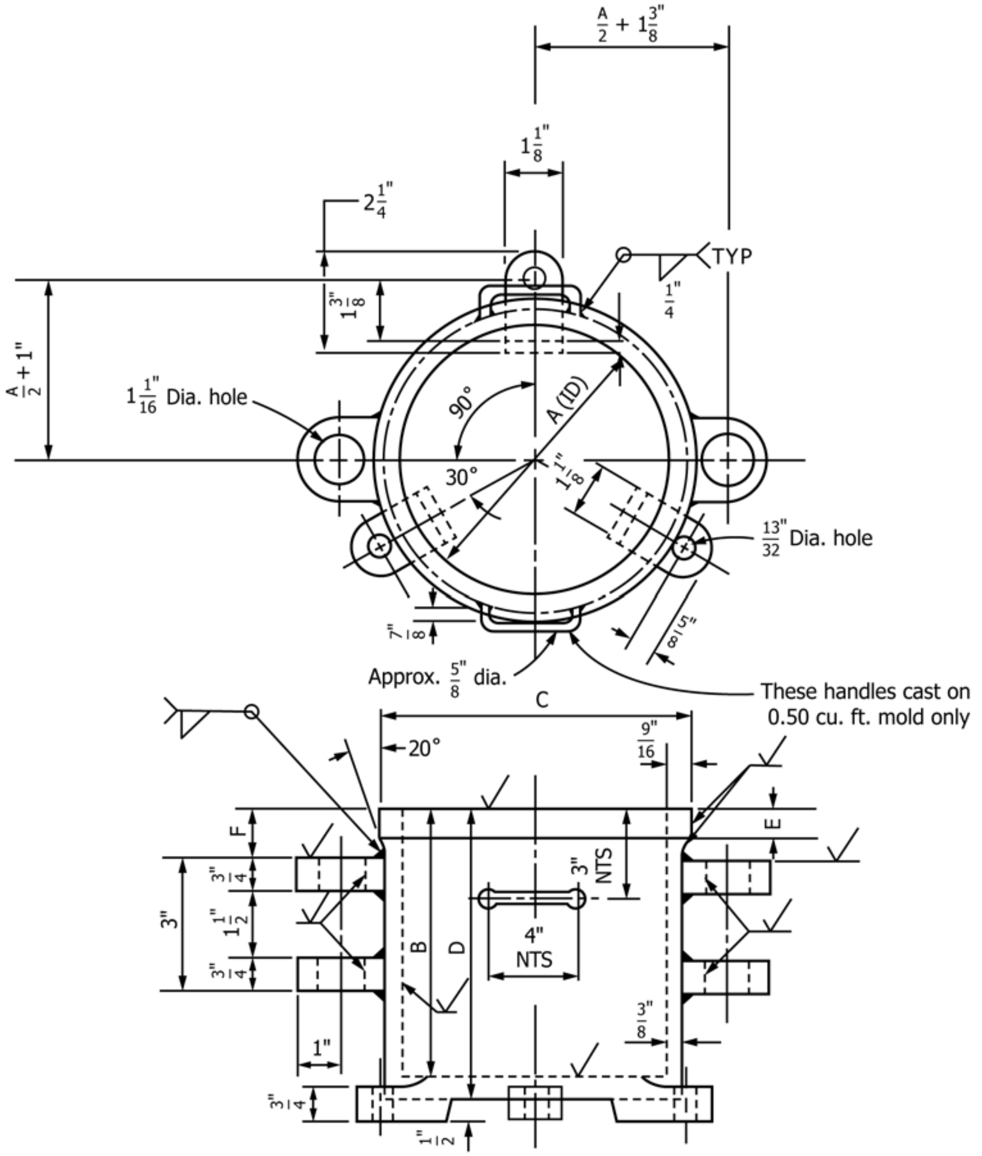


FIG. 1 Schematic Drawing of a Typical Mold Assembly



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

FIG. 2 Details of Molds

6.4 *Hoist*—A rope, chain, or cable hoist of at least 140-kg capacity when either the 0.100-ft^3 (2830-cm^3) or 0.500-ft^3 (14 200 cm^3) size molds are being used.

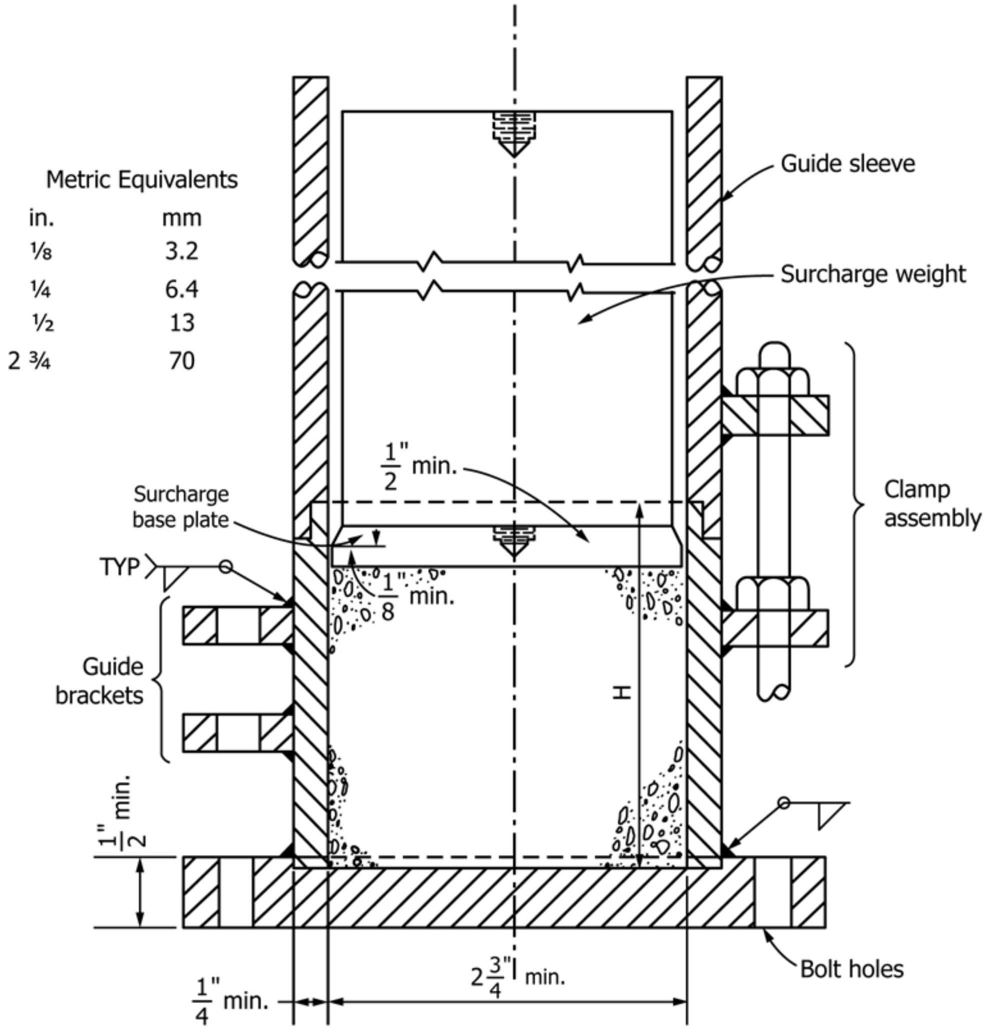
6.5 *Drying Oven,* thermostatically controlled, preferably of the forced-draft type, capable of maintaining a uniform temperature of 110 ± 5°C throughout the drying chamber.

6.6 *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 Specifications E11.

6.7 *Calibration Bar,* metal, about 3 by 12 by ¼ in. (75 by 300 by 6 mm), optional (see 10.4).

6.8 Other equipment such as mixing pans, a large metal scoop, a hair-bristled dusting brush, a timing device indicating minutes and seconds, and a micrometer with at least a 1-in. (25-mm) travel and with 0.001-in. (0.025-mm) graduations.

6.9 *Vibrating Table,* shall be mounted to a concrete floor or mass of sufficient size and configuration that excess vibrations are not transmitted to other testing areas. The vertically



H = (0.7 to 1.3) times diameter

FIG. 3 Special Cylindrical Metal Molds

vibrating deck of the table shall be of sufficient size and rigidity that the mold assembly being used can be attached and rigidly supported during the test. The table shall be capable of vertically vibrating the mold assembly with a sinusoidal time-vertical displacement relationship at an average double amplitude (peak-to-peak displacement) of 0.013 ± 0.002 in. (0.33 ± 0.05 mm) at a frequency of 60 Hz or 0.019 ± 0.003 in. (0.48 ± 0.08 mm) at 50 Hz under test conditions. The table shall have the capability for adjustment of the frequency of vibration (between 0 to 60 Hz) or double amplitude of vibration, or both, between about 0.005 in. (0.15 mm) and 0.013 in. (0.33 mm) at 60 Hz or about 0.007 in. (0.20 mm) and 0.019 in. (0.48 mm) at 50 Hz for use with Methods 1A, 1B, 2A, or 2B (11.2.3).

6.9.1 Use one of the following table types:

6.9.1.1 *Electromagnetic Vibrating Table*—A steel table conforming to the requirements of 6.9 with a vertically vibrating, cushioned steel deck generally 30 by 30 in. (760 by 760 mm), actuated by an electromagnetic vibrator of the solid-impact type with a net mass over 45 kg. The table shall be mounted to a concrete floor or slab having a mass of greater than 450 kg.

6.9.1.2 *Eccentric or Cam-Driven Vibrating Table,* conforming to the requirements of 6.9. The mass required to support cam-driven tables and eliminate vibrations in other areas may be as large as 4500 kg.

6.10 *Equipment for Calibration of Amplitude of Vibrating Table:*

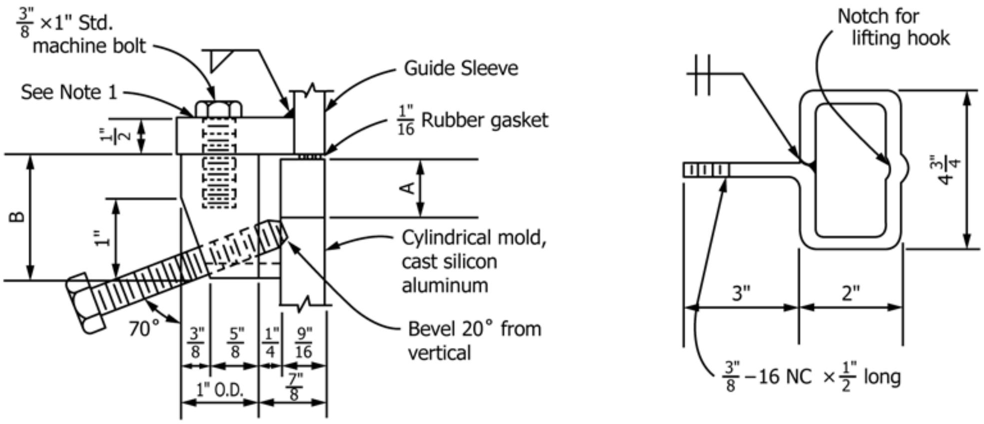
6.10.1 *Data Acquisition System*—The data acquisition system must be able to record 1000 deformation readings per second.

6.10.2 *Electronic Displacement Transducer*—The displacement transducer must be accurate to 0.0005 in. (0.015 mm).

6.10.3 *Mount for Displacement Transducer*—The displacement transducer must be mounted in such a way that the body of the transducer is stationary during the calibration and the transducer is measuring the displacement at the top of the mold.

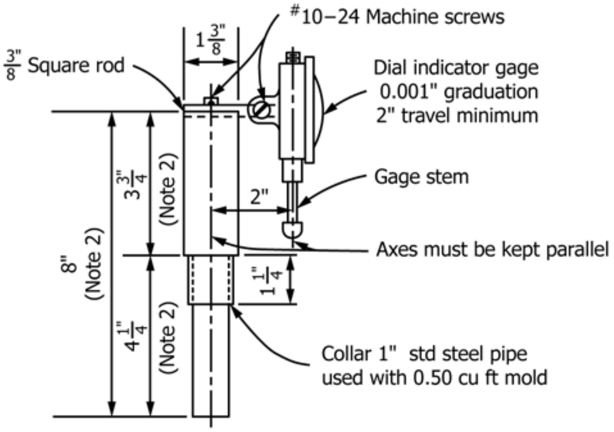
7. Precautions

7.1 *Safety Precautions*—Use of vibratory tables in certain acoustic environments may produce noise levels above those



(a)
Typical Clamp Assembly for Guide Sleeve for Guided Surcharge Weights.

(b)
Surcharge Base Plate Handle (1 Required)



(c)
Holder for Dial Indicator Gage

NOTE 1—This piece shall be a steel bar, 1½ by ½ in. (38.1 by 12.7 mm) of a length necessary to produce the indicated dimension from the inside of the guide sleeve. Weld three clamp assemblies to the guide sleeve at equal spacing.

NOTE 2—These dimensions must be changed to fit the dial gauge indicator used.

NOTE 3—Tolerances are ±1⁄64 in. (±0.4 mm) unless otherwise noted.

Size Mold, ft^3 (cm^3)	A, in. (mm)	B, in. (mm)	Guide Sleeve
0.100 (2830cm^3)	0.50 (12.7)	1.38 (34.9)	Steel tubing, 6 in. (150 mm) ID ¼ in. (6.4 mm) wall, 12 in. long (305 mm)
0.500(14 200cm^3)	0.63 (15.9)	1.50 (38.1)	Steel pipe, 11 in. (280 mm) ID ⅜ in. (9.5 mm) wall, 8 in. (200 mm) long

FIG. 4 Details of Apparatus Components

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.

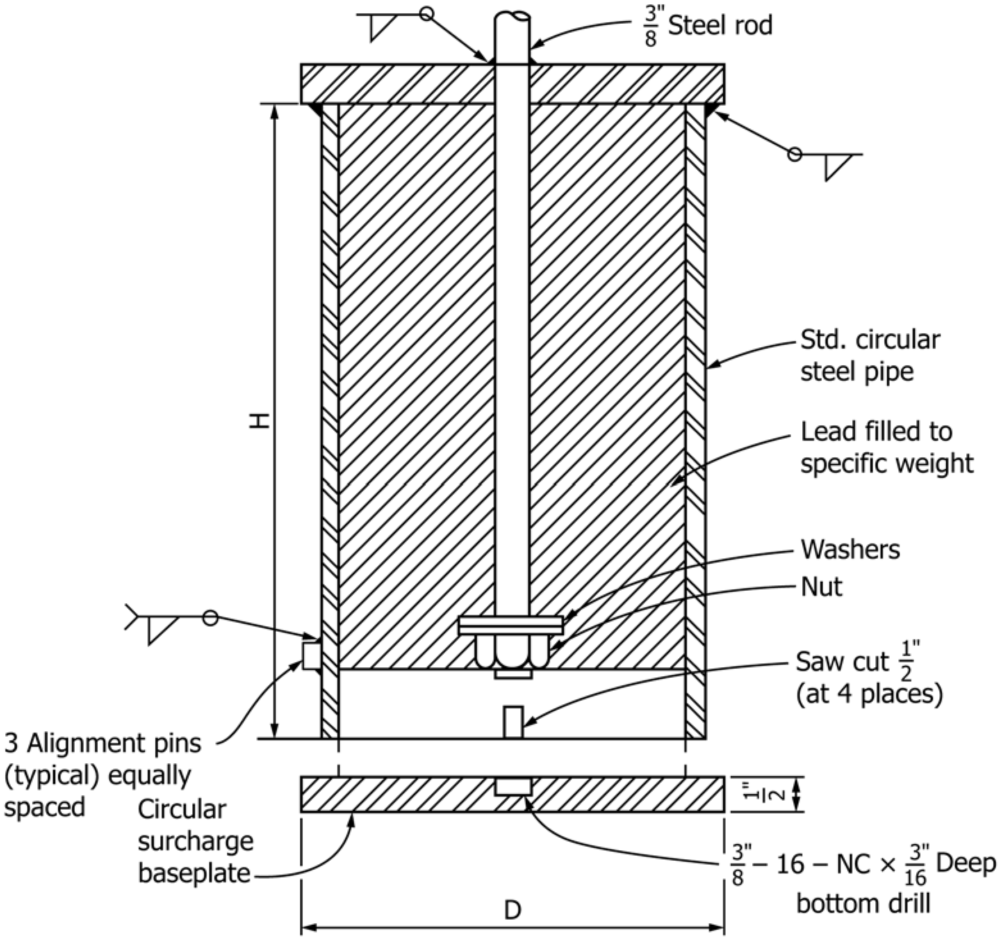
8. Sampling and Test Specimen

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 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).

8.2.1 Using a visual method or Test Method D6913 (depending upon the complexity of the gradation of the sample and operator experience), determine the maximum particle size and the percentage of particles passing the No. 200 (75-µm) sieve.

8.2.2 The determination of the maximum index density/unit weight should not be performed in accordance with these test



NOTE 1—All plates shall be 0.50-in. (12.7-mm) thick steel.

NOTE 2—Top plates for weights may be torch-cut, but edges must be ground as smooth as practicable. Surcharge base plates must be machined to the specified diameter.

NOTE 3—Hoisting handles shall have the same shape as the surcharge base plate handle (see Fig. 4 (b)).

Size Mold, ft^3 (cm^3)	D, in. (mm)	H, in. (mm)	Standard Pipe, in. (mm)	Total Weight Required, lb (kg)
0.100 (2830)	5.94 (151)	6.0 (150)	4.0 (100)	56.5 ± 0.5 (25.6± 0.2)
0.500(14 200)	10.88 (276)	9.0 (230)	10 (250)	190 ± 2 (86.2 ± 0.9)

FIG. 5 Circular Surcharge Weight and Base Plate

TABLE 1 Required Mass of Specimen[A]

Maximum Particle Size (100 % Passing) in. (mm)	Mass of Specimen Required, (kg)	Size of Mold to be Used, ft^3 (cm^3)
3 (75)	34	0.500(14 200)
1½ (38.1)	34	0.500(14 200)
¾ (19.0) or less	11	0.100 (2830)

[A] The mass of the sample should be at least two (preferably four) times these values, since normally the wet and dry method is performed and more than one trial is done in the dry method preferably using non-tested soil (see 11.1.11).

methods unless the requirements of 1.5 are met. If these conditions are met, then the mold size and specimen mass required can be determined according to the maximum particle size as prescribed in Table 1.

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

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

$$M_r = 0.0024 \cdot V_m \tag{8}$$

where:

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

8.3 Select a representative specimen of soil that meets the requirements of 8.2, using a splitter, riffle, or other method such as quartering.

8.4 If Methods 1A or 2A are being performed, dry the specimen in the drying oven, maintained at 110 ± 5°C to a constant mass. It is often desirable to obtain the water content of the field sample. If this is the case, determine the water content in accordance with Test Method D2216.

8.4.1 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 For a mold assembly in which the alignment of the guide sleeve on top of the mold is controlled by the position of the setscrews, assemble the guide sleeve on top of the mold and tighten the clamp assemblies so that the inner wall of the sleeve is in line with the inner wall of the mold. Tighten the lock nuts on the two setscrews so equipped. Loosen the set screw having no lock nut and remove the guide sleeve.

9.2 Determine and record the mass of the empty mold, using the appropriate balance specified in 6.3.

9.3 Check that the vibrating table is in good working condition and that parts are not loose or worn. Make any necessary adjustments or repairs.

9.4 Check that one set of initial dial readings is within ±0.005 in. (0.15 mm) of the value obtained in 10.4, that is, the dial-gauge zero has not been changed. As required, adjust the dial gauge or repeat the calibration (10.4.1). Alternatively, a reference bracket [similar to that shown in Fig. 6] may be used and, if required, adjust the dial gauge to the reference bracket reading.

10. Calibration

10.1 The following calibrations of test apparatus should be performed before initial use and at intervals not exceeding each 1000 tests, or annually, whichever occurs first. Additionally, the vibrating table should be calibrated after any event (including repairs), which might affect its operation.

10.2 *Molds*—Determine the volume of each mold by either the direct-measurement method or the water-filling method as provided in 10.2.1 and 10.2.2. 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 (as this method more accurately reflects the conditions over the entire mold).

10.2.1 *Direct Measurement Method*—The volume of the mold is calculated from the average of at least three internal diameter and three height measurements, evenly spaced throughout the mold, made to the nearest 0.001 in. (0.025 mm). Calculate and record the height, in m or cm to four significant digits (in accordance with Practice D6026). Calculate and record the cross-sectional area, A_m, (m^2 or cm^2) and volume, V_m, (m^3 or cm^3) to four significant digits (in accordance with Practice D6026).

10.2.2 *Water-Filling Method*—Obtain three height measurements, evenly spaced throughout the mold, made to the nearest 0.001 in. (0.025 mm). Calculate and record the height, in m or cm to four significant digits (in accordance with Practice D6026). Completely fill the mold with water. Slide a glass plate carefully over the top surface (rim) of the mold to ensure that the mold is completely filled with water. A thin film of grease or silicone lubricant on the rim of the mold will make a watertight joint between the glass plate and rim of the mold. Determine the mass of the water required to fill the mold using the appropriate balance specified in 6.3.3. Determine the temperature of this water to the nearest degree Celsius. From Table 2, obtain the unit volume of water in millilitres per gram at the observed temperature. Calculate and record the volume of the mold (m^3 or cm^3) to four significant digits as follows:

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

10.2.2.2 If only the water-filling method is used to determine the volume of the mold, then the cross-sectional area of the mold must be calculated by dividing its measured volume (10.2.2) by its measured height (10.2.1).

10.3 *Surcharge Base Plate*—Calculate and record the average thickness of the surcharge base plate (T_p) to the nearest 0.001 in. (0.025 mm) from at least four measurements using a micrometer. Calculate and record this thickness, T_p in same units that dial gauge is recorded.

10.4 *Initial Dial Reading*—This value may be obtained using the calibration bar, as provided in 10.4.1 or without the bar, as provided in 10.4.2, if the contact area between the mold guide bracket and the collar of the dial gauge holder (Fig. 2 and Fig. 4) has been machined level or made level by the use of brass inserts.

10.4.1 *Initial Dial Reading with Calibration Bar*—Determine the thickness of the calibration bar to 0.001 in. (0.025 mm) using a micrometer. Place the calibration bar across the diameter of the mold and between the vertical axis of the guide brackets. Insert the dial-indicator gauge holder in each of the guide brackets on the mold with the dial gauge stem on top of the calibration bar and its vertical axis in line with the vertical axis of the opposite guide bracket. The dial gauge holder should be placed in the same position in the guide brackets each time by means of matchmarks on the guide brackets and the holder. Obtain six dial indicator readings, three on each the left and the right sides, and average these six readings. To compute the initial dial reading, R_i, for clockwise-reading dial indicators, subtract the thickness of the calibration bar from the average of the six dial indicator readings. To compute counterclockwise-reading dial indicators, R_I, add the thickness of the calibration bar to the average of the six dial indicator readings. Record R_i to the nearest 0.001 in. (0.025 mm).

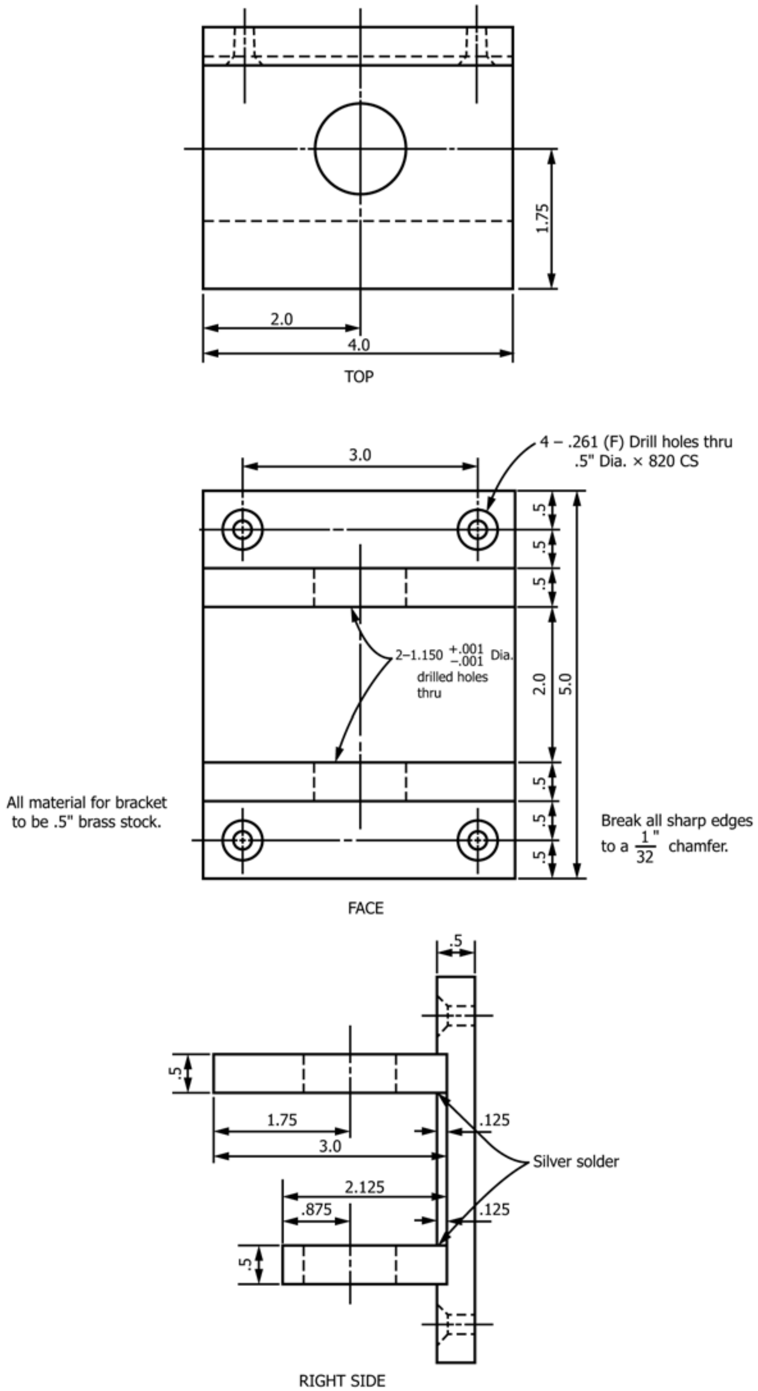


FIG. 6 Dial Gauge Calibration Standard (Reference Bracket)

10.4.2 *Initial Dial Reading Without Calibration Bar*—Insert the dial indicator gauge holder in each of the guide brackets with the dial gauge stem in contact with the rim of the mold (at its center) on both sides of the guide brackets. Obtain six sets of dial indicator readings, three on each side of each guide bracket. The average of these twelve readings is the initial dial gauge reading, R_i. Record R_i to the nearest 0.001 in. (0.025 mm).

10.5 *Vibrating Table*—The calibration shall consist of determining, under simulated test conditions and for each mold size being used, the required rheostat, eccentric, or cam setting for the electro-magnetic, eccentric, or cam-driven table, respectively, such that the mold has a double amplitude of vertical vibration of 0.013 ± 0.002 in. (0.33 ± 0.05 mm) at 60 Hz or 0.019 ± 0.003 in. (0.48 ± 0.08 mm) at 50 Hz. The double amplitude of vibration should be measured on the mold to the nearest 0.0005 in. (0.015 mm). It is recommended that during each calibration a relationship between the double amplitude of vertical vibration versus the rheostat, eccentric, or cam setting be established.

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

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

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

10.5.1 Place a typical sample into the mold using the procedure given in 11.1.2 through 11.1.5.

10.5.2 Mount an electronic displacement transducer such that the displacement between a fixed reference and the top of the mold will be measured. Use a data acquisition system capable of obtaining 1000 readings per second.

10.5.3 Select and record a setting and activate the vibrating table. Record a minimum of 10 cycles. Plot the displacement versus time. Evaluate the double amplitude of vertical vibration. If the amplitude is not within the requirement, adjust the setting and repeat until the required double amplitude is obtained.

11. Procedure

11.1 *Dry Method*—Methods 1A or 2A:

11.1.1 Mix the oven-dried specimen to provide an even distribution of particle sizes; that is, having as little segregation as possible.

11.1.2 Fill the mold with soil and level the surface of the soil using methods that minimize segregation (see Note 4). A scoop or pouring device (funnel) should be used to place the soil in the mold. The sides of the mold may be struck a few times using a metal bar, rubber hammer, or similar item to settle the soil so that the surcharge base plate can be easily placed into position and there is no surge of air from the mold when vibration is initiated.

NOTE 4—If the minimum index density/unit weight is also being performed, the soil shall be placed in accordance with the appropriate method specified in Test Methods D4254. The mass of the mold plus soil shall also be determined and recorded.

11.1.3 Place the appropriate surcharge base plate on the surface of the soil and twist it slightly several times so that it is firmly and uniformly in contact with the surface of the soil. Remove the surcharge base-plate handle.

11.1.4 Attach the mold to the vibrating table.

11.1.5 Firmly attach the guide sleeve to the mold and lower the appropriate surcharge weight onto the surcharge base plate.

11.1.6 Adjust the vibrating table control to the correct setting for the desired double amplitude of vibration.

11.1.6.1 *Method 1A*—Set the vibrator control (rheostat) at the setting determined in 10.5 for the mold assembly being used to obtain a double amplitude of vertical vibration of 0.013 ± 0.002 in. (0.33 ± 0.05 mm) at 60 Hz or 0.019 ± 0.003 in. (0.48 ± 0.08 mm) at 50 Hz.

11.1.6.2 *Method 2A*—Set the eccentric or cam at the setting determined in 10.5 for the mold assembly being used to obtain a double amplitude of vertical vibration of 0.013 ± 0.002 in. (0.33 ± 0.05 mm) at 60 Hz or 0.019 ± 0.003 in. (0.48 ± 0.08 mm) at 50 Hz.

11.1.7 Vibrate the mold assembly and specimen for 8.00 ± 0.25 min at 60 ± 2 Hz or for 10.00 ± 0.25 min at 50 ± 2 Hz. Remove the surcharge weight and guide sleeve from the mold. Check that the surcharge base plate is firmly and uniformly in contact with the surface of the soil; that is, does not wobble when pressed at the edges. If it wobbles, this should be noted on the report form (data sheet).

11.1.8 To obtain and record dial indicator gauge readings on opposite sides of the surcharge base plate, place the indicator gauge holder in each of the guide brackets. Brush aside any fines that might have collected on the surcharge base plate where these readings will be taken.

11.1.9 Remove the surcharge base plate from the mold and detach the mold from the vibratory table. During this step, prevent (as much as possible) any fines that have collected on the surfaces of the surcharge base plate and the rim of the mold from entering the mold. If the mass of these fines is greater than 0.2 % of the total mass of the specimen, determine the mass and note it on the report form (data sheet).

11.1.10 Determine and record the mass of the mold and soil using a balance meeting the requirements of 6.3. To calculate and record the mass of the soil filling the mold, subtract the mass of the empty mold from the mass of the mold and soil. Alternately, the contents of the mold may be emptied into a pan and the mass determined. Calculate the maximum-index density/unit weight, $\rho_{dmax,n}$, in accordance with Section 12.

11.1.11 Steps 11.1.1 – 11.1.10 should be repeated until consistent values of maximum index density/unit weight (within 2 %) are obtained. If excessive degradation (particle breakdown) of the soil is suspected, a sufficient quantity of representative soil sample should be provided (if possible), so that a single test specimen is not repeatedly subjected to step 11.1.7.

11.2 *Wet Method*—Methods 1B or 2B:

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

NOTE 5—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.

$$M_w = M_s \cdot \left(\frac{\rho_w - 1}{\rho_d - G_s} \right) \tag{9}$$

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.

11.2.2 Attach the mold to the vibrating table.

11.2.3 With the vibrating table turned on, slowly fill the mold with wet soil using a scoop or shovel. After each increment of soil is added, inspect to see if a small amount of free water has accumulated on the soil surface. If not, add a sufficient amount of water by squeezing from a sponge, pouring from a small container, or by other means. During this process, which is to take 5 to 6 minutes, the double amplitude or the frequency or both, of vibration must be adjusted to prevent excessive boiling and fluffing of the soil. During and just after the final minute of vibration, any water appearing above the surface of the soil should be removed using means which prevent, as much as possible, the removal of soil.

11.2.4 Assemble the surcharge base plate, surcharge weight, and guide sleeve as specified in 11.1.3 and 11.1.5.

11.2.5 Vibrate the mold assembly and specimen as specified in 11.1.6 – 11.1.7. After the vibration period, remove the surcharge weight and guide sleeve from the mold. Remove any free water appearing above, on, and around the surcharge base plate.

11.2.6 Obtain and record dial indicator-gauge readings in accordance with 11.1.8.

11.2.7 Remove the surcharge base plate and detach the mold from the vibratory table in accordance with 11.1.9. If a determination of the specimen water content is desired, determine and record the mass of the mold and soil. 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 bottom of the base plate into the pan. Dry the specimen in a drying oven, maintained at 110 ± 5°C to a constant mass (Test Method D2216). Determine and record its oven-dried mass, using a balance meeting the requirements of 6.3.

11.2.8 Steps 11.2.2 – 11.2.7 should be repeated until consistent values of maximum index density/unit weight (within 2 %) are obtained. If excessive degradation (particle breakdown) of the soil is suspected, a sufficient quantity of representative soil sample should be provided (if possible), so that a single test specimen is not repeatedly subjected to step 11.2.5.

12. Calculation

12.1 Calculate the maximum index density for each trial (see 11.1.11 or 11.2.8) as follows:

$$\rho_{\mathrm{dmax,n}} = \frac{M_s}{V} \tag{10}$$

where:

$\rho_{\mathrm{dmax,n}}$ = maximum index density for given trial, Mg/m^3 or g/cm^3
M_s = mass of the tested-dry soil, Mg or g, and
V = volume of the tested-dry soil, m^3 or cm^3, being equal to:

$$V = V_c - (A_c \cdot H \cdot \text{Conversion Factor}) \tag{11}$$

with: Conversion Factor given in Table 3; and

V_c = calibrated volume of mold, m^3 or cm^3,
A_c = calibrated cross sectional area of mold, m^2 or cm^3, and
H = positive difference in elevation between top surfaces of mold and tested soil (bottom surface of surcharge base plate), m or cm, being equal to:,

$$H = R_f - R_i + T_p \text{ for clockwise} - \text{reading dial indicator, or} \tag{12}$$

$$H = R_i - R_f + T_p \text{ for counterclockwise} - \text{reading dial indicator.}$$

$$H = |R_i - R_f| + T_p$$

with:

R_i = initial dial reading (see 10.4), mm or in.,
R_f = average of final dial gauge readings on opposite sides of the surcharge base plate after completion of the vibration period, mm or in., and
T_p = thickness of surcharge base plate, mm or in.

12.1.1 Calculate the average maximum-index density/unit weight from the trials of the dry method that agree within 2 %, see 11.1.11. This average value is to recorded/reported as the maximum-index density, ρ_{dmax}.

12.1.1.1 If it is established that the wet method produces a maximum–index density/unit weight higher than the dry method and this higher value would significantly affect its application, then the result of the wet method should be used.

12.1.2 If requested, calculate the maximum-index unit weight of the specimen as follows:

$$\gamma_{\mathrm{dmax}} = 9.807 \cdot \rho_{\mathrm{dmax}},\ \mathrm{kN/m^3}\text{ , or} \tag{13}$$

$$\gamma_{\mathrm{dmax}} = 62.428 \cdot \rho_{\mathrm{dmax}},\ \mathrm{lbf/ft^3}$$

where:

γ_{dmax} = maximum-index unit weight, kN/m^3 or lbf/ft^3
9.807 = conversion factor, Mg/m^3 or g/cm^3 to kN/m^3, and
62.428 = conversion factor, Mg/m^3 or g/cm^3 to lbf/ft^3.

NOTE 6—ρ_{dmax} is the average value if Method 1A or 2A is used, see 12.1.1.

12.2 If requested, calculate the minimum-index void ratio, e_{min}, as follows:

$$e_{\mathrm{min}} = \frac{\rho_w \cdot G_{\mathrm{avg}}}{\rho_{\mathrm{dmax}}} - 1 \tag{14}$$

TABLE 3 Dial Reading Conversion Factors for Volume Calculations

Volume Requirements	Factor	
	Dial Reading Units	
	mm	in.
m^3	0.001	0.0254
cm ^{3}	0.1	0.2540

where:

e_{min} = minimum-index void ratio,
ρ_w = density of water at 20°C (0.99821) or equal to 1 Mg/m^3 or g/cm^3,
ρ_{dmax} = maximum-index density, Mg/m^3 or g/cm^3, and
$G_{avg@20°C}$ = weighted average specific gravity of soil solids composed of particles larger and smaller than the No. 4 (4.75-mm) sieve being equal to:

$$G_{avg\ @20°C} = \frac{1}{\dfrac{R}{100G_{1\ @20°C}} + \dfrac{P}{100G_{2\ @20°C}}} \qquad (15)$$

with:

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

12.3 If the minimum index density/unit weight, ρ_{dmin} or γ_{dmin}, has been determined in accordance with Test Methods D4254; 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 by any of the equations given in 3.2.7, that is, Equations 1, 2, or 3.

13. Report: Test Data Sheet(s)/Forms

13.1 The methodology used to specify how data are recorded on the test data sheet(s)/form(s), as given below, is covered in 1.9.

13.2 Record as a minimum the following information:

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

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

13.2.3 Any special selection and preparation processes used.

13.2.4 Method(s) (1A, 1B, 2A, or 2B) used.

13.2.5 Mass, height, and diameter of mold.

13.2.6 Double amplitude of vertical vibration used if different from that specified in 11.1.6.1 or 11.1.6.2.

13.2.7 Mass and height of specimens.

13.2.8 Thickness of the surcharge plate, initial and final dial gauge readings.

13.2.9 The maximum index density, ρ_{dmax}, Mg/m^3 or g/cm^3 or maximum-index unit weight, γ_{dmax} in lbf/ft^3 (kN/m^3), or both, to four significant digits (in accordance with Practice D6026).

13.2.10 Any testing abnormalities such as loss of material, segregation, or excessive tilt of base plate.

14. Precision and Bias

14.1 *Precision*—Criteria for judging the acceptability of test results obtained by these test methods, using Method 1A and testing a poorly graded sand (SP), is given in Tables 4 and 5. These estimates of precision are based on the results of the interlaboratory program conducted by the ASTM Reference Soils and Testing Program.[4] In this program, some laboratories performed three replicate tests per soil type (triplicate test laboratory), while other laboratories performed a single test per soil type (single-test laboratory). A description of the soil tested is given in 14.1.4. The precision estimates may vary with soil type and method used (Method 1A, 1B, 2A, 2B). Judgment is required when applying these estimates to another soil or method.

14.1.1 The data in Table 4 are based on three replicate tests performed by each triplicate test laboratory on the SP sand. The single operator and multilaboratory standard deviation shown in Table 4, Column 4 were obtained in accordance with Practice E691, which recommends each testing laboratory perform a minimum of three replicate tests. Results of two properly conducted tests performed by the same operator on the same material, using the same equipment, and in the shortest practical period of time should not differ by more than the single-operator d2*s* limits shown in Table 4, Column 5. For definition of d2*s* see Footnote C in Table 4. Results of two properly conducted tests performed by different operators and on different days should not differ by more than the multilaboratory d2s limits shown in Table 4, Column 5.

14.1.2 In the ASTM Reference Soils and Testing Program, many of the laboratories performed only a single test. This is common practice in the design and construction industry. The data in Table 5 are based upon the first test results from the triplicate test laboratories and the single test results from the other laboratories. Results of two properly conducted tests performed by two different laboratories with different operators using different equipment and on different days should not vary

TABLE 4 Summary of Test Results from Triplicate Test Laboratories (Maximum Index Unit Weight)

(1) Soil Type	(2) Number of Triplicate Test Labs	(3) Average Value[A] (lbf/ft^3)	(4) Standard Deviation[B] (lbf/ft^3)	(5) Acceptable Range of Two Results[C] (lbf/ft^3)
Single-Operator Results (Within-Laboratory Repeatability):				
SP	8	117.3	0.6	1.5
Multilaboratory Results (Between-Laboratory Reproducibility):				
SP	8	117.3	1.0	2.7

[A] The number of significant digits and decimal places presented are representative of the input data. In accordance with Practice D6026, the standard deviation and acceptable range of results cannot have more decimal places than the input data.
[B] Standard deviation is calculated in accordance with Practice E691 and is referred to as the 1s limit.
[C] Acceptable range of two results is referred to as the d2s limit. It is calculated as $1.960\sqrt{2}\cdot 1s$, as defined by Practice E177. The difference between two properly conducted tests should not exceed this limit. The number of significant digits/decimal places presented is equal to that prescribed by these test methods or Practice D6026. In addition, the value presented can have the same number of decimal places as the standard deviation, even if that result has more significant digits than the standard deviation.

---

[4] Supporting data are available from ASTM Headquarters. Request RR:D18-1011.

TABLE 5 Summary of Single Test Result from Each Laboratory (Maximum Index Unit Weight)[A]

(1) Soil Type	(2) Number of Test Labs	(3) Average Value (lbf/ft^3)	(4) Standard Deviation (lbf/ft^3)	(5) Acceptable Range of Two Results (lbf/ft^3)
Multilaboratory Results—Reproducibility (Single Test Performed by Each Laboratory):				
SP	12	116.9	1.8	5.1

[A] See footnotes in Table 4.

by more than the d2*s*limits shown in Table 5, Column 5. The results in Tables 4 and 5 are dissimilar because the data sets are different.

14.1.3 Table 4 presents a rigorous interpretation of triplicate test data in accordance with Practice E691 from pre-qualified laboratories. Table 5 is derived from test data that represents common practice.

14.1.4 *Soil Type*—Based on the multilaboratory test results, the soil used in the program is described below in accordance with Practice D2487. In addition, the local name of the soil is given.

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

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

15. Keywords

15.1 maximum index density; maximum index unit weight; relative density; vibrating table

SUMMARY OF CHANGES

In accordance with Committee D18 policy, this section identifies the location of changes to this standard since the last edition (00 (Reapproved 2006)) that may impact its use.

(1) D422 was replaced with D6913.
(2) Many of the fractions were replaced by decimals.
(3) Digital dial indicators are allowed.
(4) Special testing using alternate amplitudes has been eliminated thereby eliminating the appendix. The user may perform tests at amplitudes other than the standard, but it is not part of this test method.
(5) The requirement that the table be able to obtain amplitudes other than the standard amplitude has been removed.
(6) Equipment for calibrating the amplitude has been included and description of the calibration method has been added.
(7) The requirement to measure the height of the mold when using the water-filling mold calibration method has been added.
(8) D6026 was added.
(9) The Report section has been revised.

استاندارد آزمایش چگالی منیمم

γ_{min}

ASTM-D4254-14

Designation: D4254 − 14

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

This standard is issued under the fixed designation D4254; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the U.S. Department of Defense.

1. Scope*

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

1.2 *System of Units:*

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

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

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

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

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

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

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

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

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

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

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

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

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

---

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

Current edition approved Dec. 15, 2014. Published January 2015. Originally approved in 1983. Last previous edition approved in 2006 as D4254 – 00 (2006)$^{\epsilon 1}$. DOI: 10.1520/D4254-14.

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

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

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

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

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

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

1.7 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[3]

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

D653 Terminology Relating to Soil, Rock, and Contained Fluids

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

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

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

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

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

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

D4753 Guide for Evaluating, Selecting, and Specifying Balances and Standard Masses for Use in Soil, Rock, and Construction Materials Testing

D6026 Practice for Using Significant Digits in Geotechnical Data

D6913 Test Methods for Particle-Size Distribution (Gradation) of Soils Using Sieve Analysis

E11 Specification for Woven Wire Test Sieve Cloth and Test Sieves

E177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods

E691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method

3. Terminology

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

3.2 *Definitions of Terms:*

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

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

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

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

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

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

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

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

$$D_d = \frac{e_{max} - e}{e_{max} - e_{min}} \times 100 \tag{1}$$

or, in terms of corresponding dry densities:

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

or, in terms of corresponding dry unit weights:

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

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

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

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

or, in terms of corresponding dry unit weights:

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

---

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

4. Summary of Test Method

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

5. Significance and Use

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

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

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

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

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

NOTE 2—The quality of the result produced by this standard is dependent on the competence of the personnel performing it, and the suitability of the equipment and facilities used. Agencies that meet the criteria of Practice D3740, generally, are considered capable of competent and objective testing/sampling/inspection/etc. Users of this standard are cautioned that compliance with Practice D3740 does not in itself assure reliable results. Reliable results depend on many factors; Practice D3740 provides a means of evaluating some of those factors.

6. Apparatus

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

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

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

6.2 *Apparatus for Methods A and B:*

6.2.1 *Standard Molds*—Cylindrical metal molds having nominal volumes of 0.1000 ft^3 (2830 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.

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

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

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

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

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

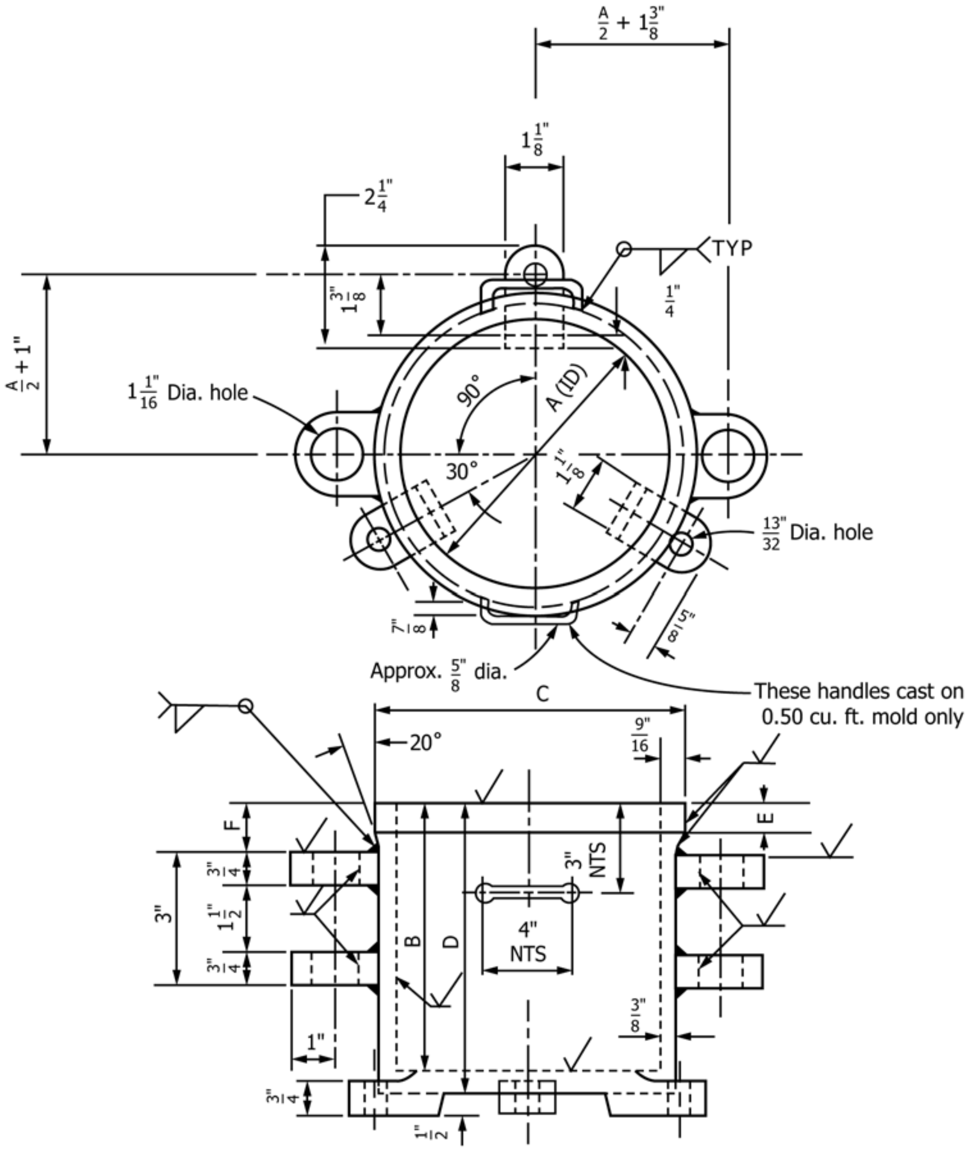
6.2.4 *Pouring Devices,* are used in conjunction with the 0.100 ft^3 (2830 cm^3) standard mold and with special molds. Pouring devices consist of relatively rigid containers having volumes about 1.25 to 2 times greater than the volumes of the mold(s) used, and fitted with spouts or tubes about 6 in.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

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

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

---

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



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

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

FIG. 1 Details of Molds

6.3 *Apparatus for Method C:*

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

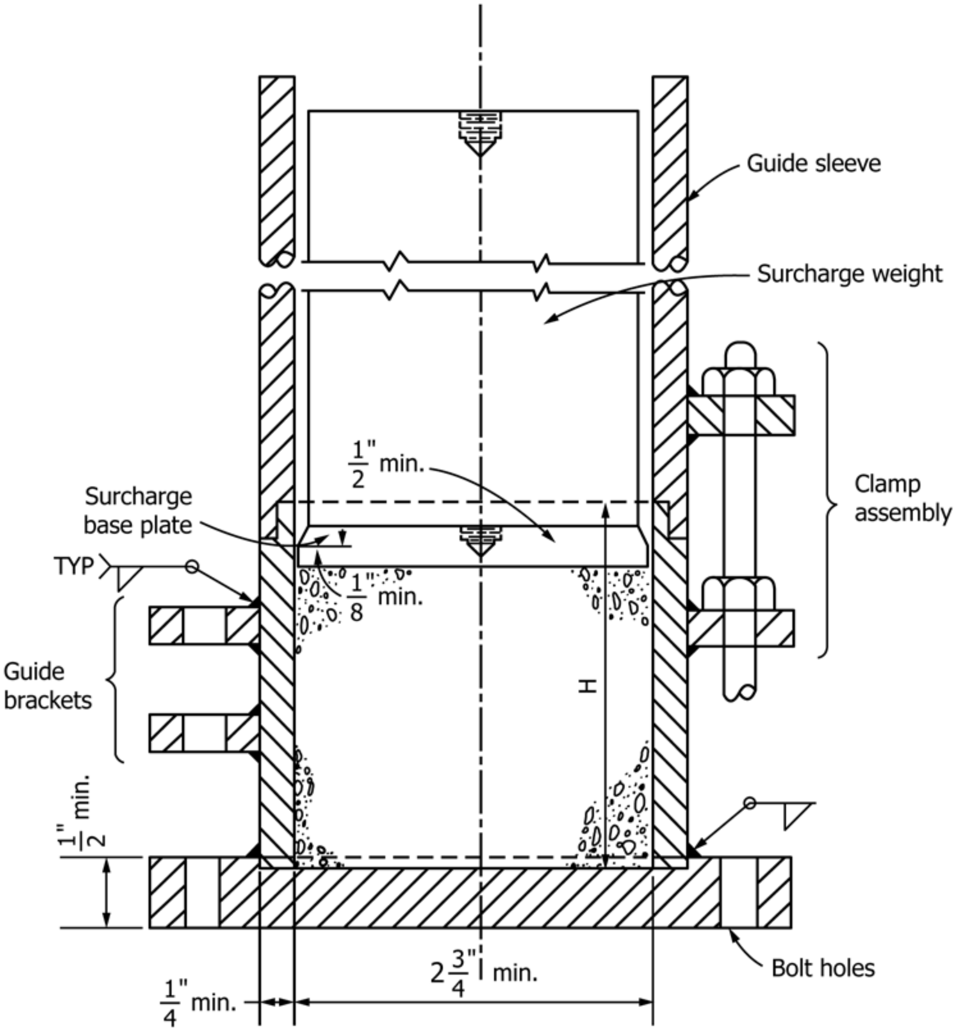
6.3.2 *Balance,* of at least 2 kg capacity and otherwise consistent with 6.2.3.3.

6.3.3 *Sieves,* 3⁄8-in. (9.5-mm), No. 10 (2.00-mm), and No. 200 (75-µm) sieves conforming to the requirements of Specification E11.

7. Sampling and Test Specimen

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

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



H = (0.7 to 1.3) times diameter

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

FIG. 2 Special Cylindrical Metal Molds

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

7.3.1 Using a visual method or Test Method D6913 (depending upon the complexity of the gradation of the sample and operator experience, determine the percentage of particles retained on the 3-in. (75-mm), 1½-in. (37.5-mm), ¾-in.

TABLE 1 Required Mass of Specimen

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

(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:

$$M_r = 0.0024 \cdot V_m \tag{6}$$

where:

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

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

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

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

8. Calibration

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

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

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

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

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

9. Procedure

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

9.2 *Method A:*

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

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

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

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

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

layer of nearly uniform thickness. Spiraling motion should be just sufficient to minimize particle segregation.

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

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

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

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

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

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

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

9.3 *Method B:*

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

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

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

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

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

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

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

9.4 *Method C*[2]:

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

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

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

10. Calculation

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

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

where:

$\rho_{dmin,n}$ = minimum index density for given trial, Mg/m^3 or g/cm^3

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

V = volume of the tested-dry soil, m^3 or cm^3. For Methods A and B, $V=V_c$ or calibrated volume of mold; and for Method C, $V=V_g$ (see 9.4.2)

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

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

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

or

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

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

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

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

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

where:

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

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

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

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

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

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

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

11.1.4 Mass, height and diameter of mold.

11.1.5 Mass of specimens.

11.1.6 Any testing abnormalities noticed.

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

12. Precision and Bias[5]

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

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

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

[A] The number of significant digits and decimal places presented are representative of the input data. In accordance with Practice D6026, the standard deviation and acceptable range of results can not have more decimal places than the input data.

[B] Standard deviation is calculated in accordance with Practice E691 and is referred to as the 1*s* limit.

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

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

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

[A] See Footnotes in Table 3.

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

12.1.2 In the ASTM Reference Soils and Testing Program, many of the laboratories performed only a single test. This is common practice in the design and construction industry. The data in Table 4 are based upon the first test results from the triplicate test laboratories and the single test results from the other laboratories. Results of two properly conducted tests performed by two different laboratories with different operators using different equipment and on different days should not vary by more than the d2*s* limits shown in Table 4, Column 5. The results in Table 3 and Table 4 are dissimilar because the data sets are different.

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

12.1.4 *Soil Type:*

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

---

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

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

13. Keywords

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

SUMMARY OF CHANGES

In accordance with D18 policy, this section identifies the location of changes to this standard since the last edition (91(Reapproved 2006$^{\epsilon 1}$)) that may impact the use of this standard:

(1) Replaced Test Method D422 with Test Method D6913.
(2) Replaced most fractions with decimals.
(3) Corrected an error in Table 2.
(4) Corrected errors in the subscripts of many equations.
(5) Added Practice D6026.
(6) Revised Section 11 (Reports).

استاندارد آزمایش چگالی ماکزیمم

خشک— $\gamma_{d(max)}$

ASTM-D7382-08

Designation: D 7382 – 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]

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 D 4718.

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 D 698 or D 1557) 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 D 4718, 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 D 4718.

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 D 4718.

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; therefore, each system shall be used independently of the other.

---

[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.

Current edition approved Nov. 1, 2008. Published November 2008. Originally approved in 2007. Last previous edition approved in 2007 as D 7382 – 07.

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

Combining values from the two systems may result in nonconformance 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]

C 127 Test Method for Density, Relative Density (Specific Gravity), and Absorption of Coarse Aggregate
C 136 Test Method for Sieve Analysis of Fine and Coarse Aggregates
C 778 Specification for Standard Sand
D 422 Test Method for Particle-Size Analysis of Soils
D 653 Terminology Relating to Soil, Rock, and Contained Fluids
D 698 Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (12 400 ft-lbf/ft^3(600 kN-m/m^3))
D 854 Test Methods for Specific Gravity of Soil Solids by Water Pycnometer
D 1140 Test Methods for Amount of Material in Soils Finer than No. 200 (75-μm) Sieve
D 1557 Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort (56,000 ft-lbf/ft^3(2,700 kN-m/m^3))
D 2216 Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass
D 2487 Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)
D 2488 Practice for Description and Identification of Soils (Visual-Manual Procedure)
D 3282 Practice for Classification of Soils and Soil-Aggregate Mixtures for Highway Construction Purposes
D 3740 Practice for Minimum Requirements for Agencies Engaged in Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction
D 4220 Practices for Preserving and Transporting Soil Samples
D 4253 Test Methods for Maximum Index Density and Unit Weight of Soils Using a Vibratory Table
D 4254 Test Methods for Minimum Index Density and Unit Weight of Soils and Calculation of Relative Density
D 4318 Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils
D 4718 Practice for Correction of Unit Weight and Water Content for Soils Containing Oversize Particles
D 4753 Guide for Evaluating, Selecting, and Specifying Balances and Standard Masses for Use in Soil, Rock, and Construction Materials Testing
D 6026 Practice for Using Significant Digits in Geotechnical Data
E 11 Specification for Wire Cloth and Sieves for Testing Purposes
E 145 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 D 653.

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. Each layer is compacted for a given amount of time by a vibrating hammer that applies vibration and surcharge to the

---

[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.

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 D 3740 are generally considered capable of competent and objective testing/sampling/inspection, and the like. 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 *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.

6.2 *Mold Assembly*—The molds shall be cylindrical in shape, made of rigid metal and be within the capacity and

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	8.8	7.9	8.6
	(10 m·N)	(12 m·N)	(11 m·N)	(12 m·N)
Length (in.)	18	17.75	17.5	18.5
	(46 cm)	(45 cm)	(44 cm)	(47 cm)
Weight (lb)	14.4	12.5	12.9	15
	(64 N)	(56 N)	(57 N)	(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.

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:

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 D 4753 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 D 4753 for Class GP 100 (readability of 50 g).

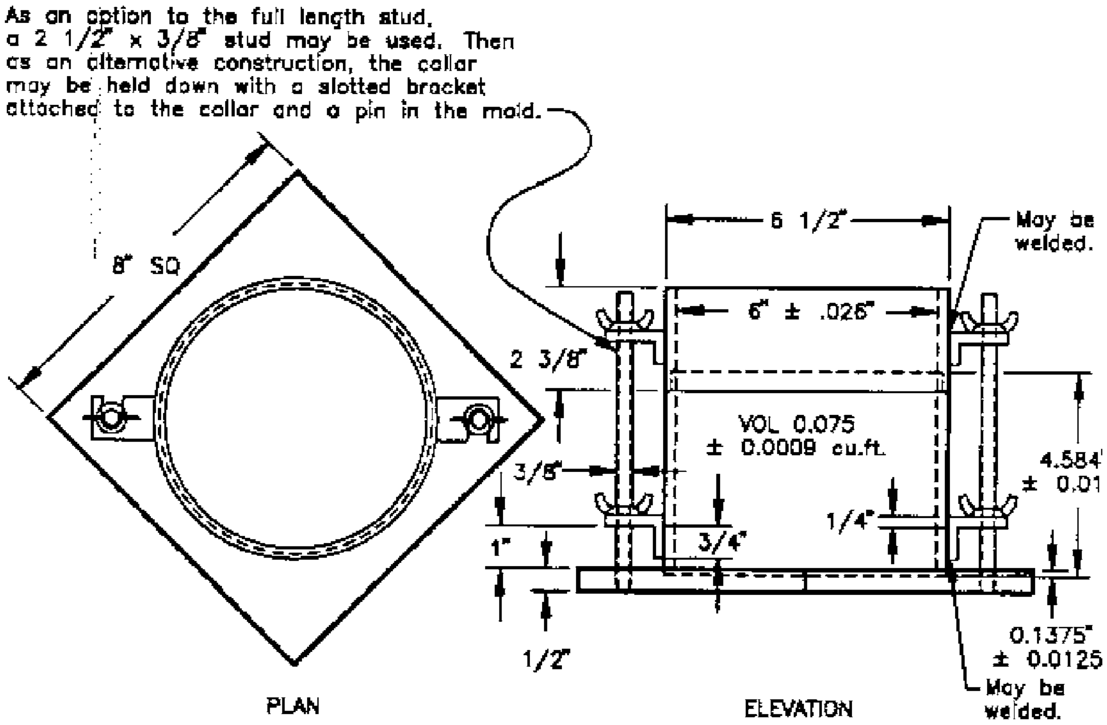
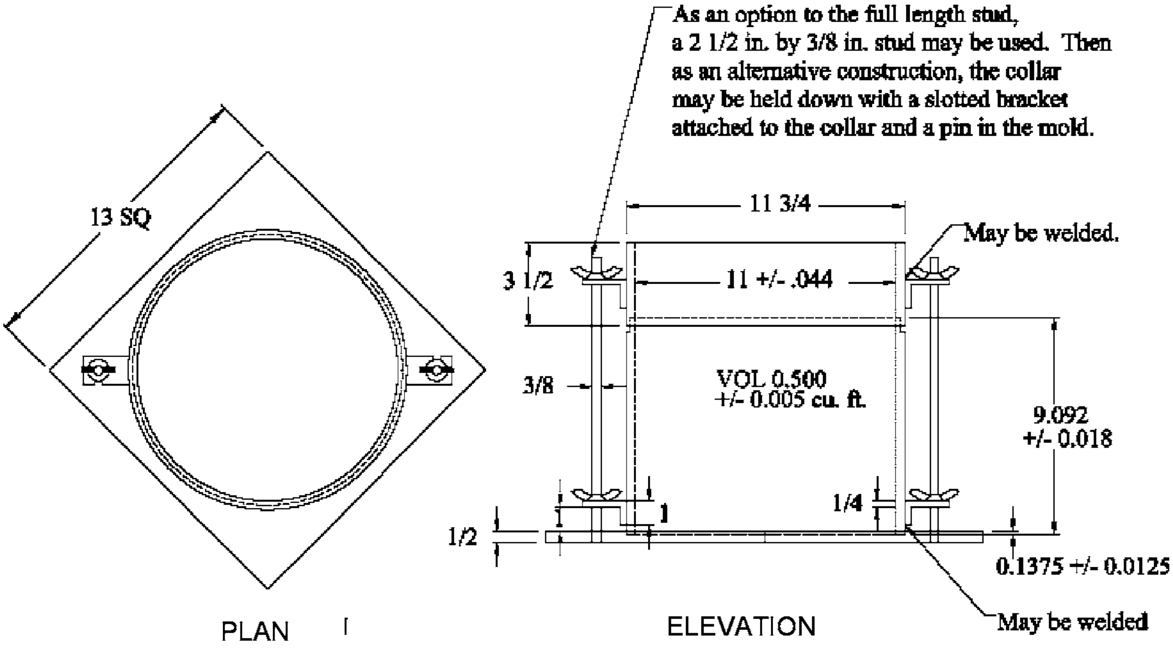


FIG. 1 6.0-in. Cylindrical Mold (see Table 2 for SI equivalent dimensions)



NOTE—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	ft^3	cm^3
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		

6.6 *Drying Oven*—Thermostatically controlled, preferably of a forced-draft type, meeting the requirements of Specification E 145 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 E 11.

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.

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 of the field sample. If this is the case, determine the water content in accordance with Test Method D 2216.

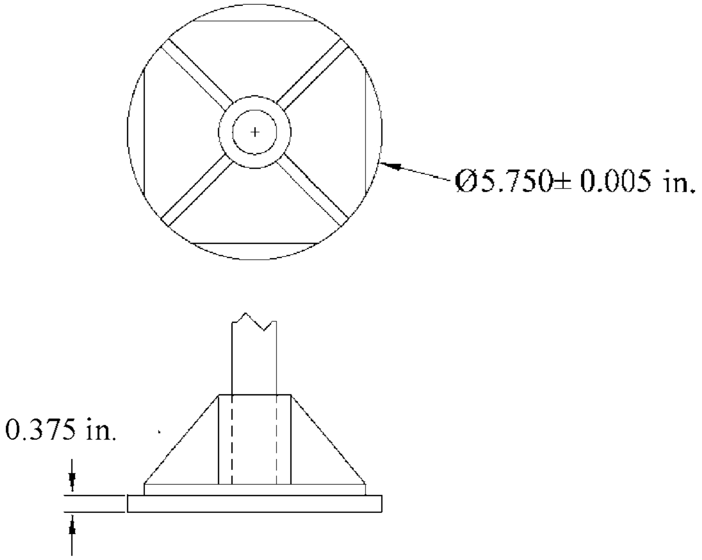
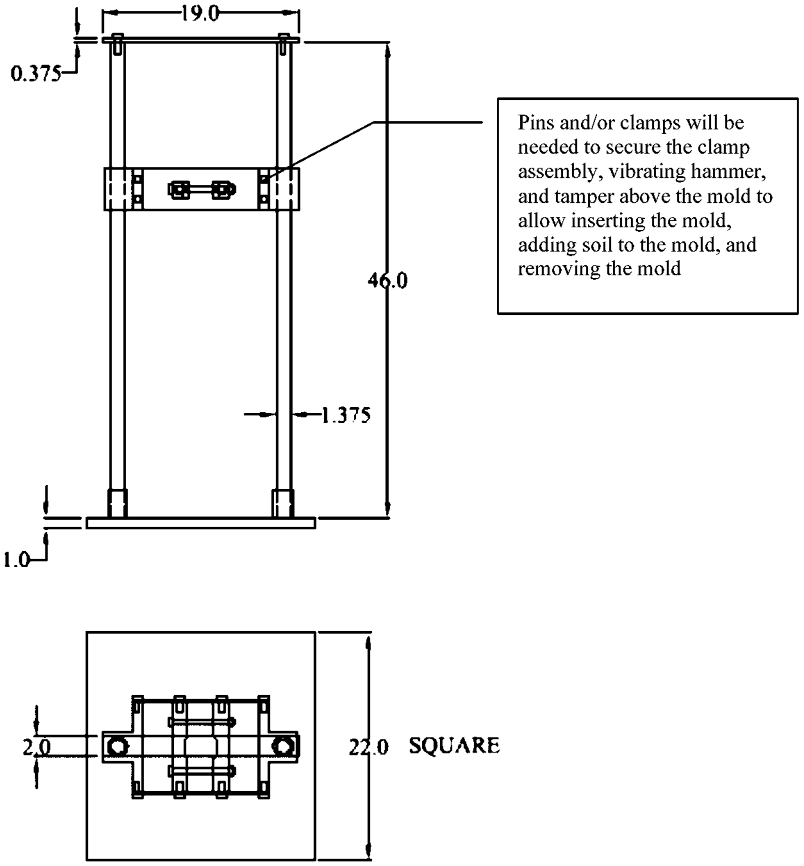


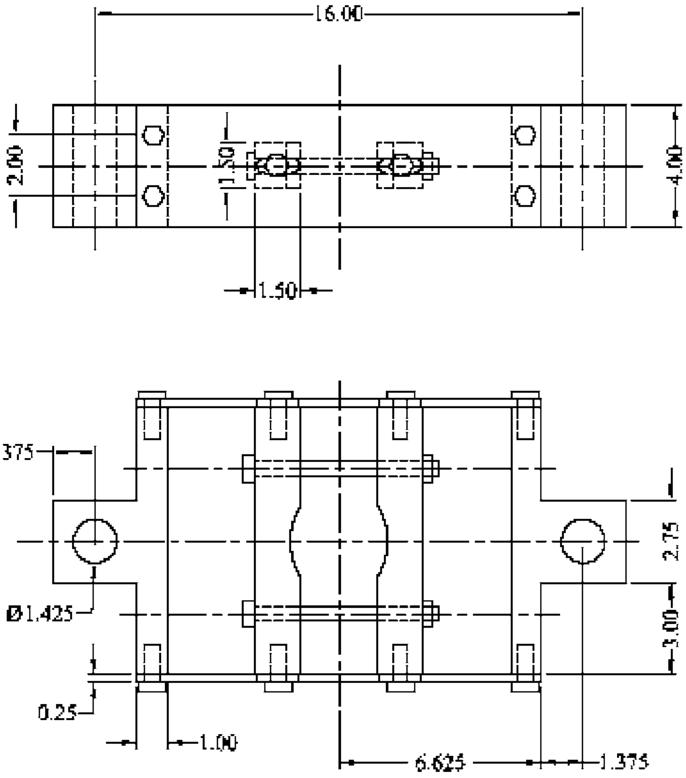
FIG. 3 6-in. Tamper (see Table 2 for SI equivalent dimensions)



Pins and/or clamps will be needed to secure the clamp assembly, vibrating hammer, and tamper above the mold to allow inserting the mold, adding soil to the mold, and removing the mold

NOTE—All dimensions are in inches.

FIG. 4 Hammer Frame



NOTE—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

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 D 4753.

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,

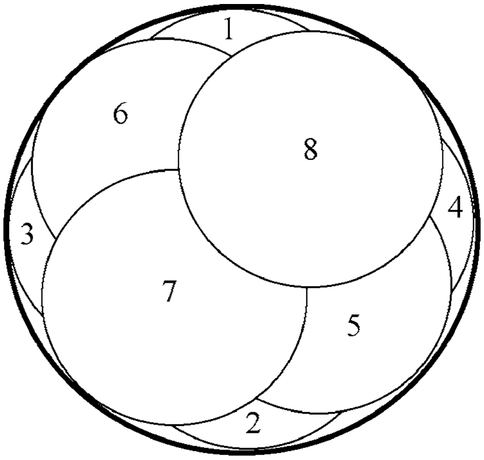


FIG. 6 Sequence of 6-in. Tamper Positions in 11-in. Mold

maintained at 110 ± 5°C to a constant mass (Test Method D 2216). 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:

$$\rho_d = \frac{M_s}{V} \tag{1}$$

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:

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

or

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

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 D 4718.

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:

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

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 D 854) 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 D 3282, or Practice D 2488 (Practice D 2487 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:

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

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

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.

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 C 778.

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 (D 7382 – 07) that may impact the use of this standard. (Approved Nov. 1, 2008.)

(*1*) Revised Section 6.3.

Designation: D 1556 – 07

Standard Test Method for Density and Unit Weight of Soil in Place by Sand-Cone Method[1]

This standard is issued under the fixed designation D 1556; 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 Department of Defense.

1. Scope*

1.1 This test method may be used to determine the in-place density and unit weight of soils using a sand cone apparatus.

1.2 This test method is applicable for soils without appreciable amounts of rock or coarse materials in excess of 1½ in. (38 mm) in diameter.

1.3 This test method may also be used for the determination of the in-place density and unit weight of intact or *in situ* soils, provided the natural void or pore openings in the soil are small enough to prevent the sand used in the test from entering the voids. The soil or other material being tested should have sufficient cohesion or particle attraction to maintain stable sides on a small hole or excavation, and be firm enough to withstand the minor pressures exerted in digging the hole and placing the apparatus over it, without deforming or sloughing.

1.4 This test method is not suitable for organic, saturated, or highly plastic soils that would deform or compress during the excavation of the test hole. This test method may not be suitable for soils consisting of unbound granular materials that will not maintain stable sides in the test hole, soils containing appreciable amounts of coarse material larger than 1½ in. (38 mm), and granular soils having high void ratios.

1.5 When materials to be tested contain appreciable amounts of particles larger than 1½ in. (38 mm), or when test hole volumes larger than 0.1 ft^3 (2830 cm^3) are required, Test Method D 4914 or D 5030 are applicable.

1.6 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, the use of balances or scales recording pounds of mass (lbm), or the recording of density in lbm/ft^3 should not be regarded as nonconformance with this test method.

1.7 All observed and calculated values shall conform to the guidelines for significant digits and rounding established in Practice D 6026 unless superseded by this standard.

1.7.1 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 or 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.

1.8 *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]

D 653 Terminology Relating to Soil, Rock, and Contained Fluids

D 698 Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (12 400 ft-lbf/ft^3(600 kN-m/m^3))

D 1557 Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort (56,000 ft-lbf/ft^3 (2,700 kN-m/m^3))

D 2216 Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass

D 3740 Practice for Minimum Requirements for Agencies Engaged in the Testing and/or Inspection of Soil and Rock

---

[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.

Current edition approved Sept. 15, 2007. Published October 2007. Originally approved in 1958. Last previous edition approved in 2000 as D 1556 – 00.

[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.**

as Used in Engineering Design and Construction

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

D 4254 Test Methods for Minimum Index Density and Unit Weight of Soils and Calculation of Relative Density

D 4643 Test Method for Determination of Water (Moisture) Content of Soil by the Microwave Oven Method

D 4718 Practice for Correction of Unit Weight and Water Content for Soils Containing Oversize Particles

D 4753 Guide for Evaluating, Selecting, and Specifying Balances and Standard Masses for Use in Soil, Rock, and Construction Materials Testing

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

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

D 4959 Test Method for Determination of Water (Moisture) Content of Soil By Direct Heating

D 5030 Test Method for Density of Soil and Rock in Place by the Water Replacement Method in a Test Pit

D 6026 Practice for Using Significant Digits in Geotechnical Data

3. Terminology

3.1 *Definitions:* For definitions of terms in this standard, refer to Terminology D 653.

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 A test hole is hand excavated in the soil to be tested and all the material from the hole is saved in a container. The hole is filled with free flowing sand of a known density, and the volume is determined. The in-place wet density of the soil is determined by dividing the wet mass of the removed material by the volume of the hole. The water content of the material from the hole is determined and the dry mass of the material and the in-place dry density are calculated using the wet mass of the soil, the water content, and the volume of the hole.

5. Significance and Use

5.1 This test method is used to determine the density and water content of compacted soils placed during the construction of earth embankments, road fill, and structural backfill. It often is used as a basis of acceptance for soils compacted to a specified density or percentage of a maximum density determined by a test method, such as Test Methods D 698 or D 1557.

5.1.1 Test Methods D 698 and D 1557 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 can be used to determine the in-place density of natural soil deposits, aggregates, soil mixtures, or other similar material.

5.3 The use of this test method is generally limited to soil in an unsaturated condition. This test method is not recommended for soils that are soft or friable (crumble easily) or in a moisture condition such that water seeps into the hand excavated hole. The precision of the test may be affected for soils that deform easily or that may undergo a volume change in the excavated hole from vibration, or from standing or walking near the hole during the test (see Note 1).

NOTE 1—When testing in soft conditions or in soils near saturation, volume changes may occur in the excavated hole as a result of surface loading, personnel performing the test, and the like. This can sometimes be avoided by the use of a platform that is supported some distance from the hole. As it is not always possible to detect when a volume change has taken place, test results should always be compared to the theoretical saturation density, or the zero air voids line on the dry density versus water content plot. Any in-place density test on compacted soils that calculates to be more than 95 % saturation is suspect and an error has probably occurred, or the volume of the hole has changed during testing.

NOTE 2—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 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.

6. Apparatus

6.1 *Sand-Cone Density Apparatus*, consisting of sand container, sand cone, and base plate.

6.1.1 *Sand Container*, an attachable jar or other sand container having a volume capacity in excess of that required to fill the test hole and sand cone during the test.

6.1.2 *Sand Cone*, a detachable appliance consisting of a cylindrical valve with an orifice approximately ½ in. (13 mm) in diameter, attached to a metal funnel and sand container on one end, and a large metal funnel (sand-cone) on the other end. The valve will have stops to prevent rotating past the completely open or completely closed positions. The appliance will be constructed of metal sufficiently rigid to prevent distortion or volume changes in the cone. The walls of the cone will form an angle of approximately 60° with the base to allow uniform filling with sand.

6.1.3 *Base Plate*, a metal base plate or template with a flanged center hole cast or machined to receive the large funnel (cone) of the appliance described in 6.1.2. The base plate may be round or square and will be a minimum of 3 in. (75 mm) larger than the funnel (sand-cone). The plate will be flat on the bottom and have sufficient thickness or stiffness to be rigid. Plates with raised edges, ridges, ribs, or other stiffeners of approximately ⅜ to ½ in. (10 to 13 mm) high may be used.

6.1.4 The mass of the sand required to fill the sand cone and base plate will be determined in accordance with the instructions in Annex A1 prior to use.

6.1.5 The details for the apparatus shown in Fig. 1 represents the minimum acceptable dimensions suitable for testing soils having maximum particle sizes of approximately 1½ in.

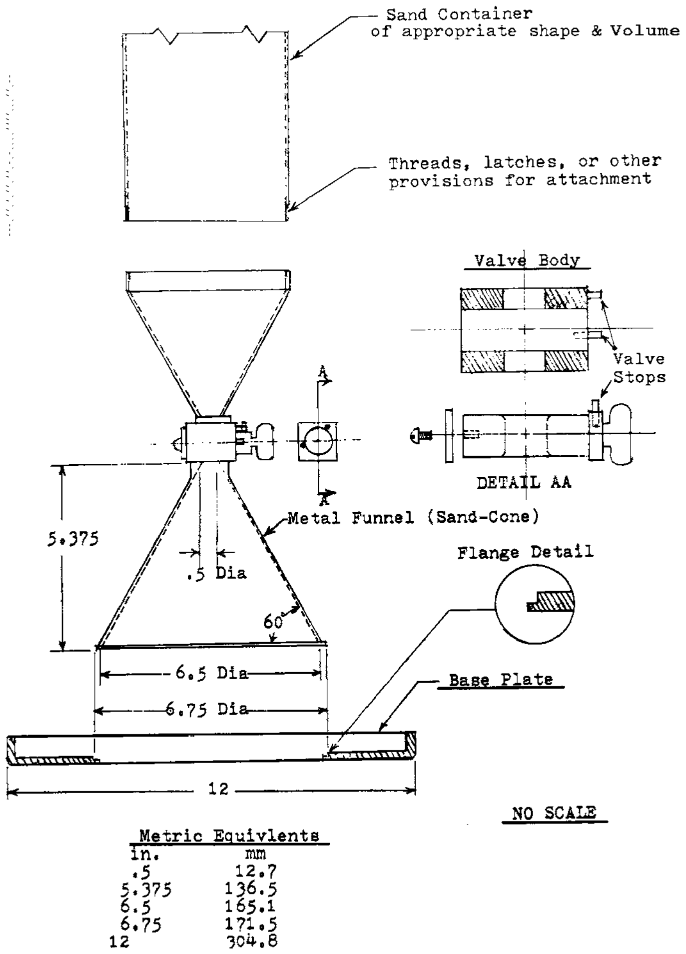


FIG. 1 Density Apparatus

(38 mm) and test hole volumes of approximately 0.1 ft^3 (2830 cm^3). When the material being tested contains a small amount of oversize and isolated larger particles are encountered, the test should be moved to a new location. Larger apparatus and test hole volumes are needed when particles larger than 1½ in. (38 mm) are prevalent. The apparatus described here represents a design that has proven satisfactory. Larger apparatus, or other designs of similar proportions may be used as long as the basic principles of the sand volume determination are observed. When test hole volumes larger than 0.1 ft^3 (5660 cm^3) are required Test Method D 4914 should be utilized.

6.2 *Sand*—Sand must be clean, dry, uniform in density and grading, uncemented, durable, and free-flowing. Any gradation may be used that has a uniformity coefficient ($C_u = D_{60}/D_{10}$) less than 2.0, a maximum particle size smaller than 2.0 mm (No. 10 sieve), and less than 3 % by weight passing 250 µm (No. 60 sieve). Uniformly graded sand is needed to prevent segregation during handling, storage, and use. Sand free of fines and fine sand particles is required to prevent significant bulk-density changes with normal daily changes in atmospheric humidity. Sand comprised of durable, natural subrounded, or rounded particles is desirable. Crushed sand or sand having angular particles may not be free-flowing, a condition that can cause bridging resulting in inaccurate density determinations (see Note 3). In selecting a sand from a potential source, a gradation and bulk-density determinations in accordance with the procedure in Annex A2 should be made on each container or bag of sand. To be an acceptable sand, the bulk-density variation between any one determination shall not be greater than 1 % of the average. Before using sand in density determinations, it shall be dried, then allowed to reach an air-dried state in the general location where it is to be used (see Note 4). Sand shall not be re-used without removing any contaminating soil, checking the gradation, drying and redetermining the bulk-density (see Note 5). Bulk-density tests of the sand will be made at time intervals not exceeding 14 days, always after any significant changes in atmospheric humidity, before reusing, and before use of a new batch from a previously approved supplier (see Note 6).

NOTE 3—Some manufactured (crushed) sands such as blasting sand have been successfully used with good reproducibility. The reproducibility of test results using angular sand should be checked under laboratory controlled testing situations before selecting an angular sand for use.

NOTE 4—Many organizations have found it beneficial to store sands in moisture resistant containers. Sand should be stored in dry areas protected from weather. The use of a lighted bulb or other heat source in, or adjacent to the storage containers has also been found to be beneficial in areas of high humidity.

NOTE 5—As a general rule, reclaiming sand after testing is not desirable.

NOTE 6—Most sands have a tendency to absorb moisture from the atmosphere. A very small amount of absorbed moisture can make a substantial change in bulk-density. In areas of high humidity, or where the humidity changes frequently, the bulk-density may need to be determined more often than the 14 day maximum interval indicated. The need for more frequent checks can be determined by comparing the results of different bulk-density tests on the same sand made in the same conditions of use over a period of time.

6.3 *Balances or Scales*—Meeting Specification D 4753, with 5.0 g readability, or better, to determine the mass of sand and excavated soils. A balance or scale having a minimum capacity of 20 kg (44 lbf) and 5 g (0.01 lbf) readability is suitable for determining the mass of the sand and the excavated soil when apparatus with the dimensions shown in Fig. 1 is used.

6.4 *Drying Equipment*—Equipment corresponding to the method used for determining water content as specified in Test Methods D 2216, D 4643, D 4959, or D 4944.

6.5 *Miscellaneous Equipment*—Knife, small pick, chisel, small trowel, screwdriver, or spoons for digging test holes, large nails or spikes for securing the base plate; buckets with lids, plastic-lined cloth sacks, or other suitable containers for retaining the density samples, moisture sample, and density sand respectively; small paint brush, calculator, notebook or test forms, etc.

7. Procedure

7.1 Select a location/elevation that is representative of the area to be tested, and determine the density of the soil in-place as follows:

7.1.1 Inspect the cone apparatus for damage, free rotation of the valve, and properly matched baseplate. Fill the cone container with conditioned sand for which the bulk-density has been determined in accordance with Annex A2, and determine the total mass.

7.1.2 Prepare the surface of the location to be tested so that it is a level plane. The base plate may be used as a tool for striking off the surface to a smooth level plane.

7.1.3 Seat the base plate on the plane surface, making sure there is contact with the ground surface around the edge of the flanged center hole. Mark the outline of the base plate to check for movement during the test, and if needed, secure the plate against movement using nails pushed into the soil adjacent to the edge of the plate, or by other means, without disturbing the soil to be tested.

7.1.4 In soils where leveling is not successful, or surface voids remain, the volume horizontally bounded by the funnel, plate and ground surface must be determined by a preliminary test. Fill the space with sand from the apparatus, determine the mass of sand used to fill the space, refill the apparatus, and determine a new initial mass of apparatus and sand before proceeding with the test. After this measurement is completed, carefully brush the sand from the prepared surface (see Note 7).

NOTE 7—A second calibrated apparatus may be taken to the field when this condition is anticipated (instead of refilling and making a second determination). The procedure in 7.1.4 may be used for each test when the best possible accuracy is desired, however, it is usually not needed for most production testing where a relatively smooth surface is obtainable.

7.1.5 The test hole volume will depend on the anticipated maximum particle size in the soil to be tested and the depth of the compacted layer. Test hole volumes are to be as large as practical to minimize the errors and shall not be less than the volumes indicated in Table 1. A hole depth should be selected that will provide a representative sample of the soil. For construction control, the depth of the hole should approximate the thickness of one, or more, compacted lift(s). The procedure for calibrating the sand must reflect this hole depth. See Annex A2.

7.1.6 Dig the test hole through the center hole in the base plate, being careful to avoid disturbing or deforming the soil that will bound the hole. The sides of the hole should slope slightly inward and the bottom should be reasonably flat or concave. The hole should be kept as free as possible of pockets, overhangs, and sharp obtrusions since these affect the accuracy of the test. Soils that are essentially granular require extreme care and may require digging a conical-shaped test hole. Place all excavated soil, and any soil loosened during digging, in a moisture tight container that is marked to identify the test number. Take care to avoid losing any materials. Protect this material from any loss of moisture until the mass has been determined and a specimen has been obtained for a water content determination.

7.1.7 Clean the flange of the base plate hole, invert the sand-cone apparatus and seat the sand-cone funnel into the flanged hole at the same position as marked during calibration (see Annex A1). Eliminate or minimize vibrations in the test area due to personnel or equipment. Open the valve and allow the sand to fill the hole, funnel, and base plate. Take care to avoid jarring or vibrating the apparatus while the sand is running. When the sand stops flowing, close the valve.

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

Maximum Particle Size		Minimum Test Hole Volumes	
in.	(mm)	cm^3	ft^3
½	(12.7)	1415	0.05
1	(25.4)	2125	0.075
1½	(38)	2830	0.1

7.1.8 Determine the mass of the apparatus with the remaining sand, record, and calculate the mass of sand used.

7.1.9 Determine and record the mass of the moist material that was removed from the test hole. When oversized material corrections are required, determine the mass of the oversized material on the appropriate sieve and record, taking care to avoid moisture losses. When required, make appropriate corrections for the oversized material using Practice D 4718.

7.1.10 Mix the material thoroughly, and either obtain a representative specimen for water content determination, or use the entire sample.

7.1.11 Determine the water content in accordance with Test Method D 2216, D 4643, D 4944, or D 4959. Correlations to Test Method D 2216 will be performed when required by other test methods.

7.2 Water content specimens must be large enough and selected in such a way that they represent all the material obtained from the test hole. The minimum mass of the water content specimens is that required to provide water content values accurate to 1.0 %.

8. Calculation

8.1 Calculations shown are for mass in grams and volumes in cubic centimetres. Other units are permissible provided the appropriate conversion factors are used to maintain consistency of units throughout the calculations. See 1.6 for additional comments on the usage of inch-pound units.

8.2 Calculate the volume of the test hole as follows:

$$V = (M_1 - M_2)/\rho_1 \tag{1}$$

where:

V = volume of the test hole, cm^3,

M_1 = mass of the sand used to fill the test hole, funnel and base plate, g (from 7.1.8),

M_2 = mass of the sand used to fill the funnel and base plate (from Annex A1.2.2.6), g, and

ρ_1 = bulk density of the sand (from A2.3.5), g/cm^3.

8.3 Calculate the dry mass of material removed from the test hole as follows:

$$M_4 = 100\, M_3/(w + 100) \tag{2}$$

where:

w = water content of the material removed from test hole, %, (from 7.1.11),

M_3 = moist mass of the material from test hole, g, (from 7.1.9), and

M_4 = dry mass of material from test hole, g, or multiply by 0.002205 for lb.

8.4 Calculate the in-place wet and dry density of the material tested as follows:

$$\rho_m = M_3/V \tag{3}$$

$$\rho_d = M_4/V$$

where:

V = volume of the test hole, cm^3 (from 8.2),
M_3 = moist mass of the material from the test hole, g, (from 7.1.9),
M_4 = dry mass of the material from the test hole, g, (from 8.3),
ρ_m = wet density of the tested material g/cm^3 or its wet unit weight, γ_m in lb/ft^3 where $\gamma_m = \rho_m \times 62.43$, and
ρ_d = dry density of the tested material, g/cm^3 or its dry unit weight, γ_d in lb/ft^3 where $\gamma_d = \rho_d \times 62.43$.

8.5 It may be desired to express the in-place density as a percentage of some other density, for example, the laboratory densities determined in accordance with Test Method D 698, D 1557, D 4253, or D 4254. This relation can be determined by dividing the in-place density by the laboratory density and multiplying by 100. Calculations for determining relative density are provided in Test Method D 4254. Corrections for oversize material, if required, should be performed in accordance with Practice D 4718.

9. Report

9.1 Report, as a minimum, the following information:

9.1.1 Test location, elevation, thickness of layer tested, or other pertinent data to locate or identify the test.

9.1.2 Test hole volume, cm^3 or ft^3.

9.1.3 In-place wet density, g/cm^3 or lb/ft^3.

9.1.4 In-place dry density, ρ_d, g/cm^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 0.1 KN/m^3, or 1.0 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 Test apparatus identity and calibrated volume.

9.1.8 Bulk density of the sand used, g/cm^3, or lb/ft^3.

9.1.9 Visual description of the soil or material designation.

9.1.10 Mass and percentage of oversized particles and the size sieve used, if performed.

9.1.11 Comments on the test, as applicable.

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

9.1.12.1 The laboratory test method used.

9.1.12.2 The comparative dry density or unit weight value and water content used.

9.1.12.3 Correction for oversized material and details, if applicable.

9.1.12.4 The comparative percentage of the in-place material to the comparison value.

9.1.13 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 *Precision*—Test data on precision is 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.

10.1.1 Subcommittee D18.08 is seeking any data from the users of this test method that might be used to make a limited statement on precision.

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

11. Keywords

11.1 acceptance tests; compaction tests; degree of compaction; density tests; earthfill; embankments; field control density; field tests; inplace density; inplace dry density;*in situ* density; relative density; sand cone; soil compaction; soil tests; unit weight.

ANNEXES

(Mandatory Information)

A1. CALIBRATION OF SAND CONE APPARATUS

A1.1 Scope

A1.1.1 This annex describes the procedure for determining the mass of sand contained in the funnel and base plate of the sand-cone apparatus.

A1.1.2 The mass of sand contained in the apparatus and base plate is dependent on the bulk-density of the sand. Consequently, this procedure must be performed for each apparatus whenever there are changes in the sand bulk-densities.

A1.2 Calibration Procedure

A1.2.1 Calibration of the apparatus can be accomplished by either of two methods:

A1.2.1.1 *Method A*—By determining the mass of calibrated sand that can be contained in each funnel and base plate set, or

A1.2.1.2 *Method B*—By determining the volume of sand needed to fill each funnel and base plate set and applying this volume constant whenever new sand bulk-densities are calculated.

A1.2.1.3 Since the mass of sand contained in the apparatus funnel and base plate is dependent on the bulk density of the sand, if Method A is used, it must be repeated whenever the bulk-density of the sand changes.

A1.2.2 All determinations of mass are to be made to the nearest 5 g.

A1.2.3 *Method A*:

A1.2.3.1 Fill the apparatus with sand that is dried and conditioned to the same state anticipated during use in testing.

A1.2.3.2 Determine the mass of the apparatus filled with sand, g.

A1.2.3.3 Place the base plate on a clean, level, plane surface. Invert the container/apparatus and seat the funnel in the flanged center hole in the base plate. Mark and identify the apparatus and base plate so that the same apparatus and plate can be matched and reseated in the same position during testing.

A1.2.3.4 Open the valve fully until the sand flow stops, making sure the apparatus, base plate, or plane surface are not jarred or vibrated before the valve is closed.

A1.2.3.5 Close the valve sharply, remove the apparatus and determine the mass of the apparatus and remaining sand. Calculate the mass of sand used to fill the funnel and base plate as the difference between the initial and final mass.

A1.2.3.6 Repeat the procedure a minimum of three times. The maximum variation between any one determination and the average will not exceed 1 %. Use the average of the three determinations for this value in the test calculations.

A1.2.4 *Method B (Optional)*:

A1.2.4.1 When large numbers of tests and batches of sand are anticipated, it may be advantageous to determine the volume of each apparatus and base plate. Baring damage to the apparatus or mismatching of the base plates, this volume will remain constant, and will eliminate the need to repeat Method A when the sand bulk-density changes (see Note A1.1). If this alternative is chosen, the calculations in the field test must be altered to determine the total volume of the sand in the field test hole and apparatus. The volume of the apparatus is then subtracted to determine the volume of the test hole.

A1.2.4.2 Determine the mass of sand required to fill the apparatus funnel and base plate in accordance with A1.2.3, following steps A1.2.3.1-A1.2.3.6 for each batch of sand.

A1.2.4.3 Calculate the volume of the funnel and base plate by dividing the bulk-density of the sand (as determined in Annex A2) by the mass of sand found in A1.2.3.6. Perform a minimum of three determinations and calculate an average value. The maximum volume variation between any one determination and the average will not exceed 1 %. Use the average of the values when performing test calculations.

NOTE A1.1—The sand-cone apparatus should be routinely inspected for damage that may affect the volume of the cone. Dings, out-of-round, or other damage will affect the volume and will necessitate a redetermination of the volume (if repairable).

A2. CALIBRATION OF DENSITY SAND

A2.1 Scope

A2.1.1 This annex is used for determining the bulk-density (calibration) of the sand for use in this test method.

A2.1.2 The calibration determines an average density of the sand for use in calculating the volume of the test hole.

A2.2 Equipment Required

A2.2.1 *Container*—Select a container of known volume that is approximately the same size and allows the sand to fall approximately the same distance as the hole excavated during a field test. The 1/30-ft^3 (944-cm^3) and 1/13.33-ft^3 (2124-cm^3) molds specified in Test Methods D 698, or the 0.1-ft^3 (2830-cm^3) mold specified in Test Method D 4253 are recommended. Alternatively, cast duplicates of actual test holes may be used. This is accomplished by forming plaster of paris negatives in actual test holes over a range of test volumes, and using these as forms for portland cement concrete castings. These should be cast against a flat plane surface, and after the removal of the negative, sealed water tight and the volume determined in accordance with the procedure in Test Method D 4253 (10.2.2).

A2.2.1.1 Determine the container volume to 1 % using water in accordance with the procedures described in Test Method D 4253.

A2.2.2 *Sand-Cone Apparatus*—Use a sand cone apparatus of the same size and design as will be used during field testing.

A2.2.2.1 Flow characteristics through different valve assemblies have been shown to cause different bulk-density values. Bulk-density determinations will be required for each apparatus set unless other assemblies are determined to provide the same results.

A2.2.3 *Balance or Scale*—A balance or scale having a sufficient capacity to determine the mass of the calibration container filled with sand. For 0.500 ft^3 (14 200 cm^3) containers, a balance having a minimum capacity of 50 lb (20 kg) and meeting the requirements of Specification D 4753 for 0.01-lb (5-g) readability is required.

A2.2.4 *Metal Straightedge*, about 2 in. (50 cm) wide, at least ⅛ in. (3 mm) thick, and length approximately 1.5 times the diameter of the calibration container.

A2.3 Bulk-Density Determination

A2.3.1 Fill the assembled apparatus with sand. The sand is to be dried and conditioned to the same state anticipated during use.

A2.3.2 Determine and record the mass of the calibration container when empty.

A2.3.3 *Method A (Preferred)*:

A2.3.3.1 When the calibration container has the same diameter as the flanged center hole in the base plate, invert and center the sand filled apparatus and base plate on the calibration container.

A2.3.3.2 Fully open the valve and allow the sand to fill the container. When the sand flow stops, close the valve.

A2.3.3.3 Determine the mass of the apparatus and remaining sand. Calculate the net mass of sand in the calibration container by subtracting the mass of sand contained in the cone and base plate (as determined in Annex A1) and record.

A2.3.4 *Method B (Alternative)*:

A2.3.4.1 Invert and support the apparatus over the calibration container so that the sand falls approximately the same distance and location as in a field test, and fully open the valve.

A2.3.4.2 Fill the container until it just overflows and close the valve. Using a minimum number of strokes and taking care not to jar or densify the sand, carefully strike off excess sand to a smooth level surface. Any vibration or jarring during the bulk-density determination will result in settling and densifying the sand, leading to erroneous results.

A2.3.4.3 Clean any sand from the outside of the calibration container. Determine the mass of the container and sand. Record the net mass of the sand by subtracting the mass of the empty container.

A2.3.5 Perform at least three bulk-density determinations and calculate the average. The maximum variation between any one determination and the average will not exceed 1 %. Repeated determinations not meeting these requirements indicates nonuniform sand density, and the sand source should be re-evaluated for suitability. The average value obtained is to be used in the test calculations.

A2.4 Calculation

A2.4.1 Calculate the bulk-density of the sand as follows:

$$\rho_1 = M_5/V_1 \tag{A2.1}$$

where:

ρ_1 = bulk-density of the sand, g/cm^3, (multiply by 9.807 for KN/m^3, or 62.43 for lb/ft^3),

M_5 = mass of the sand to fill the calibration container, g, (from A2.3.4.3), and

V_1 = volume of the calibration container, cm^3 (from A2.2.1.1).

SUMMARY OF CHANGES

Committee D18 has identified the location of selected changes to this standard since the last issue (D 1556 – 00) that may impact the use of this standard. (Approved Sept. 15, 2007.)

(*1*) Revised Section 1 to include requirements of significant digits.

(*2*) Revised Section 3 to include definition for compacted lift.

(*3*) Revised Section 5 to include guidelines for significant digits for water content and density.