Appendix A

American Society for Testing and Materials (ASTM) Standards

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engineers & scientists

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

This standard is issued under the fixed designation D 422; 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 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:*

D 421 Practice for Dry Preparation of Soil Samples for Particle-Size Analysis and Determination of Soil Constants[2]

E 11 Specification for Wire-Cloth Sieves for Testing Purposes[3]

E 100 Specification for ASTM Hydrometers[4]

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[5] (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 E 100. 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 D-18 on Soil and Rock and is the direct responsibility of Subcommittee D18.03 on Texture, Plasticity, and Density Characteristics of Soils.

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

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

[4] *Annual Book of ASTM Standards*, Vol 14.03.

[5] Detailed working drawings for this cup are available at a nominal cost from the American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428. Order Adjunct No. ADJD0422.

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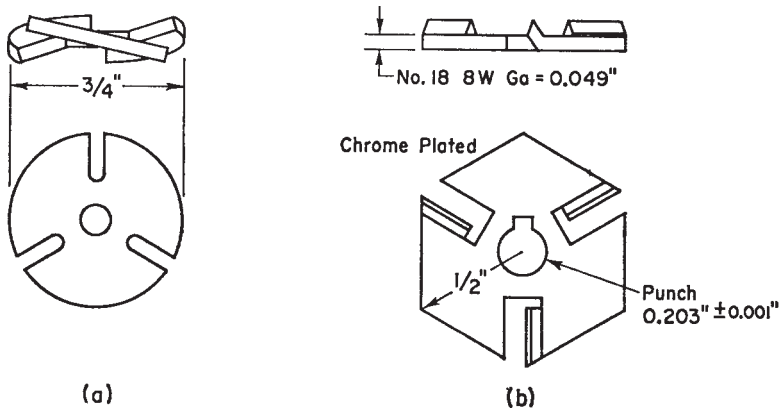
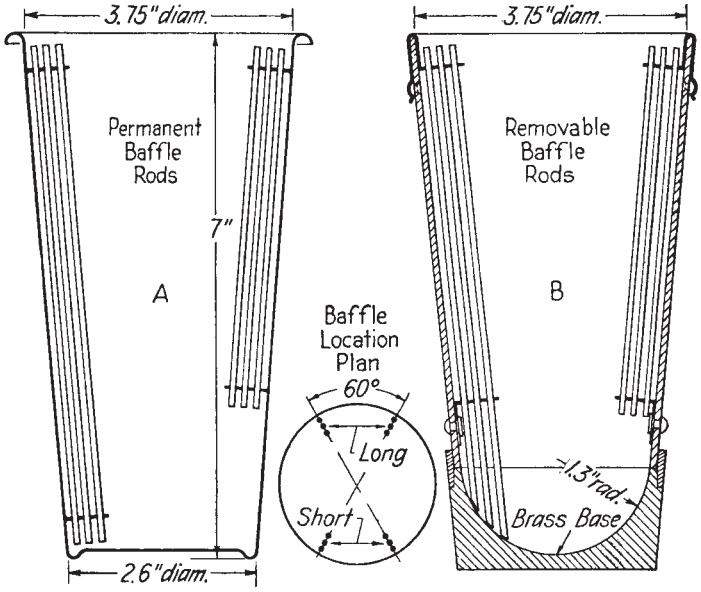


Metric Equivalents					
in.	0.001	0.049	0.203	½	¾
mm	0.03	1.24	5.16	12.7	19.0

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 E 11. A full set of sieves includes the following (Note 6):

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

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

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 temperature of the room. The basic temperature for the

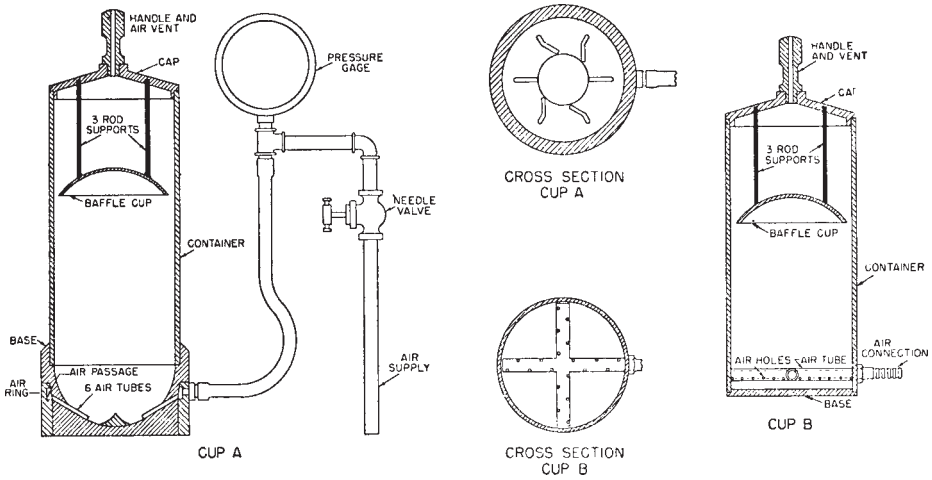
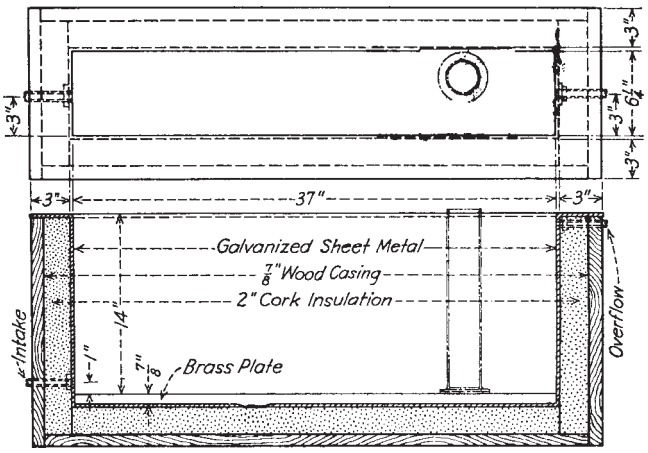


FIG. 3 Air-Jet Dispersion Cups of Apparatus B



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

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 D 421. 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 D 421, 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 D 421 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:

$$P = [(100\,000/W) \times G/(G - G_1)](R - G_1) \quad (1)$$

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:

$$P = (Ra/W) \times 100 \quad (2)$$

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

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

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

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.

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:

$$L = L_1 + 1/2\,[L_2 - (V_B/A)] \quad (5)$$

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

$$D = K\sqrt{L/T} \quad (4)$$

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	0.01510	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

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.

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):

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

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Designation: D 854 – 02

Standard Test Methods for Specific Gravity of Soil Solids by Water Pycnometer[1]

This standard is issued under the fixed designation D 854; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope *

1.1 These test methods cover the determination of the 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 C 127 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 D 5550 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 D 6026.

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 *Units*—The values stated in SI units are to be regarded as standard. No other units of measurement are included in these test methods.

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:*

C 127 Test Method for Specific Gravity and Absorption of Coarse Aggregate[2]

D 653 Terminology Relating to Soil, Rock, and Contained Fluids[3]

D 1140 Test Method for Amount of Material in Soils Finer Than the No. 200 (75-μm) Sieve[3]

D 2216 Test Method for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass[3]

D 2487 Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)[3]

D 3740 Practice for Minimum Requirements for Agencies Engaged in the Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction[3]

D 4753 Guide for Evaluating, Selecting, and Specifying Balances and Scales for Use in Soil, Rock, and Related Construction Materials Testing[3]

D 5550 Test Method for Specific Gravity of Soil Solids by Gas Pycnometer[3]

D 6026 Practice for Using Significant Digits in Geotechnical Data[4]

E 11 Specification for Wire-Cloth Sieves for Testing Purposes[5]

E 177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods[5]

E 691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method[5]

3. Terminology

3.1 *Definitions*—For definitions of terms used in these test

[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.

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[2] *Annual Book of ASTM Standards*, Vol 04.02.

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

[4] *Annual Book of ASTM Standards*, Vol 04.09.

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

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

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methods, refer to Terminology D 653.

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 D 3740 are generally considered capable of competent and objective testing/sampling/inspection/etc. Users of these test methods 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.

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 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 D 4753 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 *Thermometer*—Thermometer capable of measuring the temperature range within which the test is being performed, readable to the nearest 0.1°C and an immersion depth ranging between 25 to 80 mm. Full immersion thermometers shall not be used. Either a general-purpose precision mercury thermometer or a digital thermometer with a –1 to 57°C range will meet this requirement.

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, a water bottle, 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 ¼to 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*—No. 4 (4.75 mm) conforming to the requirements of Specification E 11.

5.11 *Blender (optional)*—A blender with mixing blades built into the base of the mixing container.[6]

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 passes the U. S. Standard No. 4 sieve in the total sample. Table 1 gives guidelines on recommended dry soil mass versus soil type and pycnometer size.

[6] Manufacturers of such blenders include, but are not limited to, Waring or Osterizer.

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

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 thermometer, a beaker of water, stopper(s) (if a stoppered pycnometer is being used), and deaired water in a bottle along with 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.

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, place the stopper in the bottle, then remove the excess water using 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 thermometer that has been thermally equilibrated in the insulated container. Insert the thermometer 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 prepare for the next calibration and allow the pycnometers to thermally equilibrate (for at least 3 h). Repeat the procedure to obtain five independent measurements on each pycnometer. 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:

$$V_p = \frac{(M_{pw,c} - M_p)}{\rho_{w,c}} \quad (1)$$

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 D 2216. 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.

9.2.2 To disperse the soil put about 100 mL of water into the mixing container of a blender or equivalnet 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

TABLE 2 Density of Water and Temperature Coefficient (*K*) for Various Temperatures[A]

Temperature (°C)	Density (g/mL)[B]	Temperature Coefficient (*K*)	Temperature (°C)	Density (g/mL)[B]	Temperature Coefficient (*K*)	Temperature (°C)	Density (g/mL)[B]	Temperature Coefficient (*K*)	Temperature (°C)	Density (g/mL)[B]	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]mL = cm^3.

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 the insulated container. The thermometer, a beaker of water, and some deaired water in a bottle along with either an eyedropper or pipette should also be placed in the insulated container. 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, place the stopper in the bottle while removing the excess water using 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 thermometer 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:

$$M_{\mathrm{pw,t}} = M_{\mathrm{p}} + (V_p \cdot \rho_{w,t}) \quad (2)$$

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 at soil solids the test temperature, G_t as follows:

$$G_t = \frac{\rho_s}{\rho_{w,t}} = \frac{M_s}{(M_{\rho_{w,t}} - (M_{\rho ws,t} - M_s))} \quad (3)$$

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:

$$G_{20°\mathrm{C}} = K \cdot G_t \quad (4)$$

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 C 127 was used to determine the specific gravity of these particles, calculate an average specific gravity. Test Method C 127 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:

$$G_{avg@20°\mathrm{C}} = \frac{1}{\frac{R}{100 \cdot G_{1@20°\mathrm{C}}} + \frac{P}{100 \cdot G_{2@20°C}}} \quad (5)$$

where:

R = the percent of soil retained on the 4.75-mm sieve,
P = the percent of soil passing the 4.75-mm sieve,
$G_{1@20°\mathrm{C}}$ = the apparent specific gravity of soils retained on the 4.75-mm sieve as determined by Test Method C 127, corrected to 20°C

$G_{2@20°C}$ = 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 D 2487).

11.2.3 Percent of soil particles passing the No. 4 (4.75-mm) 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, $G_{20°C}$) 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 $G_{avg@20°C}$) to the nearest 0.01, if applicable.

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.[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 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 E 691, 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.

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 D 6026, 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 E 691 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 E 177. 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 D 6026. 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.

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 E 691 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 D 2487. In addition, the local name of the soil is given.

[7] Supporting data is available from ASTM Headquarters. Request RR: D18-1009.

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 (00e1) that may impact the use of this standard.

(*1*) The balance capacity was reduced from 2000 g to either 500 g or 1000 g depending on pycnometer size.
(*2*) 8.3 and 9.8. The thermometer no longer is required to be in the beaker during thermal equilibrium.
(*3*) 9.2 The dispersion technique is better defined.

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Designation: D 1140 – 00

Standard Test Methods for Amount of Material in Soils Finer Than the No. 200 (75-μm) Sieve[1]

This standard is issued under the fixed designation D 1140; 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 These test methods cover determination of the amount of material finer than a 75-μm (No. 200) sieve by washing.

1.2 Two methods for determining the amount of material finer than the No. 200 sieve are provided. The method to be used shall be specified by the requesting authority. If no method is specified, the choice should be based on the guidance given in 4.2 and 7.3

1.2.1 *Method A*—Test specimen is not dispersed prior to wash sieving.

1.2.2 *Method B*—Test specimen is dispersed by soaking in water containing a deflocculating agent prior to wash sieving

1.3 The values stated in SI units are to be regarded as the standard.

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

2. Referenced Documents

2.1 *ASTM Standards:*

C 702 Practice for Reducing Field Samples of Aggregate to Testing Size[2]

D 75 Practice for Sampling Aggregates[3]

D 422 Test Method for Particle-Size Analysis of Soils[4]

D 2216 Test Method for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass[4]

D 2487 Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)[4]

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

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

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

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

E 145 Specification for Gravity-Convection and Force-Ventilation Ovens[6]

E 177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods[6]

E 691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method[6]

3. Summary of Test Method

3.1 A specimen of the soil is washed over a 75-μm (No. 200) sieve. Clay and other particles that are dispersed by the wash water, as well as water-soluble materials, are removed from the soil during the test. The loss in mass resulting from the wash treatment is calculated as mass percent of the original sample and is reported as the percentage of material finer than a 75-μm (No. 200) sieve by washing.

4. Significance and Use

4.1 Material finer than the 75-μm (No. 200) sieve can be separated from larger particles much more efficiently and completely by wet sieving than with dry sieving. Therefore, when accurate determinations of material finer than 75-μm sieve in soil are desired, this test method is used on the test specimen prior to dry sieving. Usually the additional amount of material finer than 75-μm sieve obtained in the dry sieving process is a small amount. If it is large, the efficiency of the washing operation should be checked, as it could be an indication of degradation of the soil.

4.2 With some soils, particularly clayey soils, in order to keep the finer material from adhering to the larger particles, it will be necessary to soak the soil prior to washing it through the sieve. A deflocculating agent (dispersing agent) should be added to the soil when it is soaked.

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

[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.

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[2] *Annual Book of ASTM Standards*, Vol 04.02.

[3] *Annual Book of ASTM Standards*, Vol 04.03.

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

[5] *Annual Book of ASTM Standards*, Vol 04.09.

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

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

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

5. Apparatus

5.1 *Balance*—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. To determine the balance needed, multiply your test mass by 0.001 and check Table 1 of Specification D 4753 for the class of balance readable to the number observed.

5.2 *Sieves*—A minimum nest of two sieves is recommended, the lower must be a 75-µm (No. 200) sieve and the upper may be a 425-µm (No. 40) or larger sieve. Chose a sieve with a diameter sufficient to handle the size of specimen required by 6.2. The 75-µm sieve should have a backing to prevent damage. The sieves shall conform to the requirements of Specification E 11. Stainless sieve mesh is preferred, as it is less prone to damage or wear.

5.3 *Oven*—An oven of sufficient size, capable of maintaining a uniform temperature of 100 ± 5°C (230 ± 9°F) and which meets the criteria of Specification E 145.

5.4 *Deflocculating Agent*—A solution of Sodium Hexametaphosphate of any concentration sufficient to cause particle separation can be used. A common amount is 40 g per 1000 mL of water.

6. Sampling

6.1 Sample the soil in accordance with Practice D 75.

6.2 Thoroughly mix the soil sample and reduce the quantity to an amount suitable for testing using the applicable method described in Practice C 702. The test specimen shall be the end result of the reduction. Reduction to an exact predetermined mass is not permitted. The mass of the test specimen, after drying, shall conform with the following except as noted (6.2.1 and Note 2):

Maximum Particle Size (100 % Passing)	Standard Sieve Size	Recommended Minimum Mass of Test Specimens
2 mm or less	No. 10	20 g
4.75 mm	No. 4	100 g
9.5 mm	⅜″	500 g
19.0 mm	¾″	2.5 kg
37.5 mm	1½″	10 kg
75.0 mm	3″	50 kg

6.2.1 If the same specimen is to be tested for sieve analysis according to Test Method D 422, comply with the applicable mass requirements of that Test Method.

NOTE 2—When a minimum mass is not available (split spoon sample, and the like), a smaller mass can be used. The report shall indicate the mass used.

7. Procedure

7.1 Dry the test specimen to a constant mass at a temperature of 110 ± 5°C (230 ± 9°F) and determine its mass to the nearest 0.1 g. To determine the balance needed, multiply the mass by 0.001, check the resultant number with Table 1 of Specification D 4753 for the required balance.

7.1.1 For example: Minimum readability = 276 g (mass) × 0.001 = 0.3 g. A GP-2 with a readability of 0.1 g would be suitable. A more sensitive balance could also be used.

7.1.2 As an alternative, select an auxiliary water content specimen and determine the water content (nearest 0.1 %) in accordance with Test Method D 2216. Calculate the oven-dry mass of the test specimen from the moist mass (nearest 0.1 % of its mass, or better (see 5.1)) and the water content.

7.2 *Method A*:

7.2.1 After preparing the specimen in accordance with 7.1, place the specimen on on the uppermost (coarsest) sieve. Wash the specimen (material) on the sieve(s) by means of a stream of water from a faucet (Note 3). The material may be lightly manipulated by hand, to facilitate the washing process, taking care not to lose any of the retained material. No downward pressure should be exerted on the retained material or sieve to avoid the forcing of particles through the sieve or damage to the sieve. Continue the washing until the water coming through the sieve(s) is clear (Note 4).

NOTE 3—A spray nozzle or a piece of rubber tubing attached to a water faucet may be used for the washing. The velocity of the water, which may be increased by pinching the tubing, shall not cause any splashing of the material over the sides of the sieve. The water temperature should not exceed 32°C (90°F) to avoid expanding the sieve fabric.

NOTE 4—Care should be taken not to let water accumulate on the 75-µm (No. 200) sieve due to clogging of the screen. The clogging can cause overflow of the sieve and loss of material. Lightly hand tapping the sides of the sieve or the bottom of the screen with a fingertip(s) should prevent clogging. Directing a stream of water up from below the screen is another method to unplug the sieve without physically damaging it. Be careful not to overload the screen by sieving too large a specimen, or portion of a specimen, at any one time.

7.3 *Method B*:

7.3.1 As an alternative, particularly for very cohesive soils; after preparing the specimen in accordance with 7.1, place the specimen in a container, cover with water containing a deflocculating agent, and soak for a minimum of 2 h (preferably overnight) (Note 5). The specimen should be periodically agitated manually or by mechanical means to facilitate the complete separation of the particles.

NOTE 5—It will also be easier to separate the particles if the specimen is not dried prior to soaking. The moist mass can be adjusted to a dry mass by using the water content determination procedure from 7.1.2.

7.3.2 After the soaking period is completed, agitate the contents of the container vigorously and immediately pour into the nested sieves. Wash any remaining material into the sieve(s) to make sure all of the material is transferred. Then finish the washing procedure as specified in 7.2.

7.4 When the washing by Method A or B is completed, the material retained on the 75-µm (No. 200) sieve can be dried either in the sieve, or by flushing (transferring) the contents of the sieve into another container. If the soil is transferred, excess water can be removed by decanting or suctioning to speed drying time. Take care not to lose any particles by removing only clear water.

7.4.1 Dry the residue from each sieve to a constant mass using a temperature of 110 ± 5°C (230 ± 9°F) and determine the mass using the same balance as used in 7.1.

NOTE 6—As mentioned in 4.1, if the sample is dry sieved after washing,

some material will pass the 75-μm (No. 200) sieve that did not pass during washing operations. This can be a significant amount for samples with a high percent of very fine sand or coarse silt.

8. Calculation

8.1 Calculate the amount of material passing the 75-μm (No. 200) sieve by washing using the following formula:

$$A = [(B - C)/B] \times 100 \quad (1)$$

where:

A = percentage of material finer than the 75-μm sieve by washing, nearest 0.1 %
B = original dry mass of sample, g, and
C = dry mass of specimen retained on the 75-μm sieve including the amount retained on an upper sieve after washing, g.

9. Report

9.1 Report the percentage of material finer than the 75-μm (No. 200) sieve by washing to the nearest 0.1 %.

9.2 Indicate whether the specimen was soaked and length of time.

9.3 Indicate method used (A or B).

9.4 Sample identification.

9.5 Size of initial dry mass used.

9.6 State whether the dry mass was determined directly or using the water content of the specimen as directed in 7.1.2. If so, note the water content.

10. Precision and Bias

10.1 *Precision*—Criteria for judging the acceptability of test results obtained by these test methods on a range of soil types using Method B are given in Tables 1 and 2. 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 10.1.4. The precision estimates may vary with soil type and method used (Method A or B). Judgment is required when applying these estimates to another soil or method.

TABLE 1 Summary of Test Results from Triplicate Test Laboratories (Percent of Fines)

(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)
Single-Operator Results (Within- Laboratory Repeatability):				
CH	13	98.83	0.15	0.4
CL	13	88.55	0.14	0.4
ML	14	99.00	0.12	0.3
SP	13	2.47	0.20	0.5
Multilaboratory Results (Between- Laboratory Reproducibility):				
CH	13	98.83	0.22	0.6
CL	13	88.55	0.40	1.1
ML	14	99.00	0.13	0.4
SP	13	2.47	0.36	1.0

[A] The number of significant digits and decimal places presented are representative of the input data. In accordance with Practice D 6026, 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 E 691 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 E 177. 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 D 6026. 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 2 Summary of Single-Test Result from Each Laboratory (Percent of Fines)[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)
Multilaboratory Results (Single Test Performed by Each Laboratory):				
CH	25	98.74	0.22	0.6
CL	24	88.41	0.52	1.4
ML	25	99.00	0.18	0.5
SP	25	2.647	0.60	1.7

[A] See footnotes in the Table 1.

10.1.1 The data in Table 1 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 1, Column 4 were obtained in accordance with Practice E 691, 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 1, 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 1, Column 5.

10.1.2 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 2 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 d2s limits shown in Table 2, Column 5. The results in Table 1 and Table 2 are dissimilar because the data sets are different.

10.1.3 Table 1 presents a rigorous interpretation of triplicate test data in accordance with Practice E 691 from pre-qualified laboratories. Table 2 is derived from test data that represents common practice.

10.1.4 *Soil Types*—Based on the multilaboratory test results, the soils used in the program are described below in accordance with Practice D 2487. In addition, the local names of the soils are given.

[7] Supporting data is available from ASTM Headquarters. Request RR: D18–1010.

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

11. Keywords

11.1 fines; particle sizes; sieve analysis; washing

SUMMARY OF CHANGES

In accordance with Committee D 18 policy, this section identifies the location of changes to this standard since the last edition (1997) that may impact the use of this standard.

(1) The Summary of Changes section was added.
(2) Title change to reflect multiple methods.
(3) In Scope Section, Methods A and B were defined.
(4) Reference to Practice D 670 was removed and references to Practices, D 3740, D 2487, D 6026, E 177, and E 691 were added.
(5) Following the Significance and Use section, Note 1 was added referencing Practice D 3740 in accordance with the policy of D18. The remaining notes were renumbered.
(6) Under Sampling: moved and reworded the 2nd sentence in 6.1 to 6.2.1. The two sentences following the table presenting recommended mass of test specimens were moved to 6.2.
(7) In 7.1 reworded the mass determination to agree with 7.4.1 and moved the example in 7.4.1 to this subsection. In addition, moved the alternative method (given in 7.1) to a new subsection, 7.4.1, and reworded it so Test Method D 2216 controlled how the water content specimen was obtained and the water content determined.
(8) Reworded 7.4.1 to use the same balance as used in 7.1.
(4) The precision statement in 10.1 was completely revised.

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Designation: D 1586 – 99

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Standard Test Method for Penetration Test and Split-Barrel Sampling of Soils[1]

This standard is issued under the fixed designation D 1586; 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 describes the procedure, generally known as the Standard Penetration Test (SPT), for driving a split-barrel sampler to obtain a representative soil sample and a measure of the resistance of the soil to penetration of the sampler.

1.2 *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.* For a specific precautionary statement, see 5.4.1.

1.3 The values stated in inch-pound units are to be regarded as the standard.

NOTE 1—Practice D 6066 can be used when testing loose sands below the water table for liquefaction studies or when a higher level of care is required when drilling these soils. This practice provides information on drilling methods, equipment variables, energy corrections, and blow-count normalization.

2. Referenced Documents

2.1 *ASTM Standards:*

D 2487 Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)[2]

D 2488 Practice for Description and Identification of Soils (Visual-Manual Procedure)[2]

D 4220 Practices for Preserving and Transporting Soil Samples[2]

D 4633 Test Method for Stress Wave Energy Measurement for Dynamic Penetrometer Testing Systems[2]

D 6066 Practice for Determining the Normalized Penetration Resistance Testing of Sands for Evaluation of Liquefaction Potential[3]

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *anvil*—that portion of the drive-weight assembly which the hammer strikes and through which the hammer energy passes into the drill rods.

3.1.2 *cathead*—the rotating drum or windlass in the rope-cathead lift system around which the operator wraps a rope to lift and drop the hammer by successively tightening and loosening the rope turns around the drum.

3.1.3 *drill rods*—rods used to transmit downward force and torque to the drill bit while drilling a borehole.

3.1.4 *drive-weight assembly*—a device consisting of the hammer, hammer fall guide, the anvil, and any hammer drop system.

3.1.5 *hammer*—that portion of the drive-weight assembly consisting of the 140 ± 2 lb (63.5 ± 1 kg) impact weight which is successively lifted and dropped to provide the energy that accomplishes the sampling and penetration.

3.1.6 *hammer drop system*—that portion of the drive-weight assembly by which the operator accomplishes the lifting and dropping of the hammer to produce the blow.

3.1.7 *hammer fall guide*—that part of the drive-weight assembly used to guide the fall of the hammer.

3.1.8 *N-value*—the blowcount representation of the penetration resistance of the soil. The *N*-value, reported in blows per foot, equals the sum of the number of blows required to drive the sampler over the depth interval of 6 to 18 in. (150 to 450 mm) (see 7.3).

3.1.9 Δ*N*—the number of blows obtained from each of the 6-in. (150-mm) intervals of sampler penetration (see 7.3).

3.1.10 *number of rope turns*—the total contact angle between the rope and the cathead at the beginning of the operator's rope slackening to drop the hammer, divided by 360° (see Fig. 1).

3.1.11 *sampling rods*—rods that connect the drive-weight assembly to the sampler. Drill rods are often used for this purpose.

3.1.12 *SPT*—abbreviation for standard penetration test, a term by which engineers commonly refer to this method.

4. Significance and Use

4.1 This test method provides a soil sample for identification purposes and for laboratory tests appropriate for soil obtained from a sampler that may produce large shear strain disturbance in the sample.

4.2 This test method is used extensively in a great variety of geotechnical exploration projects. Many local correlations and

[1] This method is under the jurisdiction of ASTM Committee D-18 on Soil and Rock and is the direct responsibility of Subcommittee D18.02 on Sampling and Related Field Testing for Soil Investigations.

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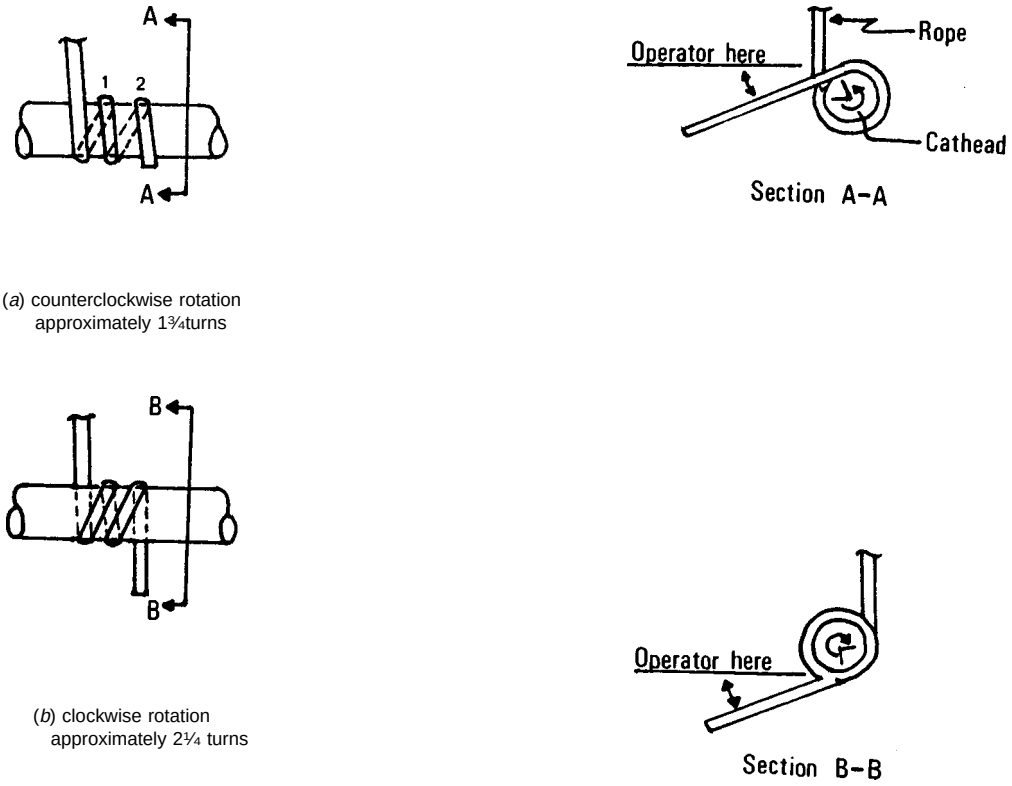
[2] *Annual Book of ASTM Standards*, Vol 04.08.

[3] *Annual Book of ASTM Standards*, Vol 04.09.

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



(*a*) counterclockwise rotation approximately 1¾turns

(*b*) clockwise rotation approximately 2¼ turns

FIG. 1 Definitions of the Number of Rope Turns and the Angle for (*a*) Counterclockwise Rotation and (*b*) Clockwise Rotation of the Cathead

widely published correlations which relate SPT blowcount, or *N*-value, and the engineering behavior of earthworks and foundations are available.

5. Apparatus

5.1 *Drilling Equipment*—Any drilling equipment that provides at the time of sampling a suitably clean open hole before insertion of the sampler and ensures that the penetration test is performed on undisturbed soil shall be acceptable. The following pieces of equipment have proven to be suitable for advancing a borehole in some subsurface conditions.

5.1.1 *Drag, Chopping, and Fishtail Bits*, less than 6.5 in. (162 mm) and greater than 2.2 in. (56 mm) in diameter may be used in conjuction with open-hole rotary drilling or casing-advancement drilling methods. To avoid disturbance of the underlying soil, bottom discharge bits are not permitted; only side discharge bits are permitted.

5.1.2 *Roller-Cone Bits*, less than 6.5 in. (162 mm) and greater than 2.2 in. (56 mm) in diameter may be used in conjunction with open-hole rotary drilling or casing-advancement drilling methods if the drilling fluid discharge is deflected.

5.1.3 *Hollow-Stem Continuous Flight Augers*, with or without a center bit assembly, may be used to drill the boring. The inside diameter of the hollow-stem augers shall be less than 6.5 in. (162 mm) and greater than 2.2 in. (56 mm).

5.1.4 *Solid, Continuous Flight, Bucket and Hand Augers*, less than 6.5 in. (162 mm) and greater than 2.2 in. (56 mm) in diameter may be used if the soil on the side of the boring does not cave onto the sampler or sampling rods during sampling.

5.2 *Sampling Rods*—Flush-joint steel drill rods shall be used to connect the split-barrel sampler to the drive-weight assembly. The sampling rod shall have a stiffness (moment of inertia) equal to or greater than that of parallel wall "A" rod (a steel rod which has an outside diameter of 1⅝ in. (41.2 mm) and an inside diameter of 1⅛ in. (28.5 mm).

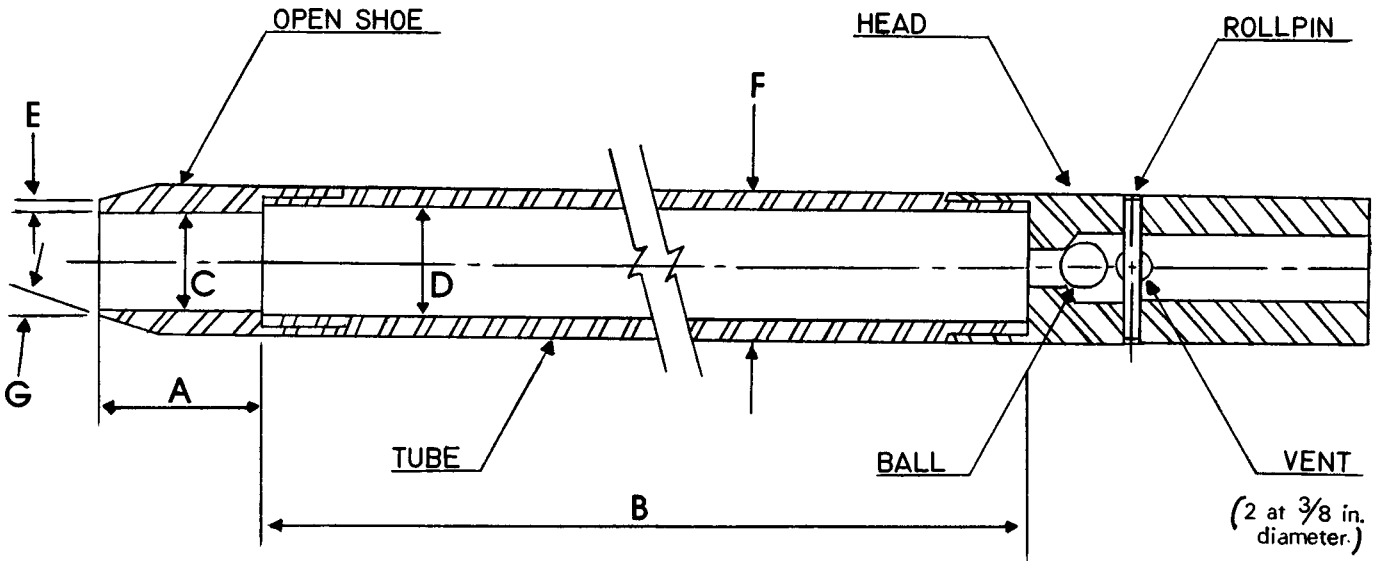
NOTE 2—Recent research and comparative testing indicates the type rod used, with stiffness ranging from "A" size rod to "N" size rod, will usually have a negligible effect on the *N*-values to depths of at least 100 ft (30 m).

5.3 *Split-Barrel Sampler*—The sampler shall be constructed with the dimensions indicated in Fig. 2. The driving shoe shall be of hardened steel and shall be replaced or repaired when it becomes dented or distorted. The use of liners to produce a constant inside diameter of 1⅜ in. (35 mm) is permitted, but shall be noted on the penetration record if used. The use of a sample retainer basket is permitted, and should also be noted on the penetration record if used.

NOTE 3—Both theory and available test data suggest that *N*-values may increase between 10 to 30 % when liners are used.

5.4 *Drive-Weight Assembly*:

5.4.1 *Hammer and Anvil*—The hammer shall weigh 140 ± 2 lb (63.5 ± 1 kg) and shall be a solid rigid metallic mass. The hammer shall strike the anvil and make steel on steel contact when it is dropped. A hammer fall guide permitting a free fall



A = 1.0 to 2.0 in. (25 to 50 mm)
B = 18.0 to 30.0 in. (0.457 to 0.762 m)
C = 1.375± 0.005 in. (34.93 ± 0.13 mm)
D = 1.50 ± 0.05 − 0.00 in. (38.1 ± 1.3 − 0.0 mm)
E = 0.10 ± 0.02 in. (2.54 ± 0.25 mm)
F = 2.00 ± 0.05 − 0.00 in. (50.8 ± 1.3 − 0.0 mm)
G = 16.0° to 23.0°

The 1½ in. (38 mm) inside diameter split barrel may be used with a 16-gage wall thickness split liner. The penetrating end of the drive shoe may be slightly rounded. Metal or plastic retainers may be used to retain soil samples.

FIG. 2 Split-Barrel Sampler

shall be used. Hammers used with the cathead and rope method shall have an unimpeded overlift capacity of at least 4 in. (100 mm). For safety reasons, the use of a hammer assembly with an internal anvil is encouraged.

NOTE 4—It is suggested that the hammer fall guide be permanently marked to enable the operator or inspector to judge the hammer drop height.

5.4.2 *Hammer Drop System*—Rope-cathead, trip, semi-automatic, or automatic hammer drop systems may be used, providing the lifting apparatus will not cause penetration of the sampler while re-engaging and lifting the hammer.

5.5 *Accessory Equipment*—Accessories such as labels, sample containers, data sheets, and groundwater level measuring devices shall be provided in accordance with the requirements of the project and other ASTM standards.

6. Drilling Procedure

6.1 The boring shall be advanced incrementally to permit intermittent or continuous sampling. Test intervals and locations are normally stipulated by the project engineer or geologist. Typically, the intervals selected are 5 ft (1.5 mm) or less in homogeneous strata with test and sampling locations at every change of strata.

6.2 Any drilling procedure that provides a suitably clean and stable hole before insertion of the sampler and assures that the penetration test is performed on essentially undisturbed soil shall be acceptable. Each of the following procedures have proven to be acceptable for some subsurface conditions. The subsurface conditions anticipated should be considered when selecting the drilling method to be used.

6.2.1 Open-hole rotary drilling method.

6.2.2 Continuous flight hollow-stem auger method.

6.2.3 Wash boring method.

6.2.4 Continuous flight solid auger method.

6.3 Several drilling methods produce unacceptable borings. The process of jetting through an open tube sampler and then sampling when the desired depth is reached shall not be permitted. The continuous flight solid auger method shall not be used for advancing the boring below a water table or below the upper confining bed of a confined non-cohesive stratum that is under artesian pressure. Casing may not be advanced below the sampling elevation prior to sampling. Advancing a boring with bottom discharge bits is not permissible. It is not permissible to advance the boring for subsequent insertion of the sampler solely by means of previous sampling with the SPT sampler.

6.4 The drilling fluid level within the boring or hollow-stem augers shall be maintained at or above the in situ groundwater level at all times during drilling, removal of drill rods, and sampling.

7. Sampling and Testing Procedure

7.1 After the boring has been advanced to the desired sampling elevation and excessive cuttings have been removed, prepare for the test with the following sequence of operations.

7.1.1 Attach the split-barrel sampler to the sampling rods and lower into the borehole. Do not allow the sampler to drop onto the soil to be sampled.

7.1.2 Position the hammer above and attach the anvil to the top of the sampling rods. This may be done before the sampling

rods and sampler are lowered into the borehole.

7.1.3 Rest the dead weight of the sampler, rods, anvil, and drive weight on the bottom of the boring and apply a seating blow. If excessive cuttings are encountered at the bottom of the boring, remove the sampler and sampling rods from the boring and remove the cuttings.

7.1.4 Mark the drill rods in three successive 6-in. (0.15-m) increments so that the advance of the sampler under the impact of the hammer can be easily observed for each 6-in. (0.15-m) increment.

7.2 Drive the sampler with blows from the 140-lb (63.5-kg) hammer and count the number of blows applied in each 6-in. (0.15-m) increment until one of the following occurs:

7.2.1 A total of 50 blows have been applied during any one of the three 6-in. (0.15-m) increments described in 7.1.4.

7.2.2 A total of 100 blows have been applied.

7.2.3 There is no observed advance of the sampler during the application of 10 successive blows of the hammer.

7.2.4 The sampler is advanced the complete 18 in. (0.45 m) without the limiting blow counts occurring as described in 7.2.1, 7.2.2, or 7.2.3.

7.3 Record the number of blows required to effect each 6 in. (0.15 m) of penetration or fraction thereof. The first 6 in. is considered to be a seating drive. The sum of the number of blows required for the second and third 6 in. of penetration is termed the "standard penetration resistance," or the "*N*-value." If the sampler is driven less than 18 in. (0.45 m), as permitted in 7.2.1, 7.2.2, or 7.2.3, the number of blows per each complete 6-in. (0.15-m) increment and per each partial increment shall be recorded on the boring log. For partial increments, the depth of penetration shall be reported to the nearest 1 in. (25 mm), in addition to the number of blows. If the sampler advances below the bottom of the boring under the static weight of the drill rods or the weight of the drill rods plus the static weight of the hammer, this information should be noted on the boring log.

7.4 The raising and dropping of the 140-lb (63.5-kg) hammer shall be accomplished using either of the following two methods:

7.4.1 By using a trip, automatic, or semi-automatic hammer drop system which lifts the 140-lb (63.5-kg) hammer and allows it to drop 30 ± 1.0 in. (0.76 m ± 25 mm) unimpeded.

7.4.2 By using a cathead to pull a rope attached to the hammer. When the cathead and rope method is used the system and operation shall conform to the following:

7.4.2.1 The cathead shall be essentially free of rust, oil, or grease and have a diameter in the range of 6 to 10 in. (150 to 250 mm).

7.4.2.2 The cathead should be operated at a minimum speed of rotation of 100 RPM, or the approximate speed of rotation shall be reported on the boring log.

7.4.2.3 No more than 2¼ rope turns on the cathead may be used during the performance of the penetration test, as shown in Fig. 1.

NOTE 5—The operator should generally use either 1¾ or 2¼ rope turns, depending upon whether or not the rope comes off the top (1¾ turns) or the bottom (2¼ turns) of the cathead. It is generally known and accepted that 2¾or more rope turns considerably impedes the fall of the hammer and should not be used to perform the test. The cathead rope should be maintained in a relatively dry, clean, and unfrayed condition.

7.4.2.4 For each hammer blow, a 30-in. (0.76-m) lift and drop shall be employed by the operator. The operation of pulling and throwing the rope shall be performed rhythmically without holding the rope at the top of the stroke.

7.5 Bring the sampler to the surface and open. Record the percent recovery or the length of sample recovered. Describe the soil samples recovered as to composition, color, stratification, and condition, then place one or more representative portions of the sample into sealable moisture-proof containers (jars) without ramming or distorting any apparent stratification. Seal each container to prevent evaporation of soil moisture. Affix labels to the containers bearing job designation, boring number, sample depth, and the blow count per 6-in. (0.15-m) increment. Protect the samples against extreme temperature changes. If there is a soil change within the sampler, make a jar for each stratum and note its location in the sampler barrel.

8. Report

8.1 Drilling information shall be recorded in the field and shall include the following:

8.1.1 Name and location of job,

8.1.2 Names of crew,

8.1.3 Type and make of drilling machine,

8.1.4 Weather conditions,

8.1.5 Date and time of start and finish of boring,

8.1.6 Boring number and location (station and coordinates, if available and applicable),

8.1.7 Surface elevation, if available,

8.1.8 Method of advancing and cleaning the boring,

8.1.9 Method of keeping boring open,

8.1.10 Depth of water surface and drilling depth at the time of a noted loss of drilling fluid, and time and date when reading or notation was made,

8.1.11 Location of strata changes,

8.1.12 Size of casing, depth of cased portion of boring,

8.1.13 Equipment and method of driving sampler,

8.1.14 Type sampler and length and inside diameter of barrel (note use of liners),

8.1.15 Size, type, and section length of the sampling rods, and

8.1.16 Remarks.

8.2 Data obtained for each sample shall be recorded in the field and shall include the following:

8.2.1 Sample depth and, if utilized, the sample number,

8.2.2 Description of soil,

8.2.3 Strata changes within sample,

8.2.4 Sampler penetration and recovery lengths, and

8.2.5 Number of blows per 6-in. (0.15-m) or partial increment.

9. Precision and Bias

9.1 *Precision*—A valid estimate of test precision has not been determined because it is too costly to conduct the necessary inter-laboratory (field) tests. Subcommittee D18.02 welcomes proposals to allow development of a valid precision statement.

9.2 *Bias*—Because there is no reference material for this test method, there can be no bias statement.

9.3 Variations in *N*-values of 100 % or more have been

observed when using different standard penetration test apparatus and drillers for adjacent borings in the same soil formation. Current opinion, based on field experience, indicates that when using the same apparatus and driller, *N*-values in the same soil can be reproduced with a coefficient of variation of about 10 %.

9.4 The use of faulty equipment, such as an extremely massive or damaged anvil, a rusty cathead, a low speed cathead, an old, oily rope, or massive or poorly lubricated rope sheaves can significantly contribute to differences in *N*-values obtained between operator-drill rig systems.

9.5 The variability in *N*-values produced by different drill rigs and operators may be reduced by measuring that part of the hammer energy delivered into the drill rods from the sampler and adjusting *N* on the basis of comparative energies. A method for energy measurement and *N*-value adjustment is given in Test Method D 4633.

10. Keywords

10.1 blow count; in-situ test; penetration resistance; split-barrel sampling; standard penetration test

SUMMARY OF CHANGES

(1) Added note to Section 1, Scope. The note refers to a related standard, Practice D 6066.

(2) Added Practice D 6066 to Section 2 on Referenced Documents.

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Designation: D 1587 – 00

Standard Practice for Thin-Walled Tube Sampling of Soils for Geotechnical Purposes[1]

This standard is issued under the fixed designation D 1587; 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 a procedure for using a thin-walled metal tube to recover relatively undisturbed soil samples suitable for laboratory tests of engineering properties, such as strength, compressibility, permeability, and density. Thin-walled tubes used in piston, plug, or rotary-type samplers should comply with Section 6.3 of this practice which describes the thin-walled tubes.

NOTE 1—This practice does not apply to liners used within the samplers.

1.2 This Practice is limited to soils that can be penetrated by the thin-walled tube. This sampling method is not recommended for sampling soils containing gravel or larger size soil particles cemented or very hard soils. Other soil samplers may be used for sampling these soil types. Such samplers include driven split barrel samplers and soil coring devices (D 1586, D 3550, and D 6151). For information on appropriate use of other soil samplers refer to D 6169.

1.3 This practice is often used in conjunction with fluid rotary drilling (D 1452D 5783) or hollow-stem augers (D 6151). Subsurface geotechnical explorations should be reported in accordance with practice (D 5434). This practice discusses some aspects of sample preservation after the sampling event. For information on preservation and transportation process of soil samples, consult Practice D 4220. This practice does not address environmental sampling; consult D 6169 and D 6232for information on sampling for environmental investigations.

1.4 The values stated in inch-pound units are to be regarded as the standard. The SI values given in parentheses are provided for information purposes only. The tubing tolerances presented in Table 2 are from sources available in North America. Use of metric equivalent is acceptable as long as thickness and proportions are similar to those required in this 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.*

1.6 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:*

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

D 1452 Practice for Soil Investigation and Sampling by Auger Borings[2]

D 1586 Penetration Resistance and Split Barrel Sampling of Soils[2]

D 2488 Practice for Description and Identification of Soils (Visual-Manual Procedure)[2]

D 3550 Practice for Ring-Lined Barrel Sampling of Soils[2]

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

D 4220 Practices for Preserving and Transporting Soil Samples[2]

D 5434 Guide for Field Logging of Subsurface Explorations of Soil and Rock[3]

D 5783 Guide for Use of Rotary Drilling with Water-Based Drilling Fluid for Geoenvironmental Exploration and the Installation of Subsurface Water-Quality Monitoring Devices[3]

D 6151 Practice for Using Hollow-Stem Augers for Geotechnical Exploration and Soil Sampling[3]

D 6169 Guide for Selection of Soil and Rock Sampling

[1] This practice is under the jurisdiction of ASTM Committee D18 on Soil and Rock and is the direct responsibility of Subcommittee D18.02 on Sampling and Related Field Testing for Soil Investigations.

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

[3] *Annual Book of ASTM Standards,* Vol 04.09.

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

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TABLE 1 Suitable Thin-Walled Steel Sample Tubes[A]

Outside diameter (D_o):			
in.	2	3	5
mm	50.8	76.2	127
Wall thickness:			
Bwg	18	16	11
in.	0.049	0.065	0.120
mm	1.24	1.65	3.05
Tube length:			
in.	36	36	54
m	0.91	0.91	1.45
Inside clearance ratio, %	<1	<1	<1

[A] The three diameters recommended in Table 1 are indicated for purposes of standardization, and are not intended to indicate that sampling tubes of intermediate or larger diameters are not acceptable. Lengths of tubes shown are illustrative. Proper lengths to be determined as suited to field conditions.

TABLE 2 Dimensional Tolerances for Thin-Walled Tubes

Nominal Tube Diameters from Table 1[A] Tolerances						
Size Outside Diameter	2 in.	50.8 mm	3 in.	76.2 mm	5 in.	127 mm
Outside diameter, D_o	+0.007 -0.000	+0.179 -0.000	+0.010 -0.000	+0.254 -0.000	+0.015 -0.000	0.381 -0.000
Inside diameter, D_i	+0.000 -0.007	+0.000 -0.179	+0.000 -0.010	+0.000 -0.254	+0.000 -0.015	+0.000 -0.381
Wall thickness	±0.007	±0.179	±0.010	±0.254	±0.015	±0.381
Ovality	0.015	0.381	0.020	0.508	0.030	0.762
Straightness	0.030/ft	2.50/m	0.030/ft	2.50/m	0.030/ft	2.50/m

[A] Intermediate or larger diameters should be proportional. Specify only two of the first three tolerances; that is, D_o and D_i, or D_o and Wall thickness, or D_i and Wall thickness.

Devices Used With Drill Rigs for Environmental Investigations[3]

D 6232 Guide for Selection of Sampling Equipment for Waste and Contaminated Media Data Collection Activities[4]

3. Terminology

3.1 *Definitions:*

3.1.1 For common definitions of terms in this standard, refer to Terminology D 653.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *inside clearance ratio, %*—the ratio of the difference in the inside diameter of the tube, D_i, minus the inside diameter of the cutting edge, D_e, to the inside diameter of the tube, D_i expressed as a percentage (see Fig. 1).

3.2.2 *ovality*—the cross section of the tube that deviates from a perfect circle.

4. Summary of Practice

4.1 A relatively undisturbed sample is obtained by pressing a thin-walled metal tube into the in-situ soil at the bottom of a boring, removing the soil-filled tube, and applying seals to the soil surfaces to prevent soil movement and moisture gain or loss.

5. Significance and Use

5.1 This practice, or Practice D 3550 with thin wall shoe, is used when it is necessary to obtain a relatively undisturbed specimen suitable for laboratory tests of engineering properties or other tests that might be influenced by soil disturbance.

NOTE 2—The quality of the result produced by this standard is dependent on the competence of the personnel performing it, and the suitability of the equipment and facilities used. Agencies that meet the criteria of Practice D 3740 are generally considered capable of competent and objective sampling. Users of this practice. are cautioned that compliance with Practice D 3740 does not in itself assure reliable results. Reliable results depend on many factors; Practice D 5740 provides a means of evaluating some of those factors.

6. Apparatus

6.1 *Drilling Equipment*—When sampling in a boring, any drilling equipment may be used that provides a reasonably clean hole; that minimizes disturbance of the soil to be sampled; and that does not hinder the penetration of the thin-walled sampler. Open borehole diameter and the inside diameter of driven casing or hollow stem auger shall not exceed 3.5 times the outside diameter of the thin-walled tube.

6.2 *Sampler Insertion Equipment*, shall be adequate to provide a relatively rapid continuous penetration force. For hard formations it may be necessary, although not recommended, to drive the thin-walled tube sampler.

6.3 *Thin-Walled Tubes*, should be manufactured to the dimensions as shown in Fig. 1. They should have an outside diameter of 2 to 5 in. (50 to 130 mm) and be made of metal having adequate strength for the type of soil to be sampled. Tubes shall be clean and free of all surface irregularities including projecting weld seams. Other diameters may be used but the tube dimensions should be proportional to the tube designs presented here.

6.3.1 *Length of Tubes*—See Table 1 and 7.4.1.

6.3.2 *Tolerances*, shall be within the limits shown in Table 2.

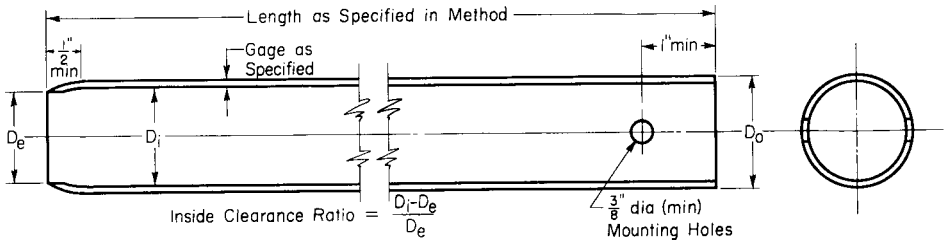
6.3.3 *Inside Clearance Ratio*, should be not greater than 1 % unless specified otherwise for the type of soil to be sampled. Generally, the inside clearance ratio used should increase with the increase in plasticity of the soil being sampled, except for sensitive soils or where local experience indicates otherwise. See 3.2.1 and Fig. 1 for definition of inside clearance ratio.

6.3.4 *Corrosion Protection*—Corrosion, whether from galvanic or chemical reaction, can damage or destroy both the thin-walled tube and the sample. Severity of damage is a function of time as well as interaction between the sample and the tube. Thin-walled tubes should have some form of protective coating, unless the soil is to be extruded less than 3 days. The type of coating to be used may vary depending upon the material to be sampled. Plating of the tubes or alternate base metals may be specified. Galvanized tubes are often used when long term storage is required. Coatings may include a light coat of lubricating oil, lacquer, epoxy, Teflon, zinc oxide, and others.

NOTE 3—Most coating materials are not resistant to scratching by soils that contain sands. Consideration should be given for prompt testing of the sample because chemical reactions between the metal and the soil sample con occur with time.

6.4 *Sampler Head*, serves to couple the thin-walled tube to the insertion equipment and, together with the thin-walled tube,

[4] *Annual Book of ASTM Standards*, Vol 11.04.



NOTE 1—Minimum of two mounting holes on opposite sides for D_o smaller than 4 in. (101.6 mm).
NOTE 2—Minimum of four mounting holes equally spaced for D_o 4 in. (101.6 mm) and larger.
NOTE 3—Tube held with hardened screws or other suitable means.
NOTE 4—2-in (50.8 mm) outside-diameter tubes are specified with an 18-gage wall thickness to comply with area ratio criteria accepted for "undisturbed samples." Users are advised that such tubing is difficult to locate and can be extremely expensive in small quantities. Sixteen-gage tubes are generally readily available.

Metric Equivalent Conversions

in.	mm
⅜	9.53
½	12.7
1	25.4
2	50.8
3	76.2
4	101.6
5	127

FIG. 1 Thin-Walled Tube for Sampling

comprises the thin-walled tube sampler. The sampler head shall contain a venting area and suitable check valve with the venting area to the outside equal to or greater than the area through the check valve. In some special cases, a check valve may not be required but venting is required to avoid sample compression. Attachment of the head to the tube shall be concentric and coaxial to assure uniform application of force to the tube by the sampler insertion equipment.

7. Procedure

7.1 Remove loose material from the center of a casing or hollow stem auger as carefully as possible to avoid disturbance of the material to be sampled. If groundwater is encountered, maintain the liquid level in the borehole at or above ground water level during the drilling and sampling operation.

7.2 Bottom discharge bits are not permitted. Side discharge bits may be used, with caution. Jetting through an open-tube sampler to clean out the borehole to sampling elevation is not permitted.

NOTE 4—Roller bits are available in downward-jetting and diffused-jet configurations. Downward-jetting configuration rock bits are not acceptable. Diffuse-jet configurations are generally acceptable.

7.3 Lower the sampling apparatus so that the sample tube's bottom rests on the bottom of the hole and record depth to the bottom of the sample tube to the nearest 0.1-ft (.03 m)

7.3.1 Keep the sampling apparatus plumb during lowering, thereby preventing the cutting edge of the tube from scraping the wall of the borehole.

7.4 Advance the sampler without rotation by a continuous relatively rapid downward motion and record length of advancement to the nearest 1 in. (25 mm).

7.4.1 Determine the length of advance by the resistance and condition of the soil formation, but the length shall never exceed 5 to 10 diameters of the tube in sands and 10 to 15 diameters of the tube in clays. In no case shall a length of advance be greater than the sample-tube length minus an allowance for the sampler head and a minimum of 3-in. (75 mm) for sludge and end cuttings.

NOTE 5—The mass of sample, laboratory handling capabilities, transportation problems, and commercial availability of tubes will generally limit maximum practical lengths to those shown in Table 1.

7.5 When the soil formation is too hard for push-type insertion, the tube may be driven or Practice D 3550 may be used. If driving methods are used, the data regarding weight and fall of the hammer and penetration achieved must be shown in the report. Additionally, that tube must be prominently labeled a "driven sample."

7.6 Withdraw the sampler from the soil formation as carefully as possible in order to minimize disturbance of the sample. The tube can be slowly rotated to shear the material at the end of the tube, and to relieve water and/or suction pressures and improve recovery. Where the soil formation is soft, a delay before withdraw of the sampler (typically 5 to 30 minutes) may improve sample recovery.

8. Sample Measurement, Sealing and Labeling

8.1 Upon removal of the tube, remove the drill cuttings in the upper end of the tube and measure the length of the soil sample recovered to the nearest 0.25 in. (5 mm) in the tube. Seal the upper end of the tube. Remove at least 1 in. (25 mm) of material from the lower end of the tube. Use this material for soil description in accordance with Practice D 2488. Measure the overall sample length. Seal the lower end of the tube. Alternatively, after measurement, the tube may be sealed without removal of soil from the ends of the tube.

8.1.1 Tubes sealed over the ends, as opposed to those sealed

with expanding packers, should be provided with spacers or appropriate packing materials, or both prior to sealing the tube ends to provide proper confinement. Packing materials must be nonabsorbent and must maintain their properties to provide the same degree of sample support with time.

8.1.2 Depending on the requirements of the investigation, field extrusion and packaging of extruded soil samples can be performed. This allows for physical examination and classification of the sample. Samples are extruded in special hydraulic jacks equipped with properly sized platens to extrude the core in a continuous smooth speed. In some cases, further extrusion may cause sample disturbance reducing suitability for testing of engineering properties. In other cases, if damage is not significant, cores can be extruded and preserved for testing (D 4220). Bent or damaged tubes should be cut off before extruding.

8.2 Prepare and immediately affix labels or apply markings as necessary to identify the sample (see Section 9). Assure that the markings or labels are adequate to survive transportation and storage.

NOTE 6—Top end of the tube should be labeled "top".

9. Field Log

9.1 Record the information that may be required for preparing field logs in general accordance to ASTM D 5434 "Guide for Field Logging of Subsurface Explorations of Soil and Rock". This guide is used for logging explorations by drilling and sampling. Some examples of the information required include;

9.1.1 Name and location of the project,

9.1.2 Boring number,

9.1.3 Log of the soil conditions,

9.1.4 Surface elevation or reference to a datum to the nearest foot (0.5 m) or better,

9.1.5 Location of the boring,

9.1.6 Method of making the borehole,

9.1.7 Name of the drilling foreman and company, and

9.1.8 Name of the drilling inspector(s).

9.1.9 Date and time of boring-start and finish,

9.1.10 Depth to groundwater level: date and time measured,

9.2 Recording the appropriate sampling information is required as follows:

9.2.1 Depth to top of sample to the nearest 0.1 ft. (.03 m) and number of sample,

9.2.2 Description of thin-walled tube sampler: size, type of metal, type of coating,

9.2.3 Method of sampler insertion: push or drive,

9.2.4 Method of drilling, size of hole, casing, and drilling fluid used,

9.2.5 Soil description in accordance with Practice D 2488,

9.2.6 Length of sampler advance (push), and

9.2.7 Recovery: length of sample obtained.

10. Keywords

10.1 geologic investigations; sampling; soil exploration; soil investigations; subsurface investigations; undisturbed

SUMMARY OF CHANGES

In accordance with committee D18 policy, this section identifies the location of changes to this standard since the last edition, 1994, which may impact the use of this standard.

(1) Editorial corrections to various sections based on comments received from Committee Balloting

(2) Added D 6232 to Section 2.

(3) Changed Note 7 to Section 8.1.2.

(4) Renumbered Note 8.

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Designation: D 2216 – 98

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Standard Test Method for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass[1]

This standard is issued under the fixed designation D 2216; 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 laboratory determination of the water (moisture) content by mass of soil, rock, and similar materials where the reduction in mass by drying is due to loss of water except as noted in 1.4, 1.5, and 1.7. For simplicity, the word "material" hereinafter also refers to either soil or rock, whichever is most applicable.

1.2 Some disciplines, such as soil science, need to determine water content on the basis of volume. Such determinations are beyond the scope of this test method.

1.3 The water content of a material is defined in 3.2.1.

1.4 The term "solid material" as used in geotechnical engineering is typically assumed to mean naturally occurring mineral particles of soil and rock that are not readily soluble in water. Therefore, the water content of materials containing extraneous matter (such as cement, and the like) may require special treatment or a qualified definition of water content. In addition, some organic materials may be decomposed by oven drying at the standard drying temperature for this method (110°C). Materials containing gypsum (calcium sulfate dihydrate or other compounds having significant amounts of hydrated water) may present a special problem as this material slowly dehydrates at the standard drying temperature (110°C) and at very low relative humidities, forming a compound (calcium sulfate hemihydrate) which is not normally present in natural materials except in some desert soils. In order to reduce the degree of dehydration of gypsum in those materials containing gypsum, or to reduce decomposition in highly organic soils, it may be desirable to dry these materials at 60°C or in a desiccator at room temperature. Thus, when a drying temperature is used which is different from the standard drying temperature as defined by this test method, the resulting water content may be different from standard water content determined at the standard drying temperature.

NOTE 1—Test Methods D 2974 provides an alternate procedure for determining water content of peat materials.

1.5 Materials containing water with substantial amounts of soluble solids (such as salt in the case of marine sediments) when tested by this method will give a mass of solids which includes the previously soluble solids. These materials require special treatment to remove or account for the presence of precipitated solids in the dry mass of the specimen, or a qualified definition of water content must be used. For example, see Noorany[2] regarding information on marine soils.

1.6 This test method requires several hours for proper drying of the water content specimen. Test Method D 4643 provides for drying of the test specimen in a microwave oven which is a shorter process. Also see Gilbert[3] for details on the background of this test method.

1.7 This standard requires the drying of material in an oven at high temperatures. If the material being dried is contaminated with certain chemicals, health and safety hazards can exist. Therefore, this standard should not be used in determining the water content of contaminated soils unless adequate health and safety precautions are taken.

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:*

D 653 Terminology Relating to Soil, Rock, and Contained Fluids[4]

D 2974 Test Methods for Moisture, Ash, and Organic Matter of Peat and Other Organic Soils[4]

D 4220 Practice for Preserving and Transporting Soil Samples[4]

D 4318 Test Method for Liquid Limit, Plastic Limit, and Plasticity Index of Soils[4]

D 4643 Test Method for Determination of Water (Moisture) Content of Soil by the Microwave Oven Method[4]

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

[1] This test method is under the jurisdiction of ASTM Committee D-18 on Soil and Rock and is the direct responsibility of Subcommittee D18.03 on Texture, Plasticity and Density Characteristics of Soils.

Current edition approved Feb. 10, 1998. Published January 1999. Originally published as D 2216 – 63 T. Last previous edition D 2216 – 92.

[2] Noorany, I., "Phase Relations in Marine Soils", Journal of Geotechnical Engineering, ASCE, Vol. 110, No. 4, April 1984, pp. 539–543.

[3] Gilbert, P.A., "Computer Controlled Microwave Oven System for Rapid Water Content Determination", Tech. Report GL-88–21, Department of the Army, Waterways Experiment Station, Corps of Engineers, Vicksburg, MS, November 1988.

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

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

D 6026 Guide for Using Significant Digits in Calculating and Reporting Geotechnical Test Data[5]

E 145 Specification for Gravity-Convection And Forced-Ventilation Ovens[6]

3. Terminology

3.1 Refer to Terminology D 653 for standard definitions of terms.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *water content (of a material)*—the ratio expressed as a percent of the mass of "pore" or "free" water in a given mass of material to the mass of the solid material. A standard temperature of 110° ± 5°C is used to determine these masses.

4. Summary of Test Method

4.1 A test specimen is dried in an oven at a temperature of 110° ± 5°C to a constant mass. The loss of mass due to drying is considered to be water. The water content is calculated using the mass of water and the mass of the dry specimen.

5. Significance and Use

5.1 For many materials, the water content is one of the most significant index properties used in establishing a correlation between soil behavior and its index properties.

5.2 The water content of a material is used in expressing the phase relationships of air, water, and solids in a given volume of material.

5.3 In fine-grained (cohesive) soils, the consistency of a given soil type depends on its water content. The water content of a soil, along with its liquid and plastic limits as determined by Test Method D 4318, is used to express its relative consistency or liquidity index.

6. Apparatus

6.1 *Drying Oven*, thermostatically-controlled, preferably of the forced-draft type, meeting the requirements of Specification E 145 and capable of maintaining a uniform temperature of 110 ± 5°C throughout the drying chamber.

6.2 *Balances*—All balances must meet the requirements of Specification D 4753 and this section. A Class GP1 balance of 0.01g readability is required for specimens having a mass of up to 200 g (excluding mass of specimen container) and a Class GP2 balance of 0.1g readability is required for specimens having a mass over 200 g. However, the balance used may be controlled by the number of significant digits needed (see 8.2.1 and 12.1.2).

6.3 *Specimen Containers*—Suitable containers made of material resistant to corrosion and change in mass upon repeated heating, cooling, exposure to materials of varying pH, and cleaning. Unless a dessicator is used, containers with close-fitting lids shall be used for testing specimens having a mass of less than about 200 g; while for specimens having a mass greater than about 200 g, containers without lids may be used (see Note 7). One container is needed for each water content determination.

NOTE 2—The purpose of close-fitting lids is to prevent loss of moisture from specimens before initial mass determination and to prevent absorption of moisture from the atmosphere following drying and before final mass determination.

6.4 *Desiccator*—A desiccator cabinet or large desiccator jar of suitable size containing silica gel or anhydrous calcium sulfate. It is preferable to use a desiccant which changes color to indicate it needs reconstitution. See 10.5.

NOTE 3—Anhydrous calcium sulfate is sold under the trade name Drierite.

6.5 *Container Handling Apparatus*, gloves, tongs, or suitable holder for moving and handling hot containers after drying.

6.6 *Miscellaneous*, knives, spatulas, scoops, quartering cloth, sample splitters, etc, as required.

7. Samples

7.1 Samples shall be preserved and transported in accordance with Practice 4220 Groups B, C, or D soils. Keep the samples that are stored prior to testing in noncorrodible airtight containers at a temperature between approximately 3 and 30°C and in an area that prevents direct contact with sunlight. Disturbed samples in jars or other containers shall be stored in such a way as to prevent or minimize moisture condensation on the insides of the containers.

7.2 The water content determination should be done as soon as practicable after sampling, especially if potentially corrodible containers (such as thin-walled steel tubes, paint cans, etc.) or plastic sample bags are used.

8. Test Specimen

8.1 For water contents being determined in conjunction with another ASTM method, the specimen mass requirement stated in that method shall be used if one is provided. If no minimum specimen mass is provided in that method then the values given below shall apply. See Howard[7] for background data for the values listed.

8.2 The minimum mass of moist material selected to be representative of the total sample shall be in accordance with the following:

Maximum particle size (100 % passing)	Standard Sieve Size	Recommended minimum mass of moist test specimen for water content reported to ±0.1 %	Recommended minimum mass of moist test specimen for water content reported to ±1 %
2 mm or less	No. 10	20 g	20 g[A]
4.75 mm	No. 4	100 g	20 g[A]
9.5 mm	⅜-in.	500 g	50 g
19.0 mm	¾-in.	2.5 kg	250 g
37.5 mm	1½ in.	10 kg	1 kg
75.0 mm	3-in.	50 kg	5 kg

[A] To be representative not less than 20 g shall be used.

8.2.1 The minimum mass used may have to be increased to obtain the needed significant digits for the mass of water when reporting water contents to the nearest 0.1 % or as indicated in 12.1.2.

[5] *Annual Book of ASTM Standards*, Vol 04.09.

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

[7] Howard, A. K., "Minimum Test Specimen Mass for Moisture Content Determination", *Geotechnical Testing Journal*, A.S.T.M., Vol. 12, No. 1, March 1989, pp. 39-44.

8.3 Using a test specimen smaller than the minimum indicated in 8.2 requires discretion, though it may be adequate for the purposes of the test. Any specimen used not meeting these requirements shall be noted on the test data forms or test data sheets.

8.4 When working with a small (less than 200g) specimen containing a relatively large gravel particle, it is appropriate not to include this particle in the test specimen. However, any discarded material shall be described and noted on the test data forms or test data sheets.

8.5 For those samples consisting entirely of intact rock, the minimum specimen mass shall be 500 g. Representative portions of the sample may be broken into smaller particles, depending on the sample's size, the container and balance being used and to facilitate drying to constant mass, see 10.4. Specimen sizes as small as 200 g may be tested if water contents of only two significant digits are acceptable.

9. Test Specimen Selection

9.1 When the test specimen is a portion of a larger amount of material, the specimen must be selected to be representative of the water condition of the entire amount of material. The manner in which the test specimen is selected depends on the purpose and application of the test, type of material being tested, the water condition, and the type of sample (from another test, bag, block, and the likes.)

9.2 For disturbed samples such as trimmings, bag samples, and the like, obtain the test specimen by one of the following methods (listed in order of preference):

9.2.1 If the material is such that it can be manipulated and handled without significant moisture loss and segregation, the material should be mixed thoroughly and then select a representative portion using a scoop of a size that no more than a few scoopfuls are required to obtain the proper size of specimen defined in 8.2.

9.2.2 If the material is such that it cannot be thoroughly mixed or mixed and sampled by a scoop, form a stockpile of the material, mixing as much as possible. Take at least five portions of material at random locations using a sampling tube, shovel, scoop, trowel, or similar device appropriate to the maximum particle size present in the material. Combine all the portions for the test specimen.

9.2.3 If the material or conditions are such that a stockpile cannot be formed, take as many portions of the material as practical, using random locations that will best represent the moisture condition. Combine all the portions for the test specimen.

9.3 Intact samples such as block, tube, split barrel, and the like, obtain the test specimen by one of the following methods depending on the purpose and potential use of the sample.

9.3.1 Using a knife, wire saw, or other sharp cutting device, trim the outside portion of the sample a sufficient distance to see if the material is layered and to remove material that appears more dry or more wet than the main portion of the sample. If the existence of layering is questionable, slice the sample in half. If the material is layered, see 9.3.3.

9.3.2 If the material is not layered, obtain the specimen meeting the mass requirements in 8.2 by: (1) taking all or one-half of the interval being tested; (2) trimming a representative slice from the interval being tested; or (3) trimming the exposed surface of one-half or from the interval being tested.

NOTE 4—Migration of moisture in some cohesionless soils may require that the full section be sampled.

9.3.3 If a layered material (or more than one material type is encountered), select an average specimen, or individual specimens, or both. Specimens must be properly identified as to location, or what they represent, and appropriate remarks entered on the test data forms or test data sheets.

10. Procedure

10.1 Determine and record the mass of the clean and dry specimen container (and its lid, if used).

10.2 Select representative test specimens in accordance with Section 9.

10.3 Place the moist test specimen in the container and, if used, set the lid securely in position. Determine the mass of the container and moist material using a balance (see 6.2) selected on the basis of the specimen mass. Record this value.

NOTE 5—To prevent mixing of specimens and yielding of incorrect results, all containers, and lids if used, should be numbered and the container numbers shall be recorded on the laboratory data sheets. The lid numbers should match the container numbers to eliminate confusion.

NOTE 6—To assist in the oven-drying of large test specimens, they should be placed in containers having a large surface area (such as pans) and the material broken up into smaller aggregations.

10.4 Remove the lid (if used) and place the container with moist material in the drying oven. Dry the material to a constant mass. Maintain the drying oven at 110 ± 5°C unless otherwise specified (see 1.4). The time required to obtain constant mass will vary depending on the type of material, size of specimen, oven type and capacity, and other factors. The influence of these factors generally can be established by good judgment, and experience with the materials being tested and the apparatus being used.

NOTE 7—In most cases, drying a test specimen overnight (about 12 to 16 h) is sufficient. In cases where there is doubt concerning the adequacy of drying, drying should be continued until the change in mass after two successive periods (greater than 1 h) of drying is an insignificant amount (less than about 0.1 %). Specimens of sand may often be dried to constant mass in a period of about 4 h, when a forced-draft oven is used.

NOTE 8—Since some dry materials may absorb moisture from moist specimens, dried specimens should be removed before placing moist specimens in the same oven. However, this would not be applicable if the previously dried specimens will remain in the drying oven for an additional time period of about 16 h.

10.5 After the material has dried to constant mass remove the container from the oven (and replace the lid if used). Allow the material and container to cool to room temperature or until the container can be handled comfortably with bare hands and the operation of the balance will not be affected by convection currents and/or its being heated. Determine the mass of the container and oven-dried material using the same type/capacity balance used in 10.3. Record this value. Tight fitting lids shall be used if it appears that the specimen is absorbing moisture from the air prior to determination of its dry mass.

NOTE 9—Cooling in a desiccator is acceptable in place of tight fitting lids since it greatly reduces absorption of moisture from the atmosphere during cooling especially for containers without tight fitting lids.

11. Calculation

11.1 Calculate the water content of the material as follows:

$$w = [(M_{cws} - M_{cs})/(M_{cs} - M_c)] \times 100 = \frac{M_w}{M_s} \times 100 \quad (1)$$

where:

w = water content, %,
M_{cws} = mass of container and wet specimen, g,
M_{cs} = mass of container and oven dry specimen, g,
M_c = mass of container, g,
M_w = mass of water ($M_w = M_{cws} - M_{cds}$), g, and
M_s = mass of solid particles ($M_s = M_{cds} - M_c$), g.

12. Report

12.1 Test data forms or test data sheets shall include the following:

12.1.1 Identification of the sample (material) being tested, such as boring number, sample number, test number, container number etc.

12.1.2 Water content of the specimen to the nearest 1 % or 0.1 %, as appropriate based on the minimum sample used. If this method is used in concert with another method, the water content of the specimen should be reported to the value required by the test method for which the water content is being determined. Refer to Guide D 6026 for guidance concerning significant digits, especially if the value obtained from this test method is to be used to calculate other relationships such as unit weight or density. For instance, if it is desired to express dry unit weight to the nearest 0.1 lbf/f^3(0.02 kN/m^3), it may be necessary to use a balance with a greater readability or use a larger specimen mass to obtain the required significant digits the mass of water so that the water content can be determined to the required significant digits. Also, the significant digits in Guide D 6026 may need to be increased when calculating phase relationships requiring four significant digits.

12.1.3 Indicate if test specimen had a mass less than the minimum indicated in 8.2.

12.1.4 Indicate if test specimen contained more than one material type (layered, etc.).

12.1.5 Indicate the temperature of drying if different from 110 ± 5°C.

12.1.6 Indicate if any material (size and amount) was excluded from the test specimen.

12.2 When reporting water content in tables, figures, etc., any data not meeting the requirements of this test method shall be noted, such as not meeting the mass, balance, or temperature requirements or a portion of the material is excluded from the test specimen.

13. Precision and Bias

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

13.2 *Statements on Precision*:

13.2.1 *Single-Operator Precision (Repeatability)*—The single-operator coefficient of variation has been found to be 2.7 percent. Therefore, results of two properly conducted tests by the same operator with the same equipment should not be considered suspect unless they differ by more than 7.8 percent of their mean.[8]

13.2.2 *Multilaboratory Precision (Reproducibility)*[9]—The multilaboratory coefficient of variation has been found to be 5.0 percent. Therefore, results of two properly conducted tests by different operators using different equipment should not be considered suspect unless they differ by more than 14.0 percent of their mean.

14. Keywords

14.1 consistency; index property; laboratory; moisture analysis; moisture content; soil aggregate; water content

[8] These numbers represent the (1s) and (d2s) limits as described in Practice C 670.

[9] These numbers represent the (1s %) and (d2s %) limits as described in Practice C 670.

SUMMARY OF CHANGES

Committee D-18 has identified the location of selected changes to this standard since the last issue. (D 2216-92) that may impact the use of this standard.

(*1*) Title was changed to emphasize that mass is the basis for the standard.

(*2*) Section 1.1 was revised to clarify “similar materials”.

(*3*) New 1.2 was added to explain a limitation in scope. The other sections were renumbered as appropriate.

(*4*) An information reference was included in 1.5.

(*5*) An information reference was included in 1.6

(*6*) A new ASTM referenced document was included in 2.1.

(*7*) New Footnotes 2, 3, and 5 were added and identified. Other footnotes were renumbered where necessary for sequential identification.

(*8*) Information concerning balances was added in 6.2

(*9*) Section 6.3 was revised to clarify the use of close-fitting lids, and a reference to Note 8 was added.

(*10*) In 6.4, “anhydrous calcium phosphate” was changed to “anyhydrous calcium sulfate” to correct an error and to agree with Note 3.

(*11*) A typo in 8.1 was corrected from “before” to “below” and a footnoted reference was added for information.

(*12*) A portion of 8.2 was deleted for clarity.

(*13*) A new 8.2.1 was added to clarify minimum mass requirements.

(*14*) Sections 8.3, 8.4, 9.3.3, and 12.1 were changed to substitute “test data form/sheet” for “report”.

(*15*) Footnote seven was identified.

(*16*) Section 9.2.1 was revised to improve clarity and intent.

(*17*) The word “possible” was changed to “practical” in 9.2.3.

(*18*) Section 9.3.1 and 9.3.2 were revised to improve clarity and for practicality.
(*19*) A reference to Guide D 6026 was added in 12.1.2.
(*20*) Footnotes 8 and 9 were added to 13.2.1 and 13.2.2, respectively. These were inadvertently omitted from the 1992 version. These explanations provide clarity and information to the user.
(*21*) A Summary of Changes was added to reflect D-18's policy.

The American Society for Testing and Materials takes no position respecting the validity of any patent rights asserted in connection with any item mentioned in this standard. Users of this standard are expressly advised that determination of the validity of any such patent rights, and the risk of infringement of such rights, are entirely their own responsibility.

This standard is subject to revision at any time by the responsible technical committee and must be reviewed every five years and if not revised, either reapproved or withdrawn. Your comments are invited either for revision of this standard or for additional standards and should be addressed to ASTM Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee, which you may attend. If you feel that your comments have not received a fair hearing you should make your views known to the ASTM Committee on Standards, 100 Barr Harbor Drive, West Conshohocken, PA 19428.

Designation: D 2487 – 00

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

This standard is issued under the fixed designation D 2487; 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 E 11).

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 1940's.[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:*

C 117 Test Method for Materials Finer Than 75-µm (No. 200) Sieve in Mineral Aggregates by Washing[3]

C 136 Test Method for Sieve Analysis of Fine and Coarse Aggregates[3]

C 702 Practice for Reducing Field Samples of Aggregate to Testing Size[3]

D 420 Guide to Site Characterization for Engineering, Design and Construction Purposes

D 421 Practice for Dry Preparation of Soil Samples for Particle-Size Analysis and Determination of Soil Constants[4]

D 422 Test Method for Particle-Size Analysis of Soils[4]

D 653 Terminology Relating to Soil, Rock, and Contained Fluids[4]

[1] This standard is under the jurisdiction of ASTM Committee D-18 on Soil and Rock and is the direct responsibility of Subcommittee D18.07 on Identification and Classification of Soils.

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

[3] *Annual Book of ASTM Standards*, Vol 04.02.

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

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

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D 1140 Test Method for Amount of Material in Soils Finer than the No. 200 (75-μm) Sieve[4]
D 2216 Test Method for Laboratory Determination of Water (Moisture) Content of Soil and Rock[4]
D 2217 Practice for Wet Preparation of Soil Samples for Particle-Size Analysis and Determination of Soil Constants[4]
D 2488 Practice for Description and Identification of Soils (Visual-Manual Procedure)[4]
D 3740 Practice for Minimum Requirements for Agencies Engaged in the Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction[5]
D 4083 Practice for Description of Frozen Soils (Visual-Manual Procedure)[4]
D 4318 Test Method for Liquid Limit, Plastic Limit, and Plasticity Index of Soils[4]
D 4427 Classification of Peat Samples by Laboratory Testing[4]
E 11 Specification for Wire-Cloth Sieves for Testing Purposes[6]

3. Terminology

3.1 *Definitions*—Except as listed below, all definitions are in accordance with Terminology D 653.

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.

[5] *Annual Book of ASTM Standards*, Vol 04.09.
[6] *Annual Book of ASTM Standards*, Vol 14.02.

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	Gravels	Clean Gravels	Cu ≥ 4 and 1 ≤ Cc ≤ 3[C]	GW	Well-graded gravel[D]
More than 50 % retained on No. 200 sieve	More than 50 % of coarse fraction retained on No. 4 sieve	Less than 5 % fines[E]	Cu < 4 and/or 1 > Cc > 3[C]	GP	Poorly graded gravel[D]
		Gravels with Fines	Fines classify as ML or MH	GM	Silty gravel[D,F,G]

TABLE 1 *Continued*

Criteria for Assigning Group Symbols and Group Names Using Laboratory Tests[A]				Soil Classification	
				Group Symbol	Group Name[B]
		More than 12 % fines[E]	Fines classify as CL or CH	,urule;1>GC	Clayey gravel[D,F,G]
	Sands	Clean Sands	Cu ≥ 6 and $1 \le Cc \le 3^C$	SW	Well-graded sand[H]
	50 % or more of coarse	Less than 5 % fines[I]	Cu < 6 and/or $1 > Cc > 3^C$	SP	Poorly graded sand[H]
	fraction passes No. 4 sieve	Sands with Fines	Fines classify as ML or MH	SM	Silty sand[F,G,H]
		More than 12 % fines[I]	Fines classify as CL or CH	SC	Clayey sand[F,G,H]
FINE-GRAINED SOILS	Silts and Clays	inorganic	PI > 7 and plots on or above "A" line[J]	CL	Lean clay[K,L,M]
50 % or more passes the No.	Liquid limit less than 50		PI < 4 or plots below "A" line[J]	ML	Silt[K,L,M]
200 seive		organic	Liquid limit − oven dried / Liquid limit − not dried < 0.75	OL	Organic clay[K,L,M,N]
				OL	Organic silt[K,L,M,O]
	Silts and Clays	inorganic	PI plots on or above "A" line	CH	Fat clay[K,L,M]
	Liquid limit 50 or more		PI plots below "A" line	MH	Elastic silt[K,L,M]
		organic	Liquid limit − oven dried / 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] $Cu = D_{60}/D_{10}$ $Cc = (D_{30})^2 / D_{10} \times D_{60}$
[D] If soil contains ≥15 % sand, add "with sand" to group name.
[E] 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
[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] If soil contains ≥15 % gravel, add "with gravel" to group name.
[I] 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
[J] If Atterberg limits plot in hatched area, soil is a CL-ML, silty clay.
[K] If soil contains 15 to 29 % 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.

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 D 2488 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 D 2488.

5.5 This standard may be used in combination with Practice D 4083 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 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 assure reliable testing. Reliable testing depends on several factors; Practice D 3740 provides a means for evaluating some of those factors.

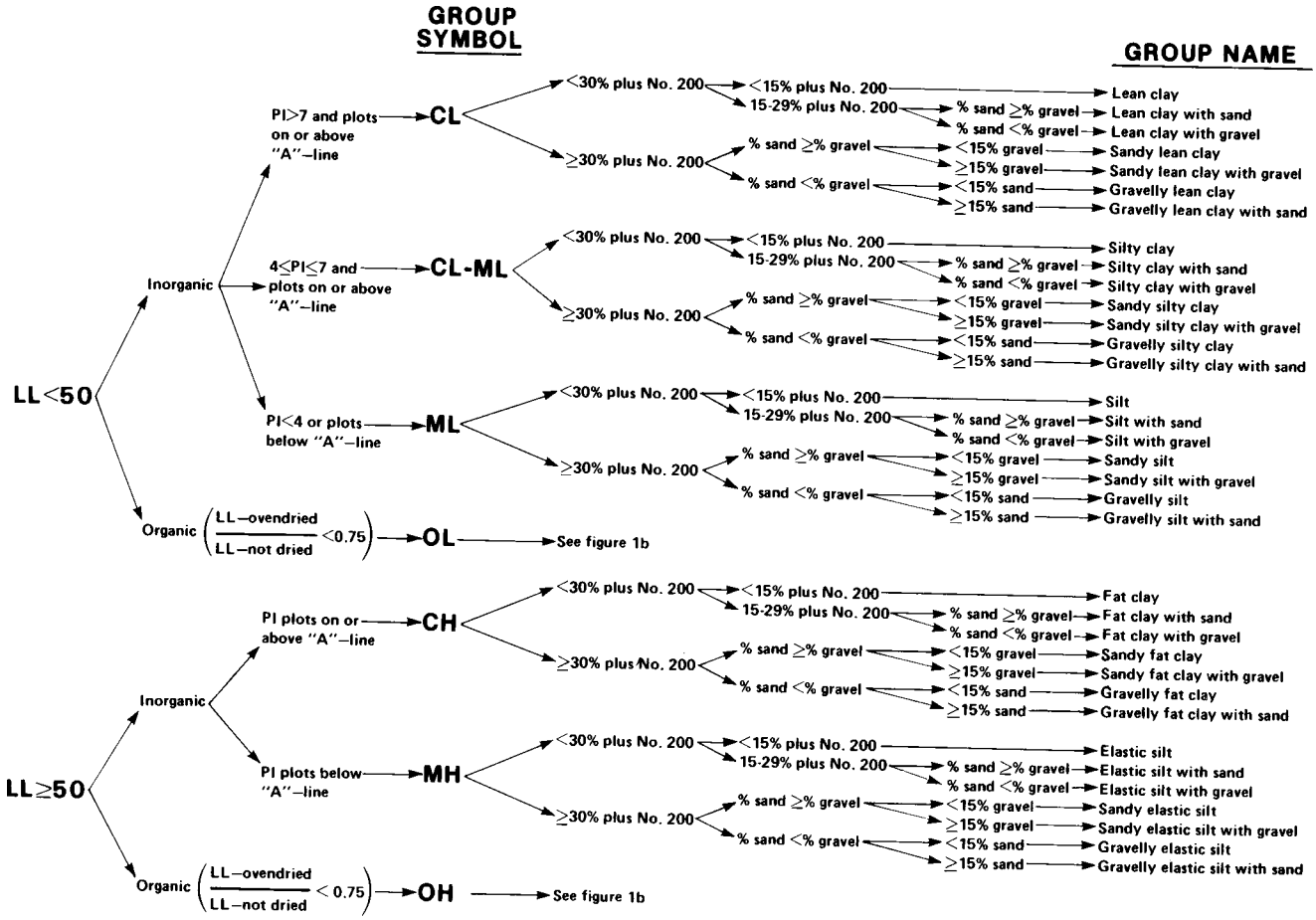

FIG. 1 Flow Chart for Classifying Fine-Grained Soil (50 % or More Passes No. 200 Sieve)

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 D 420 or by other accepted procedures.

7.2 For accurate identification, the minimum amount of test sample required for this test method will depend on which of the laboratory tests need to be performed. Where only the particle-size analysis of the sample is required, specimens having the following minimum dry weights are required:

Maximum Particle Size, Sieve Opening	Minimum Specimen Size, Dry Weight
4.75 mm (No. 4)	100 g (0.25 lb)
9.5 mm (⅜ in.)	200 g (0.5 lb)
19.0 mm (¾ in.)	1.0 kg (2.2 lb)
38.1 mm (1½ in.)	8.0 kg (18 lb)
75.0 mm (3 in.)	60.0 kg (132 lb)

Whenever possible, the field samples should have weights two to four times larger than shown.

7.3 When the liquid and plastic limit tests must also be performed, additional material will be required sufficient to provide 150 g to 200 g of soil finer than the No. 40 (425-μm) sieve.

7.4 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 D 4427.

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.

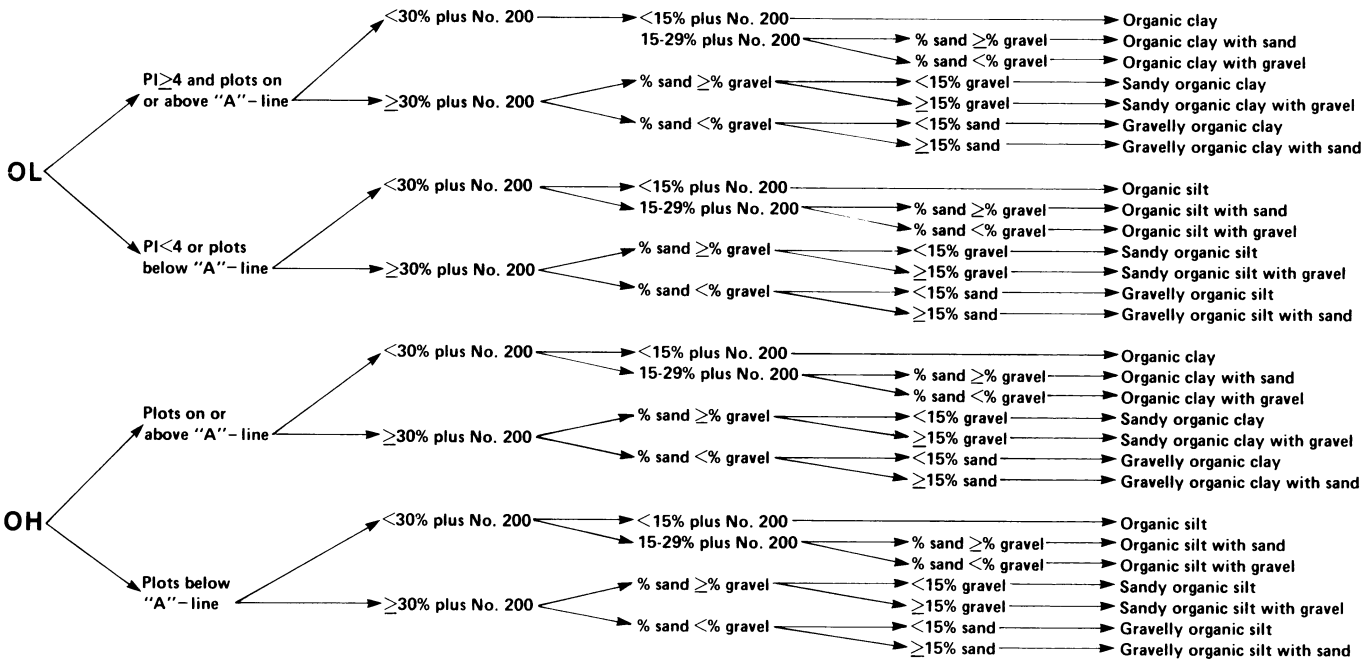

FIG. 2 Flow Chart for Classifying Organic Fine-Grained Soil (50 % or More Passes No. 200 Sieve)

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 D 2488 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 D 2488 and so noted in the report.

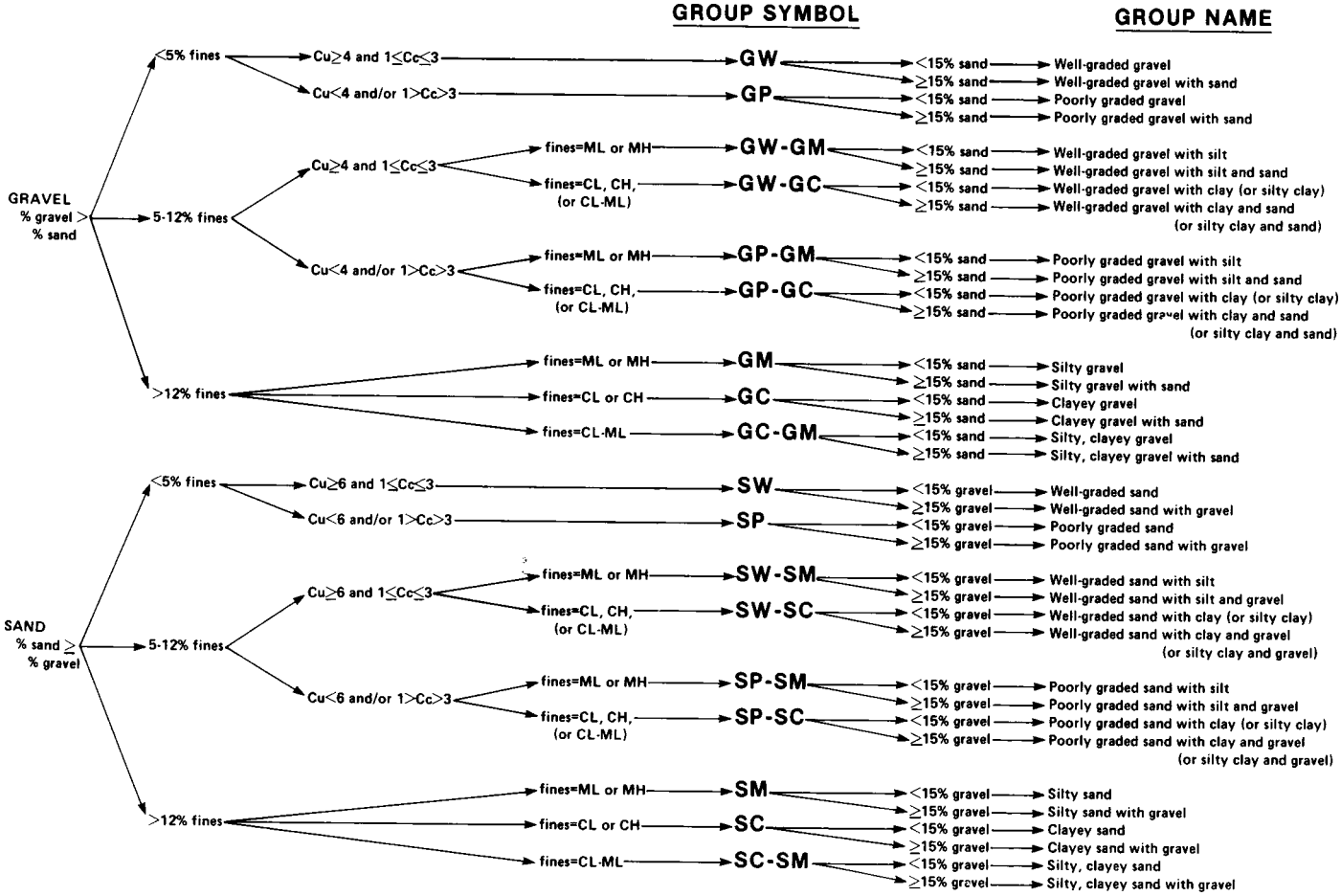

FIG. 3 Flow Chart for Classifying Coarse-Grained Soils (More Than 50 % Retained on No. 200 Sieve)

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 (see Procedure B of Practice D 2217).

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 %.

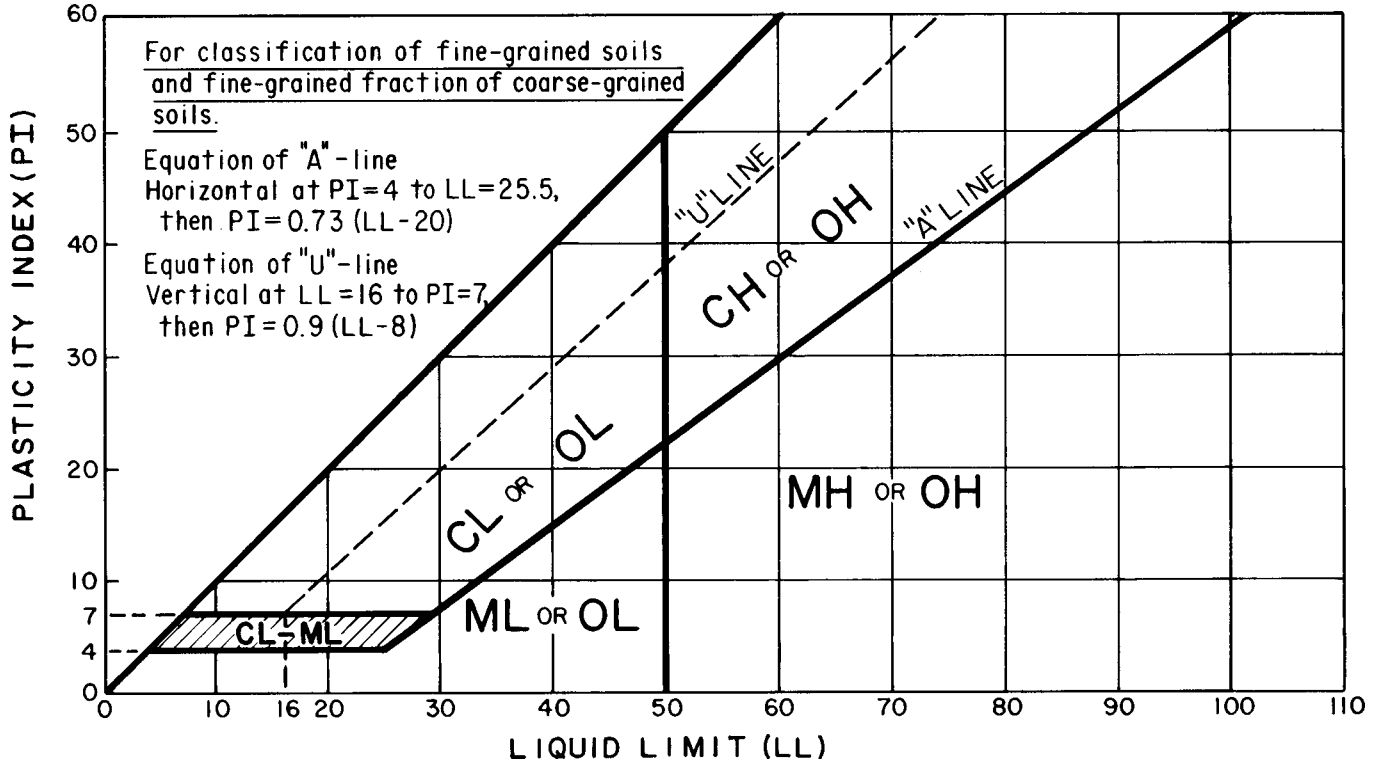

FIG. 4 Plasticity Chart

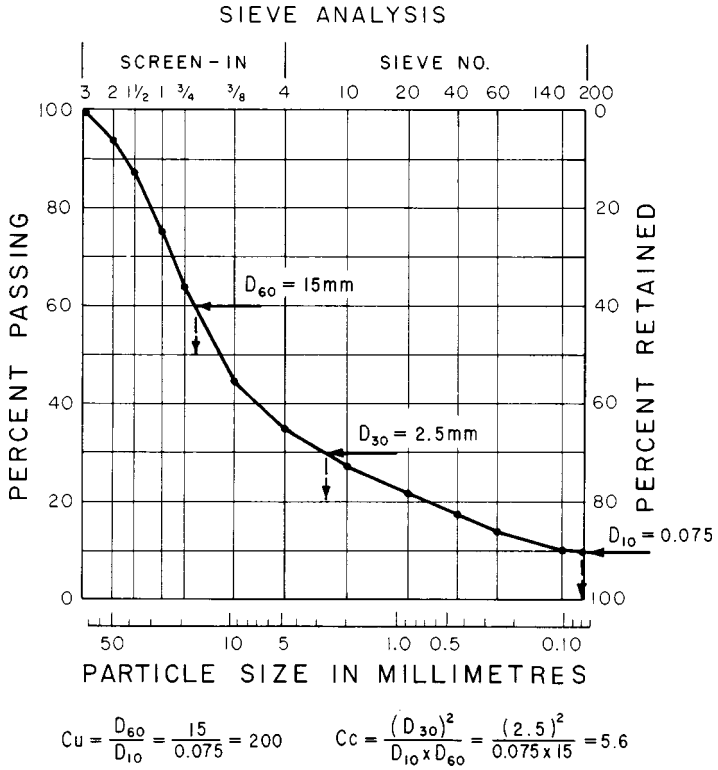

FIG. 5 Cumulative Particle-Size Plot

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 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.

$$Cu = D_{60}/D_{10} \quad (1)$$

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

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.

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 D 2488. 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 D 422, D 1140 and D 4318.

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 D 2488 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*—62 % gravel-size broken shells; 31 % sand and sand-size shell pieces; 7 % fines; 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 D 2216, 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 C 702.

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 Procedure B of Practice D 2217.

X3.7.3 Perform the liquid-limit test in accordance with Test Method D 4318, 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 D 4318, 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 C 702 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 D 422. 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 Method C 136. 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 C 117 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 C 117, being sure to soak the specimen long enough to soften all clayey aggregations, followed by Test Method C 136 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 D 422. 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 D 1140 followed by Method C 136. 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 D 1140 followed by Method C 136 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 D 4318.

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

In accordance with Committee D18 policy, this section identifies the location of changes to this standard since the last edition (1998) that may impact the use of this standard.

(1) Added Practice D 3740 to Section 2.

(2) Added Note 5 under 5.5 and renumbered subsequent notes.

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Designation: D 2488 – 00

Standard Practice for Description and Identification of Soils (Visual-Manual Procedure)[1]

This standard is issued under the fixed designation D 2488; 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 procedures for the description of soils for engineering purposes.

1.2 This practice also describes a procedure for identifying soils, at the option of the user, based on the classification system described in Test Method D 2487. The identification is based on visual examination and manual tests. It must be clearly stated in reporting an identification that it is based on visual-manual procedures.

1.2.1 When precise classification of soils for engineering purposes is required, the procedures prescribed in Test Method D 2487 shall be used.

1.2.2 In this practice, the identification portion assigning a group symbol and name is limited to soil particles smaller than 3 in. (75 mm).

1.2.3 The identification portion of this practice is limited to naturally occurring soils (disturbed and undisturbed).

NOTE 1—This practice may be used as a descriptive system applied to such materials as shale, claystone, shells, crushed rock, etc. (see Appendix X2).

1.3 The descriptive information in this practice may be used with other soil classification systems or for materials other than naturally occurring soils.

1.4 The values stated in inch-pound units are to be regarded as the standard.

1.5 *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.* For specific precautionary statements see Section 8.

1.6 *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:*

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

D 1452 Practice for Soil Investigation and Sampling by Auger Borings[2]

D 1586 Test Method for Penetration Test and Split-Barrel Sampling of Soils[2]

D 1587 Practice for Thin-Walled Tube Sampling of Soils[2]

D 2113 Practice for Diamond Core Drilling for Site Investigation[2]

D 2487 Classification of Soils for Engineering Purposes (Unified Soil Classification System)[2]

D 3740 Practice for Minimum Requirements for Agencies Engaged in the Testing and/or Inspection of Soil and rock as Used in Engineering Design and Construction[3]

D 4083 Practice for Description of Frozen Soils (Visual-Manual Procedure)[2]

3. Terminology

3.1 *Definitions*—Except as listed below, all definitions are in accordance with Terminology D 653.

NOTE 2—For particles retained on a 3-in. (75-mm) US 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) 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) 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

[1] This practice is under the jurisdiction of ASTM Committee D-18 on Soil and Rock and is the direct responsibility of Subcommittee D18.07 on Identification and Classification of Soils.

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

[3] *Annual Book of ASTM Standards*, Vol 04.09.

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

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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 (see Fig. 3 of Test Method D 2487).

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) sieve with the following subdivisions:

coarse—passes a 3-in. (75-mm) sieve and is retained on a ¾-in. (19-mm) sieve.

fine—passes a ¾-in. (19-mm) sieve and is retained on a 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 primarily 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) sieve with the following subdivisions:

coarse—passes a No. 4 (4.75-mm) sieve and is retained on a No. 10 (2.00-mm) sieve.

medium—passes a No. 10 (2.00-mm) sieve and is retained on a No. 40 (425-µm) sieve.

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

3.1.7 *silt*—soil passing a No. 200 (75-µm) 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 the plot of plasticity index versus liquid limit falls below the "A" line (see Fig. 3 of Test Method D 2487).

4. Summary of Practice

4.1 Using visual examination and simple manual tests, this practice gives standardized criteria and procedures for describing and identifying soils.

4.2 The soil can be given an identification by assigning a group symbol(s) and name. The flow charts, Fig. 1a and Fig. 1b for fine-grained soils, and Fig. 2, for coarse-grained soils, can be used to assign the appropriate group symbol(s) and name. If the soil has properties which do not distinctly place it into a specific group, borderline symbols may be used, see Appendix X3.

NOTE 3—It is suggested that a distinction be made between *dual symbols* and *borderline symbols.*

Dual Symbol—A dual symbol is two symbols separated by a hyphen, for example, GP-GM, SW-SC, CL-ML used to indicate that the soil has been identified as having the properties of a classification in accordance with Test Method D 2487 where two symbols are required. Two symbols are required when the soil has between 5 and 12 % fines or when the liquid limit and plasticity index values plot in the CL-ML area of the plasticity chart.

Borderline Symbol—A borderline symbol is two symbols separated by a slash, for example, CL/CH, GM/SM, CL/ML. A borderline symbol should be used to indicate that the soil has been identified as having properties that do not distinctly place the soil into a specific group (see Appendix X3).

5. Significance and Use

5.1 The descriptive information required in this practice can be used to describe a soil to aid in the evaluation of its significant properties for engineering use.

5.2 The descriptive information required in this practice should be used to supplement the classification of a soil as determined by Test Method D 2487.

5.3 This practice may be used in identifying soils using the classification group symbols and names as prescribed in Test Method D 2487. Since the names and symbols used in this practice to identify the soils are the same as those used in Test Method D 2487, it shall be clearly stated in reports and all other appropriate documents, that the classification symbol and name are based on visual-manual procedures.

5.4 This practice is to be used not only for identification of soils in the field, but also in the office, laboratory, or wherever soil samples are inspected and described.

5.5 This practice has particular value in grouping similar soil samples so that only a minimum number of laboratory tests need be run for positive soil classification.

NOTE 4—The ability to describe and identify soils correctly is learned more readily under the guidance of experienced personnel, but it may also be acquired systematically by comparing numerical laboratory test results for typical soils of each type with their visual and manual characteristics.

5.6 When describing and identifying soil samples from a given boring, test pit, or group of borings or pits, it is not necessary to follow all of the procedures in this practice for every sample. Soils which appear to be similar can be grouped together; one sample completely described and identified with the others referred to as similar based on performing only a few of the descriptive and identification procedures described in this practice.

5.7 This practice may be used in combination with Practice D 4083 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 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 assure reliable testing. Reliable testing depends on several factors; Practice D 3740 provides a means for evaluating some of those factors.

6. Apparatus

6.1 *Required Apparatus*:

6.1.1 *Pocket Knife or Small Spatula*.

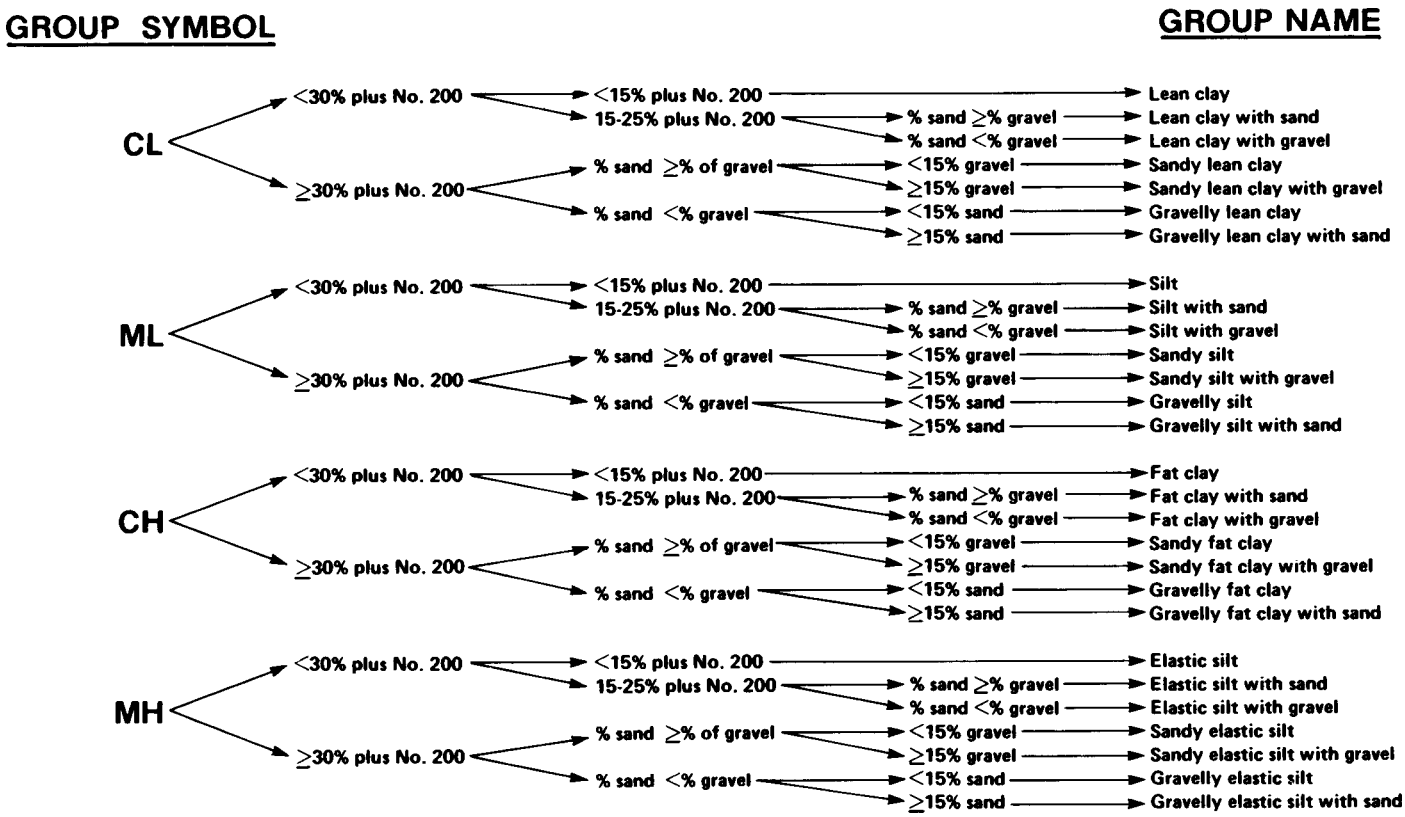
6.2 *Useful Auxiliary Apparatus*:

6.2.1 *Small Test Tube and Stopper* (or jar with a lid).

6.2.2 *Small Hand Lens*.

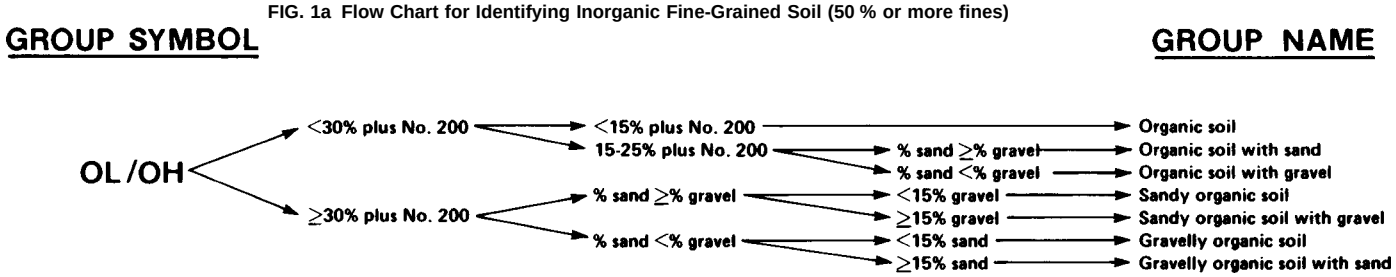
7. Reagents

7.1 *Purity of Water*—Unless otherwise indicated, references



NOTE 1—Percentages are based on estimating amounts of fines, sand, and gravel to the nearest 5 %.

FIG. 1a Flow Chart for Identifying Inorganic Fine-Grained Soil (50 % or more fines)



NOTE 1—Percentages are based on estimating amounts of fines, sand, and gravel to the nearest 5 %.

FIG. 1 b Flow Chart for Identifying Organic Fine-Grained Soil (50 % or more fines)

to water shall be understood to mean water from a city water supply or natural source, including non-potable water.

7.2 *Hydrochloric Acid*—A small bottle of dilute hydrochloric acid, HCl, one part HCl (10 *N*) to three parts water (This reagent is optional for use with this practice). See Section 8.

8. Safety Precautions

8.1 When preparing the dilute HCl solution of one part concentrated hydrochloric acid (10 *N*) to three parts of distilled water, slowly add acid into water following necessary safety precautions. Handle with caution and store safely. If solution comes into contact with the skin, rinse thoroughly with water.

8.2 **Caution**—Do not add water to acid.

9. Sampling

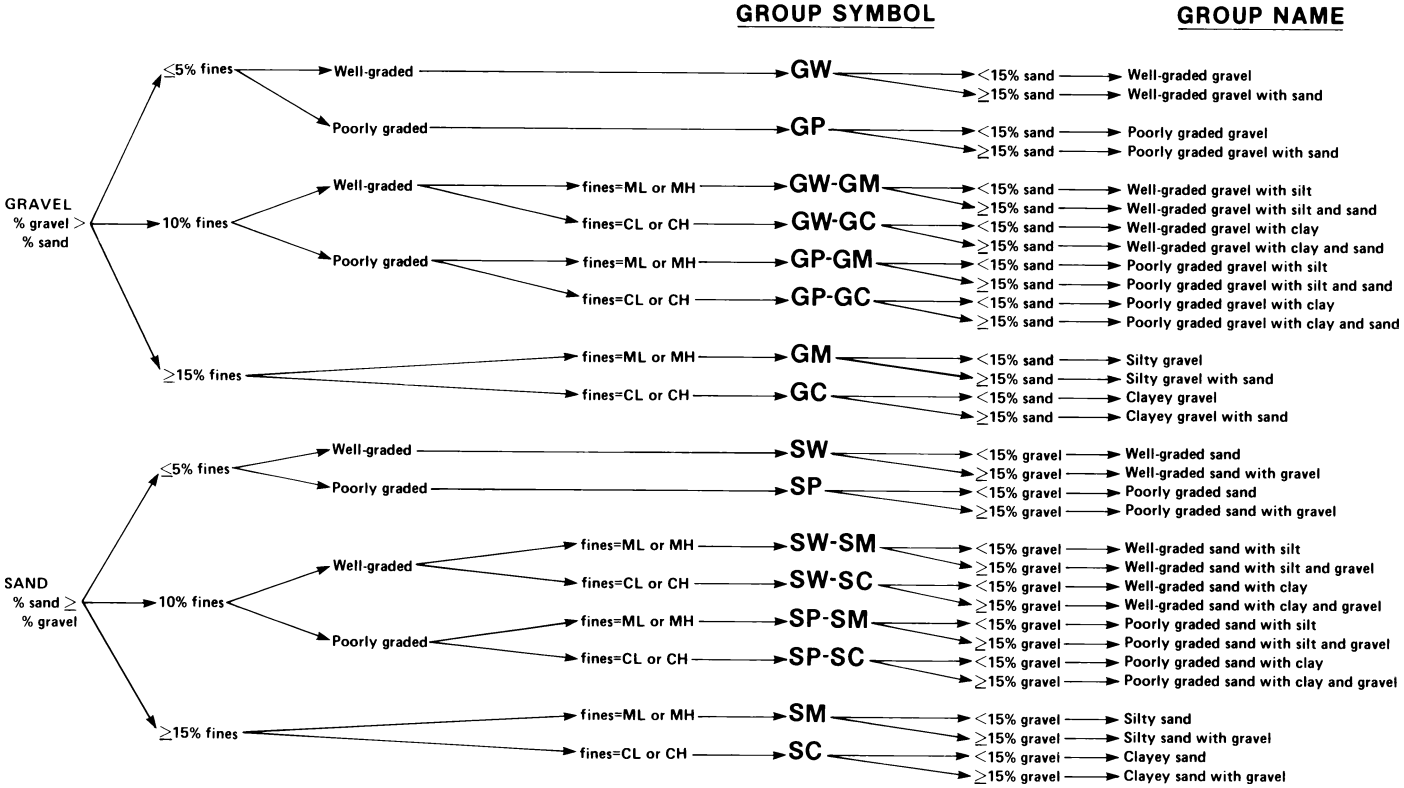
9.1 The sample shall be considered to be representative of the stratum from which it was obtained by an appropriate, accepted, or standard procedure.

NOTE 6—Preferably, the sampling procedure should be identified as having been conducted in accordance with Practices D 1452, D 1587, or D 2113, or Test Method D 1586.

9.2 The sample shall be carefully identified as to origin.

NOTE 7—Remarks as to the origin may take the form of a boring number and sample number in conjunction with a job number, a geologic stratum, a pedologic horizon or a location description with respect to a permanent monument, a grid system or a station number and offset with respect to a stated centerline and a depth or elevation.

9.3 For accurate description and identification, the minimum amount of the specimen to be examined shall be in accordance with the following schedule:



NOTE 1—Percentages are based on estimating amounts of fines, sand, and gravel to the nearest 5 %.

FIG. 2 Flow Chart for Identifying Coarse-Grained Soils (less than 50 % fines)

Maximum Particle Size, Sieve Opening	Minimum Specimen Size, Dry Weight
4.75 mm (No. 4)	100 g (0.25 lb)
9.5 mm (⅜ in.)	200 g (0.5 lb)
19.0 mm (¾ in.)	1.0 kg (2.2 lb)
38.1 mm (1½ in.)	8.0 kg (18 lb)
75.0 mm (3 in.)	60.0 kg (132 lb)

NOTE 8—If random isolated particles are encountered that are significantly larger than the particles in the soil matrix, the soil matrix can be accurately described and identified in accordance with the preceeding schedule.

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

10. Descriptive Information for Soils

10.1 *Angularity*—Describe the angularity of the sand (coarse sizes only), gravel, cobbles, and boulders, as angular, subangular, subrounded, or rounded in accordance with the criteria in Table 1 and Fig. 3. A range of angularity may be stated, such as: subrounded to rounded.

10.2 *Shape*—Describe the shape of the gravel, cobbles, and boulders as flat, elongated, or flat and elongated if they meet the criteria in Table 2 and Fig. 4. Otherwise, do not mention the shape. Indicate the fraction of the particles that have the shape, such as: one-third of the gravel particles are flat.

10.3 *Color*—Describe the color. Color is an important property in identifying organic soils, and within a given locality it may also be useful in identifying materials of similar geologic origin. If the sample contains layers or patches of varying colors, this shall be noted and all representative colors shall be described. The color shall be described for moist samples. If the color represents a dry condition, this shall be stated in the report.

TABLE 1 Criteria for Describing Angularity of Coarse-Grained Particles (see Fig. 3)

Description	Criteria
Angular	Particles have sharp edges and relatively plane sides with unpolished surfaces
Subangular	Particles are similar to angular description but have rounded edges
Subrounded	Particles have nearly plane sides but have well-rounded corners and edges
Rounded	Particles have smoothly curved sides and no edges

10.4 *Odor*—Describe the odor if organic or unusual. Soils containing a significant amount of organic material usually have a distinctive odor of decaying vegetation. This is especially apparent in fresh samples, but if the samples are dried, the odor may often be revived by heating a moistened sample. If the odor is unusual (petroleum product, chemical, and the like), it shall be described.

10.5 *Moisture Condition*—Describe the moisture condition as dry, moist, or wet, in accordance with the criteria in Table 3.

10.6 *HCl Reaction*—Describe the reaction with HCl as none, weak, or strong, in accordance with the critera in Table 4. Since calcium carbonate is a common cementing agent, a report of its presence on the basis of the reaction with dilute hydrochloric acid is important.

10.7 *Consistency*—For intact fine-grained soil, describe the

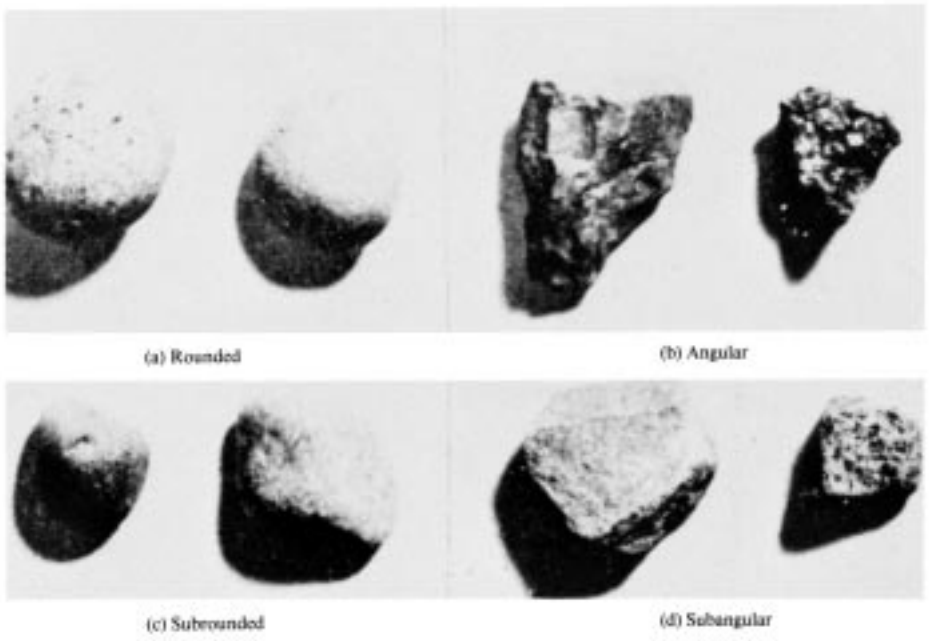


FIG. 3 Typical Angularity of Bulky Grains

TABLE 2 Criteria for Describing Particle Shape (see Fig. 4)

The particle shape shall be described as follows where length, width, and thickness refer to the greatest, intermediate, and least dimensions of a particle, respectively.	
Flat	Particles with width/thickness > 3
Elongated	Particles with length/width > 3
Flat and elongated	Particles meet criteria for both flat and elongated

consistency as very soft, soft, firm, hard, or very hard, in accordance with the criteria in Table 5. This observation is inappropriate for soils with significant amounts of gravel.

10.8 *Cementation*—Describe the cementation of intact coarse-grained soils as weak, moderate, or strong, in accordance with the criteria in Table 6.

10.9 *Structure*—Describe the structure of intact soils in accordance with the criteria in Table 7.

10.10 *Range of Particle Sizes*—For gravel and sand components, describe the range of particle sizes within each component as defined in 3.1.2 and 3.1.6. For example, about 20 % fine to coarse gravel, about 40 % fine to coarse sand.

10.11 *Maximum Particle Size*—Describe the maximum particle size found in the sample in accordance with the following information:

10.11.1 *Sand Size*—If the maximum particle size is a sand size, describe as fine, medium, or coarse as defined in 3.1.6. For example: maximum particle size, medium sand.

10.11.2 *Gravel Size*—If the maximum particle size is a gravel size, describe the maximum particle size as the smallest sieve opening that the particle will pass. For example, maximum particle size, 1½ in. (will pass a 1½-in. square opening but not a ¾-in. square opening).

10.11.3 *Cobble or Boulder Size*—If the maximum particle size is a cobble or boulder size, describe the maximum dimension of the largest particle. For example: maximum dimension, 18 in. (450 mm).

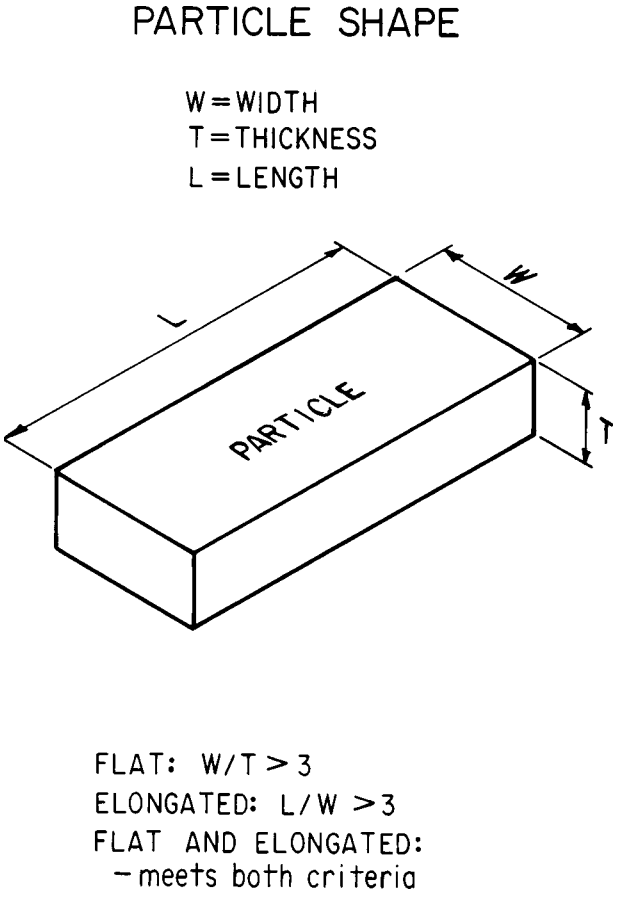


FIG. 4 Criteria for Particle Shape

10.12 *Hardness*—Describe the hardness of coarse sand and larger particles as hard, or state what happens when the

TABLE 3 Criteria for Describing Moisture Condition

Description	Criteria
Dry	Absence of moisture, dusty, dry to the touch
Moist	Damp but no visible water
Wet	Visible free water, usually soil is below water table

TABLE 4 Criteria for Describing the Reaction With HCl

Description	Criteria
None	No visible reaction
Weak	Some reaction, with bubbles forming slowly
Strong	Violent reaction, with bubbles forming immediately

TABLE 5 Criteria for Describing Consistency

Description	Criteria
Very soft	Thumb will penetrate soil more than 1 in. (25 mm)
Soft	Thumb will penetrate soil about 1 in. (25 mm)
Firm	Thumb will indent soil about ¼in. (6 mm)
Hard	Thumb will not indent soil but readily indented with thumbnail
Very hard	Thumbnail will not indent soil

TABLE 6 Criteria for Describing Cementation

Description	Criteria
Weak	Crumbles or breaks with handling or little finger pressure
Moderate	Crumbles or breaks with considerable finger pressure
Strong	Will not crumble or break with finger pressure

TABLE 7 Criteria for Describing Structure

Description	Criteria
Stratified	Alternating layers of varying material or color with layers at least 6 mm thick; note thickness
Laminated	Alternating layers of varying material or color with the layers less than 6 mm thick; note thickness
Fissured	Breaks along definite planes of fracture with little resistance to fracturing
Slickensided	Fracture planes appear polished or glossy, sometimes striated
Blocky	Cohesive soil that can be broken down into small angular lumps which resist further breakdown
Lensed	Inclusion of small pockets of different soils, such as small lenses of sand scattered through a mass of clay; note thickness
Homogeneous	Same color and appearance throughout

particles are hit by a hammer, for example, gravel-size particles fracture with considerable hammer blow, some gravel-size particles crumble with hammer blow. "Hard" means particles do not crack, fracture, or crumble under a hammer blow.

10.13 Additional comments shall be noted, such as the presence of roots or root holes, difficulty in drilling or augering hole, caving of trench or hole, or the presence of mica.

10.14 A local or commercial name or a geologic interpretation of the soil, or both, may be added if identified as such.

10.15 A classification or identification of the soil in accordance with other classification systems may be added if identified as such.

11. Identification of Peat

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

12. Preparation for Identification

12.1 The soil identification portion of this practice is based on the portion of the soil sample that will pass a 3-in. (75-mm) sieve. The larger than 3-in. (75-mm) particles must be removed, manually, for a loose sample, or mentally, for an intact sample before classifying the soil.

12.2 Estimate and note the percentage of cobbles and the percentage of boulders. Performed visually, these estimates will be on the basis of volume percentage.

NOTE 9—Since the percentages of the particle-size distribution in Test Method D 2487 are by dry weight, and the estimates of percentages for gravel, sand, and fines in this practice are by dry weight, it is recommended that the report state that the percentages of cobbles and boulders are by volume.

12.3 Of the fraction of the soil smaller than 3 in. (75 mm), estimate and note the percentage, by dry weight, of the gravel, sand, and fines (see Appendix X4 for suggested procedures).

NOTE 10—Since the particle-size components appear visually on the basis of volume, considerable experience is required to estimate the percentages on the basis of dry weight. Frequent comparisons with laboratory particle-size analyses should be made.

12.3.1 The percentages shall be estimated to the closest 5 %. The percentages of gravel, sand, and fines must add up to 100 %.

12.3.2 If one of the components is present but not in sufficient quantity to be considered 5 % of the smaller than 3-in. (75-mm) portion, indicate its presence by the term *trace*, for example, trace of fines. A trace is not to be considered in the total of 100 % for the components.

13. Preliminary Identification

13.1 The soil is *fine grained* if it contains 50 % or more fines. Follow the procedures for identifying fine-grained soils of Section 14.

13.2 The soil is *coarse grained* if it contains less than 50 % fines. Follow the procedures for identifying coarse-grained soils of Section 15.

14. Procedure for Identifying Fine-Grained Soils

14.1 Select a representative sample of the material for examination. Remove particles larger than the No. 40 sieve (medium sand and larger) until a specimen equivalent to about a handful of material is available. Use this specimen for performing the dry strength, dilatancy, and toughness tests.

14.2 *Dry Strength*:

14.2.1 From the specimen, select enough material to mold into a ball about 1 in. (25 mm) in diameter. Mold the material until it has the consistency of putty, adding water if necessary.

14.2.2 From the molded material, make at least three test specimens. A test specimen shall be a ball of material about ½ in. (12 mm) in diameter. Allow the test specimens to dry in air, or sun, or by artificial means, as long as the temperature does not exceed 60°C.

14.2.3 If the test specimen contains natural dry lumps, those that are about ½ in. (12 mm) in diameter may be used in place of the molded balls.

NOTE 11—The process of molding and drying usually produces higher strengths than are found in natural dry lumps of soil.

14.2.4 Test the strength of the dry balls or lumps by crushing between the fingers. Note the strength as none, low, medium, high, or very high in accorance with the criteria in Table 8. If natural dry lumps are used, do not use the results of any of the lumps that are found to contain particles of coarse sand.

14.2.5 The presence of high-strength water-soluble cementing materials, such as calcium carbonate, may cause exceptionally high dry strengths. The presence of calcium carbonate can usually be detected from the intensity of the reaction with dilute hydrochloric acid (see 10.6).

14.3 *Dilatancy*:

14.3.1 From the specimen, select enough material to mold into a ball about ½ in. (12 mm) in diameter. Mold the material, adding water if necessary, until it has a soft, but not sticky, consistency.

14.3.2 Smooth the soil ball in the palm of one hand with the blade of a knife or small spatula. Shake horizontally, striking the side of the hand vigorously against the other hand several times. Note the reaction of water appearing on the surface of the soil. Squeeze the sample by closing the hand or pinching the soil between the fingers, and note the reaction as none, slow, or rapid in accordance with the criteria in Table 9. The reaction is the speed with which water appears while shaking, and disappears while squeezing.

14.4 *Toughness*:

14.4.1 Following the completion of the dilatancy test, the test specimen is shaped into an elongated pat and rolled by hand on a smooth surface or between the palms into a thread about ⅛ in. (3 mm) in diameter. (If the sample is too wet to roll easily, it should be spread into a thin layer and allowed to lose some water by evaporation.) Fold the sample threads and reroll repeatedly until the thread crumbles at a diameter of about ⅛ in. The thread will crumble at a diameter of ⅛ in. when the soil is near the plastic limit. Note the pressure required to roll the thread near the plastic limit. Also, note the strength of the thread. After the thread crumbles, the pieces should be lumped together and kneaded until the lump crumbles. Note the toughness of the material during kneading.

14.4.2 Describe the toughness of the thread and lump as low, medium, or high in accordance with the criteria in Table 10.

TABLE 8 Criteria for Describing Dry Strength

Description	Criteria
None	The dry specimen crumbles into powder with mere pressure of handling
Low	The dry specimen crumbles into powder with some finger pressure
Medium	The dry specimen breaks into pieces or crumbles with considerable finger pressure
High	The dry specimen cannot be broken with finger pressure. Specimen will break into pieces between thumb and a hard surface
Very high	The dry specimen cannot be broken between the thumb and a hard surface

TABLE 9 Criteria for Describing Dilatancy

Description	Criteria
None	No visible change in the specimen
Slow	Water appears slowly on the surface of the specimen during shaking and does not disappear or disappears slowly upon squeezing
Rapid	Water appears quickly on the surface of the specimen during shaking and disappears quickly upon squeezing

14.5 *Plasticity*—On the basis of observations made during the toughness test, describe the plasticity of the material in accordance with the criteria given in Table 11.

14.6 Decide whether the soil is an *inorganic* or an *organic* fine-grained soil (see 14.8). If inorganic, follow the steps given in 14.7.

14.7 *Identification of Inorganic Fine-Grained Soils*:

14.7.1 Identify the soil as a *lean clay*, CL, if the soil has medium to high dry strength, no or slow dilatancy, and medium toughness and plasticity (see Table 12).

14.7.2 Identify the soil as a *fat clay*, CH, if the soil has high to very high dry strength, no dilatancy, and high toughness and plasticity (see Table 12).

14.7.3 Identify the soil as a *silt*, ML, if the soil has no to low dry strength, slow to rapid dilatancy, and low toughness and plasticity, or is nonplastic (see Table 12).

14.7.4 Identify the soil as an *elastic silt*, MH, if the soil has low to medium dry strength, no to slow dilatancy, and low to medium toughness and plasticity (see Table 12).

NOTE 12—These properties are similar to those for a lean clay. However, the silt will dry quickly on the hand and have a smooth, silky feel when dry. Some soils that would classify as MH in accordance with the criteria in Test Method D 2487 are visually difficult to distinguish from lean clays, CL. It may be necessary to perform laboratory testing for proper identification.

14.8 *Identification of Organic Fine-Grained Soils*:

14.8.1 Identify the soil as an *organic soil*, OL/OH, if the soil contains enough organic particles to influence the soil properties. Organic soils usually have a dark brown to black color and may have an organic odor. Often, organic soils will change color, for example, black to brown, when exposed to the air. Some organic soils will lighten in color significantly when air dried. Organic soils normally will not have a high toughness or plasticity. The thread for the toughness test will be spongy.

NOTE 13—In some cases, through practice and experience, it may be possible to further identify the organic soils as organic silts or organic clays, OL or OH. Correlations between the dilatancy, dry strength, toughness tests, and laboratory tests can be made to identify organic soils in certain deposits of similar materials of known geologic origin.

TABLE 10 Criteria for Describing Toughness

Description	Criteria
Low	Only slight pressure is required to roll the thread near the plastic limit. The thread and the lump are weak and soft
Medium	Medium pressure is required to roll the thread to near the plastic limit. The thread and the lump have medium stiffness
High	Considerable pressure is required to roll the thread to near the plastic limit. The thread and the lump have very high stiffness

TABLE 11 Criteria for Describing Plasticity

Description	Criteria
Nonplastic	A ⅛-in. (3-mm) thread cannot be rolled at any water content
Low	The thread can barely be rolled and the lump cannot be formed when drier than the plastic limit
Medium	The thread is easy to roll and not much time is required to reach the plastic limit. The thread cannot be rerolled after reaching the plastic limit. The lump crumbles when drier than the plastic limit
High	It takes considerable time rolling and kneading to reach the plastic limit. The thread can be rerolled several times after reaching the plastic limit. The lump can be formed without crumbling when drier than the plastic limit

TABLE 12 Identification of Inorganic Fine-Grained Soils from Manual Tests

Soil Symbol	Dry Strength	Dilatancy	Toughness
ML	None to low	Slow to rapid	Low or thread cannot be formed
CL	Medium to high	None to slow	Medium
MH	Low to medium	None to slow	Low to medium
CH	High to very high	None	High

14.9 If the soil is estimated to have 15 to 25 % sand or gravel, or both, the words “with sand” or “with gravel” (whichever is more predominant) shall be added to the group name. For example: “lean clay with sand, CL” or “silt with gravel, ML” (see Fig. 1a and Fig. 1b). If the percentage of sand is equal to the percentage of gravel, use “with sand.”

14.10 If the soil is estimated to have 30 % or more sand or gravel, or both, the words “sandy” or “gravelly” shall be added to the group name. Add the word “sandy” if there appears to be more sand than gravel. Add the word “gravelly” if there appears to be more gravel than sand. For example: “sandy lean clay, CL”, “gravelly fat clay, CH”, or “sandy silt, ML” (see Fig. 1a and Fig. 1b). If the percentage of sand is equal to the percent of gravel, use “sandy.”

15. Procedure for Identifying Coarse-Grained Soils

(Contains less than 50 % fines)

15.1 The soil is a *gravel* if the percentage of gravel is estimated to be more than the percentage of sand.

15.2 The soil is a *sand* if the percentage of gravel is estimated to be equal to or less than the percentage of sand.

15.3 The soil is a *clean gravel* or *clean sand* if the percentage of fines is estimated to be 5 % or less.

15.3.1 Identify the soil as a *well-graded gravel*, GW, or as a *well-graded sand*, SW, if it has a wide range of particle sizes and substantial amounts of the intermediate particle sizes.

15.3.2 Identify the soil as a *poorly graded gravel*, GP, or as a *poorly graded sand*, SP, if it consists predominantly of one size (uniformly graded), or it has a wide range of sizes with some intermediate sizes obviously missing (gap or skip graded).

15.4 The soil is either a *gravel with fines* or a *sand with fines* if the percentage of fines is estimated to be 15 % or more.

15.4.1 Identify the soil as a *clayey gravel*, GC, or a *clayey sand*, SC, if the fines are clayey as determined by the procedures in Section 14.

15.4.2 Identify the soil as a *silty gravel*, GM, or a *silty sand*, SM, if the fines are silty as determined by the procedures in Section 14.

15.5 If the soil is estimated to contain 10 % fines, give the soil a dual identification using two group symbols.

15.5.1 The first group symbol shall correspond to a clean gravel or sand (GW, GP, SW, SP) and the second symbol shall correspond to a gravel or sand with fines (GC, GM, SC, SM).

15.5.2 The group name shall correspond to the first group symbol plus the words “with clay” or “with silt” to indicate the plasticity characteristics of the fines. For example: “well-graded gravel with clay, GW-GC” or “poorly graded sand with silt, SP-SM” (see Fig. 2).

15.6 If the specimen is predominantly sand or gravel but contains an estimated 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, GP” or “clayey sand with gravel, SC” (see Fig. 2).

15.7 If the field sample contains 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.”

16. Report

16.1 The report shall include the information as to origin, and the items indicated in Table 13.

NOTE 14—*Example: Clayey Gravel with Sand and Cobbles, GC*—About 50 % fine to coarse, subrounded to subangular gravel; about 30 % fine to coarse, subrounded sand; about 20 % fines with medium plasticity, high dry strength, no dilatancy, medium toughness; weak reaction with HCl; original field sample had about 5 % (by volume) subrounded cobbles, maximum dimension, 150 mm.

In-Place Conditions—Firm, homogeneous, dry, brown

Geologic Interpretation—Alluvial fan

TABLE 13 Checklist for Description of Soils

1. Group name
2. Group symbol
3. Percent of cobbles or boulders, or both (by volume)
4. Percent of gravel, sand, or fines, or all three (by dry weight)
5. Particle-size range:
   Gravel—fine, coarse
   Sand—fine, medium, coarse
6. Particle angularity: angular, subangular, subrounded, rounded
7. Particle shape: (if appropriate) flat, elongated, flat and elongated
8. Maximum particle size or dimension
9. Hardness of coarse sand and larger particles
10. Plasticity of fines: nonplastic, low, medium, high
11. Dry strength: none, low, medium, high, very high
12. Dilatancy: none, slow, rapid
13. Toughness: low, medium, high
14. Color (in moist condition)
15. Odor (mention only if organic or unusual)
16. Moisture: dry, moist, wet
17. Reaction with HCl: none, weak, strong

For intact samples:

18. Consistency (fine-grained soils only): very soft, soft, firm, hard, very hard
19. Structure: stratified, laminated, fissured, slickensided, lensed, homogeneous
20. Cementation: weak, moderate, strong
21. Local name
22. Geologic interpretation
23. Additional comments: presence of roots or root holes, presence of mica, gypsum, etc., surface coatings on coarse-grained particles, caving or sloughing of auger hole or trench sides, difficulty in augering or excavating, etc.

NOTE 15—Other examples of soil descriptions and identification are given in Appendix X1 and Appendix X2.

NOTE 16—If desired, the percentages of gravel, sand, and fines may be stated in terms indicating a range of percentages, as follows:

Trace—Particles are present but estimated to be less than 5 %
Few—5 to 10 %
Little—15 to 25 %
Some—30 to 45 %
Mostly—50 to 100 %

16.2 If, in the soil description, the soil is identified using a classification group symbol and name as described in Test Method D 2487, it must be distinctly and clearly stated in log forms, summary tables, reports, and the like, that the symbol and name are based on visual-manual procedures.

17. Precision and Bias

17.1 This practice provides qualitative information only, therefore, a precision and bias statement is not applicable.

18. Keywords

18.1 classification; clay; gravel; organic soils; sand; silt; soil classification; soil description; visual classification

APPENDIXES

(Nonmandatory Information)

X1. EXAMPLES OF VISUAL SOIL DESCRIPTIONS

X1.1 The following examples show how the information required in 16.1 can be reported. The information that is included in descriptions should be based on individual circumstances and need.

X1.1.1 *Well-Graded Gravel with Sand (GW)*—About 75 % fine to coarse, hard, subangular gravel; about 25 % fine to coarse, hard, subangular sand; trace of fines; maximum size, 75 mm, brown, dry; no reaction with HCl.

X1.1.2 *Silty Sand with Gravel (SM)*—About 60 % predominantly fine sand; about 25 % silty fines with low plasticity, low dry strength, rapid dilatancy, and low toughness; about 15 % fine, hard, subrounded gravel, a few gravel-size particles fractured with hammer blow; maximum size, 25 mm; no reaction with HCl (Note—Field sample size smaller than recommended).

In-Place Conditions—Firm, stratified and contains lenses of silt 1 to 2 in. (25 to 50 mm) thick, moist, brown to gray; in-place density 106 lb/ft^3; in-place moisture 9 %.

X1.1.3 *Organic Soil (OL/OH)*—About 100 % fines with low plasticity, slow dilatancy, low dry strength, and low toughness; wet, dark brown, organic odor; weak reaction with HCl.

X1.1.4 *Silty Sand with Organic Fines (SM)*—About 75 % fine to coarse, hard, subangular reddish sand; about 25 % organic and silty dark brown nonplastic fines with no dry strength and slow dilatancy; wet; maximum size, coarse sand; weak reaction with HCl.

X1.1.5 *Poorly Graded Gravel with Silt, Sand, Cobbles and Boulders (GP-GM)*—About 75 % fine to coarse, hard, subrounded to subangular gravel; about 15 % fine, hard, subrounded to subangular sand; about 10 % silty nonplastic fines; moist, brown; no reaction with HCl; original field sample had about 5 % (by volume) hard, subrounded cobbles and a trace of hard, subrounded boulders, with a maximum dimension of 18 in. (450 mm).

X2. USING THE IDENTIFICATION PROCEDURE AS A DESCRIPTIVE SYSTEM FOR SHALE, CLAYSTONE, SHELLS, SLAG, CRUSHED ROCK, AND THE LIKE

X2.1 The identification procedure 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, and the like).

X2.2 Materials such as shells, crushed rock, slag, and the like, should be identified as such. However, the procedures used in this practice for describing the particle size and plasticity characteristics may be used in the description of the material. If desired, an identification using a group name and symbol according to this practice may be assigned to aid in describing the material.

X2.3 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 group names and symbols can be incororated into a descriptive system for materials that are not naturally occurring soils are as follows:

X2.4.1 *Shale Chunks*—Retrieved as 2 to 4-in. (50 to 100-mm) pieces of shale from power auger hole, dry, brown, no reaction with HCl. After slaking in water for 24 h, material identified as “Sandy Lean Clay (CL)”; about 60 % fines with medium plasticity, high dry strength, no dilatancy, and medium toughness; about 35 % fine to medium, hard sand; about 5 % gravel-size pieces of shale.

X2.4.2 *Crushed Sandstone*—Product of commercial crushing operation; “Poorly Graded Sand with Silt (SP-SM)”; about 90 % fine to medium sand; about 10 % nonplastic fines; dry, reddish-brown, strong reaction with HCl.

X2.4.3 *Broken Shells*—About 60 % gravel-size broken

shells; about 30 % sand and sand-size shell pieces; about 10 % fines; "Poorly Graded Gravel with Sand (GP)."

X2.4.4 *Crushed Rock*—Processed from gravel and cobbles in Pit No. 7; "Poorly Graded Gravel (GP)"; about 90 % fine, hard, angular gravel-size particles; about 10 % coarse, hard, angular sand-size particles; dry, tan; no reaction with HCl.

X3. SUGGESTED PROCEDURE FOR USING A BORDERLINE SYMBOL FOR SOILS WITH TWO POSSIBLE IDENTIFICATIONS.

X3.1 Since this practice is based on estimates of particle size distribution and plasticity characteristics, it may be difficult to clearly identify the soil as belonging to one category. To indicate that the soil may fall into one of two possible basic groups, a borderline symbol may be used with the two symbols separated by a slash. For example: SC/CL or CL/CH.

X3.1.1 A borderline symbol may be used when the percentage of fines is estimated to be between 45 and 55 %. One symbol should be for a coarse-grained soil with fines and the other for a fine-grained soil. For example: GM/ML or CL/SC.

X3.1.2 A borderline symbol may be used when the percentage of sand and the percentage of gravel are estimated to be about the same. For example: GP/SP, SC/GC, GM/SM. It is practically impossible to have a soil that would have a borderline symbol of GW/SW.

X3.1.3 A borderline symbol may be used when the soil could be either well graded or poorly graded. For example: GW/GP, SW/SP.

X3.1.4 A borderline symbol may be used when the soil could either be a silt or a clay. For example: CL/ML, CH/MH, SC/SM.

X3.1.5 A borderline symbol may be used when a fine-grained soil has properties that indicate that it is at the boundary between a soil of low compressibility and a soil of high compressibility. For example: CL/CH, MH/ML.

X3.2 The order of the borderline symbols should reflect similarity to surrounding or adjacent soils. For example: soils in a borrow area have been identified as CH. One sample is considered to have a borderline symbol of CL and CH. To show similarity, the borderline symbol should be CH/CL.

X3.3 The group name for a soil with a borderline symbol should be the group name for the first symbol, except for:

CL/CH lean to fat clay
ML/CL clayey silt
CL/ML silty clay

X3.4 The use of a borderline symbol should not be used indiscriminately. Every effort shall be made to first place the soil into a single group.

X4. SUGGESTED PROCEDURES FOR ESTIMATING THE PERCENTAGES OF GRAVEL, SAND, AND FINES IN A SOIL SAMPLE

X4.1 *Jar Method*—The relative percentage of coarse- and fine-grained material may be estimated by thoroughly shaking a mixture of soil and water in a test tube or jar, and then allowing the mixture to settle. The coarse particles will fall to the bottom and successively finer particles will be deposited with increasing time; the sand sizes will fall out of suspension in 20 to 30 s. The relative proportions can be estimated from the relative volume of each size separate. This method should be correlated to particle-size laboratory determinations.

X4.2 *Visual Method*—Mentally visualize the gravel size particles placed in a sack (or other container) or sacks. Then, do the same with the sand size particles and the fines. Then, mentally compare the number of sacks to estimate the percentage of plus No. 4 sieve size and minus No. 4 sieve size present. The percentages of sand and fines in the minus sieve size No. 4 material can then be estimated from the wash test (X4.3).

X4.3 *Wash Test (for relative percentages of sand and fines)*—Select and moisten enough minus No. 4 sieve size material to form a 1-in (25-mm) cube of soil. Cut the cube in half, set one-half to the side, and place the other half in a small dish. Wash and decant the fines out of the material in the dish until the wash water is clear and then compare the two samples and estimate the percentage of sand and fines. Remember that the percentage is based on weight, not volume. However, the volume comparison will provide a reasonable indication of grain size percentages.

X4.3.1 While washing, it may be necessary to break down lumps of fines with the finger to get the correct percentages.

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 = with cobbles
	b = with boulders

X5.4 The soil classification symbol is to be enclosed in parenthesis. 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

In accordance with Committee D18 policy, this section identifies the location of changes to this standard since the last edition (1993$^{\epsilon 1}$) that may impact the use of this standard.

(1) Added Practice D 3740 to Section 2.

(2) Added Note 5 under 5.7 and renumbered subsequent notes.

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Designation: D 2573 – 01

Standard Test Method for Field Vane Shear Test in Cohesive Soil[1]

This standard is issued under the fixed designation D 2573; 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 field vane test in saturated clay and silt soils for determination of undrained shear strength. Knowledge of the nature of the soil in which each vane test is to be made is necessary for assessment of the applicability and interpretation of the test. The test is not applicable for sandy soils which may allow drainage during the test.

1.2 This test method addresses testing on land and for testing in drill holes or by self drilling or continuous push methods from the ground surface. This method does not address marine testing where special test requirements or variations in equipment may be required. The user is referred to ASTM STP 1014 for additional information on in-place vane shear testing.[2]

1.3 This method is often used in conjunction with fluid rotary drilling (D 5783) or hollow-stem augers (D 6151). Some apparatuses have the vane retracted in protective shoe for advancement and incremental testing. Sampling, such as with thin wall tubes (D 1587) is often combined with vane testing. Subsurface geotechnical explorations are reported in accordance with practice (D 5434).

1.4 Undrained shear strength and sensitivity of cohesive soils can also be measured in Unconfined Compression D 2166 and Laboratory Vane Test (D 4648).

1.5 The values stated in SI units are to be regarded as the standard. English (Imperial) units are given in parentheses.

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

2. Referenced Documents

2.1 *ASTM Standards:*

D 653 Terminology Relating Soil and Rock and Contained Fluids[3]

D 1587 Practice for Thin-Walled Tube Sampling of Soils[3]

D 2166 Test Method for Unconfined Compressive Strength of Cohesive Soil[3]

D 2488 Practice for Description and Identification of Soils (Visual-Manual Procedure)[3]

D 3740 Minimum Requirements for Agencies Engaged in the Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction[3]

D 4648 Test Method for Laboratory Miniature Vane Shear Test for Saturated Fine-Grained Clayey Soil[3]

D 5434 Guide for Field Logging of Subsurface Explorations of Soil and Rock[3]

D 5783 Guide for the Use of Direct-Rotary Drilling with Water-Based Drilling Fluid for Geoenvironmental Exploration and the Installation of Subsurface Water-Quality Monitoring[4]

D 6151 Practice for Hollow-Stem Auger Drilling and Sampling of Soil for Geotechnical Purposes[4]

2.2 *Other Standards:*

Recommended Standard for Field Vane Shear Test, Swedish Geotechnical Society, SGF Report 2:93E, Swedish Geotechnical Institute, Linköping: www.swedgeo.se

EuroCode 7: Geotechnical Design–Part 3 Design Assisted by Field Testing, ENV 1997-3:1999E, CEN

3. Terminology

3.1 *Definitions:*

3.1.1 For common definitions of terms in this standard, refer to Terminology D 653.

3.1.2 *sensitivity*—the effect of remolding on the consistency of cohesive soil.

3.1.3 *vane shear test (VST)*—an in-place shear test in which a rod with thin radial vanes at the end is forced into the soil and the resistance to rotation of the rod is determined.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *remolded undrained shear strength*—shear strength of fine-grained soil in rapid loading with little or no drainage of pore water pressure after significant failure and remolding of

[1] This test method is under the jurisdiction of ASTM Committee D18 on Soil and Rock and is the direct responsibility of Subcommittee D18.02 on Sampling and Related Field Testing for Soil Investigations. Originally published as D 2573 – 67 T. Last previous edition D 2573 – 72 94.

Current edition approved Nov. 10, 2001. Published March 2002.

[2] ASTM STP 1014 on Vane Shear Strength Testing in Soils (1988).

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

[4] *Annual Book of ASTM Standards*, Vol 04.09.

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

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the initial soil structure. (Also see D 2166 and D 4648).

3.2.2 *undrained shear strength*—shear strength of fine-grained soil (primarily clays and clayey silts) in rapid loading with essentially no drainage of porewater pressure. (Also see D 2166 and D 4648).

3.2.3 *vane*—a device with four, thin, flat metal blades or plates, fixed at an angle of 90 degrees to each other, which is inserted into the soil and then rotated about a vertical axis for shear testing (see Fig. 1).

3.2.4 *vane shoe*—a section of drill casing and cutting bit at the end in which the vane can be retracted while drilling or pushing

3.3 *Symbols:*

3.3.1 In accordance with ASTM D 653.

3.3.2 *shear strength, s_u*—the maximum (undrained) resistance of soil to shearing stresses.

3.4 *Symbols Specific to This Standard:*

3.4.1 *peak undrained shear strength, $(s_u)_{fv}$*—the peak undrained shearing resistance measured during the initial rotation of the vane in a vane shear test.

3.4.2 *remolded undrained shear strength, $(s_{ur})_{fv}$*—the remolded undrained shear strength is measured after five to ten of vane rotations in a vane shear test.

3.4.3 *sensitivity–$S_{T\ fv}$*—the ratio of peak undrained shear strength to remolded undrained shear strength measured in the field vane shear test: $S_{T\ fv} = (s_u)f_v/(s_{ur})f_v$. The remolded shear strength is measured after large shearing strains (see 8.7 and 9.3).

NOTE 1—Previous and existing standards have specified different amounts of rotation, from 5 to 25 revolutions, for measurement of remolded strength.[2] If sensitivity is reported, the number of revolutions must also be reported. Sensitivity can also be measured in unconfined compression testing (D 2166) and laboratory vane testing (D 4648).

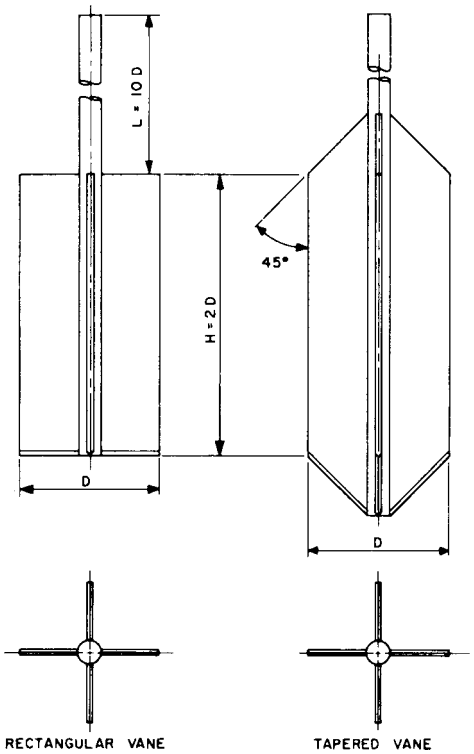


FIG. 1 Geometry of Field Vanes

3.4.4 *torque–T, (FL)*—the measured torque (or moment) required to rotate the vane.

3.4.5 *vane area ratio–V_A–%* —the ratio of the cross section area of the vane to the circular area of the rotated vane expressed as a percent (see Fig. 2).

3.5 *Acronyms:*

3.5.1 *VST*—vane shear test.

3.5.2 *FV*—field vane.

4. Summary of Test Method

4.1 The vane shear test consists of placing a four-bladed vane in the undisturbed soil and rotating it from the surface to determine the torque required to shear a cylindrical surface with the vane. This torque, or moment, is then converted to a the unit shearing resistance of the failure surface by limit equilibrium analysis. Friction of the vane rod and instrument are either minimized during readings by special casings or housing, or else accounted for and subtracted from the total torque to determine the torque applied to the vane.

5. Significance and Use

5.1 This test method provides an indication of in-situ undrained shear strength of fine- grained clays and silts or other fine geomaterials such as mine tailings, organic muck, and substances where undrained strength determination is required. The test is applicable to soils with undrained strengths of less than 200 kPa (2 tsf). Very sensitive soils can be remolded during vane insertion.

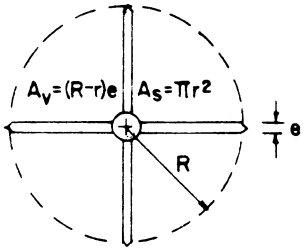
5.2 This test method is used extensively in a variety of geotechnical explorations to evaluate rapid loading strength for total stress analysis of saturated fine-grained clays and silts. The test is routinely performed in conjunction with other field and laboratory tests.

5.3 The peak undrained shear resistance of the vane test is commonly corrected to determine the undrained shear strength for geotechnical analysis. The agency requesting the testing must interpret these data to determine applicability for strength analysis. It is beyond the scope of this standard to recommend applicability of vane testing for geotechnical analysis. For information on the general use of these correction factors, consult Appendix X1.

5.4 This method is not applicable in sands, gravels, or other high permeability soils. With the shearing rates described in this standard, sand lenses, if present, will allow total or partial drainage. Soils with higher permeability, in rapid shear, can dilate or collapse and generate negative or positive pore pressures which may, or may not, dissipate in the shearing process. It is important to check the soil type being tested. It is very beneficial to sample the soil either before or after testing, to understand the drainage conditions (permeability) of the soil tested.

5.5 This test is often performed in drilled boreholes or with self-push or self-drilling or pushed (vane shoe) methods. This method also applies to hand held vane shear tests performed at shallow depths, however, hand held equipment may be less accurate, because it may be more difficult to maintain vane/rod stability and verticality.

NOTE 2—The quality of the result produced by this standard is



$$V_A = \frac{4(R-r)e + \pi r^2}{\pi R^2}$$

Where : V_A = Vane Area Ratio
R = Radius of Failure Cylinder (in or mm)
r = Radius of Vane Shaft (in or mm)
e = Vane Blade Thickness (in or mm)

VANE TYPE	BLADE DIA. in (mm)	SHAFT DIA. in (mm)	BLADE THICKNESS in (mm)	AREA RATIO (%)
Miniature	0.50 (12.7)	0.1275 (3.5)	0.019 (0.05)	13.7

FIG. 2 Definition of Vane Area Ratio (ASTM D 4648) (Note, r is radius of central shaft).

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 standard are cautioned that compliance with Practice D 3740 does not in itself assure reliable results. Reliable results depend on many factors; Standard Practice D 3740 provides a means of evaluating some of those factors.

6. Apparatus

6.1 The vane shall consist of a four-bladed vane as illustrated in Fig. 1. Vanes are normally constructed of steel. Different alloys of steel such as nickel-chromium, or steel treatment processes such as hardening, can be used to reduce blade thickness. The ends of the vane may be flat or tapered. Vane dimensions are as follows with notation from Fig. 1.

Vane Diameter, D: 35 to 100 mm (1.5 to 4 in.)
Vane Shaft Diameter, d: 12.5 to 16.5 mm (0.5 in.)
Vane Height, H: $1D \leq H \leq 2.5D$
Taper Angle, *i*: usually 0 (rectangular) or 45 degrees (tapered)

6.1.1 For good torque resolution, select a vane diameter that is large enough to provide optimum torque resolution. The diameter selected is directly related to the consistency of the soil being tested. For softer soils, larger sizes are required for good resolution. In stiffer soils, smaller vanes are required to avoid damage to the torque measurement device (6.2). When used in drill holes, the maximum vane size is dependent on the inside diameter of the boring or casing.

6.1.2 *Blade Thickness*—Maximum blade thickness is limited to $e < 3$ mm (0.006 to 0.125 in.). The average thickness shall be $e = 2$ mm. Vane blade edge or dimension (e) on Fig. 2 can be tapered to be thinner at the edges to reduce disturbance from insertion.[2]

6.1.3 The vane shaft diameter, d (shown also as 2r in Fig. 1) above the top of the vane blades shall be less than 17 mm. The vane shaft diameter (d) shall not exceed 14 mm at the center of the vane.

6.1.4 *Vane Area Ratio*—As shown on the detail in Fig. 2, the vane blade edges and fillet rod and welds shall be sufficiently small to minimize soil disturbance during insertion. The Vane Area Ratio, V_A, must be less than 12 %. With blade tapering and tapering reduction of the vane shaft ($d = 2r$), V_A can be reduced less than 10 %.

6.1.5 The distance, 1, from the top edge of the vane to an increase in torque rod diameter (6.3) is 5d where d is the vane shaft diameter at the top of the vane. If a large diameter friction coupler or torque rod sleeve is used, distance 1 is 150 mm (6-in.).

6.1.6 A vane with the upper tapered edges has the advantage that the vane will not get caught on an exterior casing upon withdrawal.

6.1.7 The bottom edge of the vane blades can be sharpened to facilitate penetration into the soil. The edges of the blades can be sharpened and beveled to counter-rotate against a friction coupler (6.4).

6.2 *Torque Measurement Device*—Torque shall be applied to the rods, hence to the vane. This is accomplished with a clamping device and torque application apparatus set at the top of the rods. The accuracy of the torque reading shall be such that it will produce a variation not to exceed ±1.0 kPa (±25 lb/ft^2) in computed shear strength.

6.2.1 It is preferable to apply torque to the vane with a geared drive. In the absence of a geared drive, it is acceptable to apply the torque directly by hand with a torque wrench or equivalent. If torque is applied by hand an asterisk shall be placed next to the resultant shear stress and "hand torqued" shall be noted. The duration of the test shall be controlled by

the requirements of 8.6.

6.2.2 Some torque measurement devices are capable of making hard copy or computer records of the load-displacement history. Other manually read systems use torque rings and dial gauges. These automatic reading systems have an advantage over manually read systems, because operator error is reduced, and a permanent record of the test is generated during the test.

6.3 *Torque Rods*—The vane shall be connected to the surface by means of steel torque rods. Typical rod diameter ranges from 18 to 25 mm (0.5 to 1 in.). These rods shall have sufficient diameter such that their elastic limit is not exceeded when the vane is stressed to its capacity (Note 3). They shall be so coupled that the shoulders of the male and female ends meet to prevent any possibility of the coupling tightening when the torque is applied during the test.

6.3.1 *Protective Casing and Vane Shoe*—Torque rods can be sleeved in an small diameter casing to reduce rod friction. If a torque rod sleeve or casing and vane shoe is used, the torque rods shall be equipped-with well-lubricated bearings where they pass through the housing.[5] These bearings shall be provided with seals that prevent soil from entering them. The casing may require venting of water pressures. The torque rods shall be guided so as to prevent friction from developing between the torque rods and the walls of the casing or the boring.

6.3.2 Rod friction measurements under no-load conditions (such as the use of a blank stem in place of the vanes, or a vane that allows some free rotation of the rod prior to loading) are permissible only if the torque is applied by a balanced moment that does not result in a side thrust. As torque becomes greater during a test, a side thrust in the instrument will result in an increase in friction that is not accounted for by initial no-load readings. Instruments involving side thrust are not allowable. The vane rod may be of sufficient rigidity that it does not twist excessively under full load conditions; otherwise a correction must be made for plotting torque-rotation curves. Most steel torque rod meeting the requirements in this standard does twist during testing and requires a correction if vane rotation is to be determined.

NOTE 3—If torque versus rotation curves are to be determined, the torque rods can be calibrated. The amount of rod twist are established in degrees per meter (foot) per unit torque. This correction becomes progressively more important as the depth of the test increases and the calibration must be made at least to the maximum depth of testing anticipated. Alternately, rod twist can be calculated based on the properties of the rod. If twist is calculated, the material property assumption must be reported.

6.4 *Friction Coupling*—The connection between the vane and the rods may include a friction coupling or slip coupling device. This device is used with single rod systems where the vane may be advanced far in advance of the protective casing. This device is designed not to engage the vane until a certain amount of rotation, typically 15 degrees has occurred, and thus allows for determination of rod friction prior to the test. Use of this coupling is preferred over blank rod testing for determination of rod friction, because measurements are made directly in the soil tested.

6.5 *Centralizers*—For tests performed in drill holes, it will be necessary to equip the torque rods with centralizers to assure a vertical push and to prevent torque rod buckling. They are designed to support the rods, while minimizing any rod friction when deflected. Centralizers must be smaller in diameter than the drill hole. They shall be designed to allow the passage of drill fluids.

6.6 *Advancement Equipment*—When used in drill holes, the drive head and pull-down capability of the drill rig can be used to push the vane below the base of the hole. Some equipment is designed to push the vane from the surface. It is important to push the vane vertically and straight. A top centralizer and rod centralizers can be used with casings to assure straight push.

6.7 *Reaction Casing*—In drill hole applications, where the torque head clamps to the casing, it may be necessary to use an upper finned casing to assure torque reaction. Typically, hollowstem augers (D 6151) provide sufficient reaction for a torque head without fins. The need for casing reaction can be determined by slippage of the casing or augers during testing causing periodic/intermittent drops in torque· If slippage occurs, use finned casing, or perform less cleaning of the augers flights.

6.8 *Vane Housing/Casing*—Some vane systems are designed to retract into a casing equipped with a cutting bit (four-bladed drag bit). Fluid can be circulated through the cutting bit. When the test depth is reached, the vane can be pushed into the test interval.

7. Calibration

7.1 The torque measurement device is calibrated by inserting a rod with a moment wheel in the device. Known weights are hung from the wheel with set radius (R_w), and the torque measurements are taken and compared with the applied moments ($T = W \cdot R_w$).

7.2 The torque measurement device must be calibrated at regularly scheduled intervals of time or amount of use, in accordance with a systematic quality assurance plan of the company performing the testing. Records of the calibrations of each instrument shall be maintained and available for review during testing.

7.3 If the torque measurement device is damaged or repaired, a new calibration shall be performed.

7.4 The report must include the calibration data for the instrument, date of calibration, and a note on the amount of use since the last calibration.

8. Procedure

8.1 Locate the advancement equipment over the test location. The test can be performed in a pre-drilled hole, pushing from the surface, or with drilling through a vane housing.

8.2 If necessary, set a reaction casing to transfer forces to the torque head without twist or slippage.

8.3 When drilling, stop the drill hole at a depth such that the vane tip may penetrate undisturbed soil for a depth of at least five times the outside diameter of the hole. In the case where a vane housing is used, advance the housing to a depth which

[5] *Earth Manual*, Part II, Third Edition, 1990, U.S. Department of the Interior, Bureau of Reclamation, U.S. Government Printing Office.

that is at least five vane housing diameters less than the desired depth of the vane tip.

8.4 Advance the vane from the bottom of the hole or the vane housing in a single thrust to the depth at which the test is to be conducted. The vane shall be pushed down without any use of blows, vibration, or rotation. No torque should be applied to the rods during the thrust.

8.5 *Friction Determinations*:

8.5.1 *Friction from Slip Couplings*—For vanes equipped with slip couplings, after pushing the vane, the first part of the test will be to apply torque and measure the force to turn the torque rods above the slip coupling. Apply the force at the same rate as the actual vane loading given in 8.6. Record the rod friction.

8.5.2 *Blank Rod Friction Tests*—In the case were soil is in contact with the torque rods, and there is no slip coupling, determine the friction between the soil and the rod by means of torque tests conducted on similar rods at similar depths with no vane attached. These tests can be performed in between vane tests. Conduct the rod friction test at least once on each site; this shall consist of a series of torque tests at varying depths.

8.5.2.1 When using an apparatus in which the torque rod is completely isolated from the soil (vane shoe push/drill system), testing is performed in increments. The vane is retracted in the casing, when the test zone is reached the vane is pushed out of the shoe 35 to 50 cm. Vane rod friction is this case should be negligible.

8.6 The time from the end of vane penetration to beginning rotation shall be no more than 5 minutes. With the vane in position, apply the torque to the vane at a rate of 0.1 deg/s. Permissible variations are in the range of 0.05 to 0.2 deg/s. This generally requires a time to failure of from 2 to 5 min, except in very soft clays where the time to failure may be as much as 10 to 20 min. In stiffer materials, which reach failure at small deformations, it may be desirable to reduce the rate of angular displacement so that a reasonable determination of the stress-strain properties can be obtained. During the rotation of the vane, hold it at a fixed elevation. Record the maximum torque. With apparatus with manually read gauges, it is desirable to record intermediate values of torque at intervals of 15 s or at lesser frequency if conditions allow. Note all unusual occurrences during testing, such as slippage or shape of the loading curve.

8.7 Following the determination of the maximum torque, rotate the vane rapidly through a minimum of five to ten revolutions. The determination of the remolded strength shall be started immediately after completion of rapid rotation and never more than 1 min after the remolding process (Note 4).

NOTE 4—In many sensitive clayey soils, residual strength may be obtained within one to two revolutions or less. If such soils are being tested, it is recommended that several remolded strengths be obtained using the standard five to ten revolutions for verification. If no major remolded strength differences are noted, remolded strengths may be obtained at less than the recommended five to ten revolutions.

8.8 When combined with rotary drilling methods it may be advantageous to take thin wall tube or double tube auger (D 6151) samples over the tested interval. Over-sampling will allow for inspection of soil in the test zone. Often evidence of the shear zone can be found in the sample. If a sample is recovered and the shear zone is detected, describe the soil sample (D 2488) and the soils in the shear zone.

8.9 Conduct undisturbed and remolded vane tests at intervals of not less than 0.5 to 0.75 m throughout the soil profile when conditions will permit vane testing (Note 5). Do not conduct the vane test in any soil that permits drainage or dilates during the test period, such as stiff clays, sands or sandy silts, or soils where stones or shells are encountered by the vane in such a manner as to influence the results. Unreliable data can be evaluated by the torque rotation curves, or by subsequent sampling of the test zone.

NOTE 5—This spacing may be varied only by the engineer in charge of the boring program.

9. Calculations

9.1 Calculate the undrained shear strength (S_{uv}) in the following manner. The equations below can be in any units as long as shear strength, torque, and diameter are in consistent units:

9.1.1 For a rectangular vane of H/D = 2;

$$(S_u)_{fv} = \frac{6\,T_{max}}{7\Pi D^3} \tag{1}$$

where:

$(S_u)_{fv}$ = undrained shear strength from the vane,
T_{max} = maximum value of measured torque corrected for apparatus and rod friction, and
D = vane diameter (Fig. 1).

9.1.2 *For Tapered and Other Vanes*—The general expression for rectangular, both ends tapered, bottom taper only, as well as rhomboidal vanes for any angles (for example, Silvestri & Aubertin, ASTM STP 1014, pp. 88-103) is given by:

$$(s_{ur})_{fv} = \frac{12 \cdot T_{max}}{\Pi D^2 \cdot \left(\frac{D}{cos\,(i_T)} + \frac{D}{cos\,(i_B)} + 6H\right)} \tag{2}$$

where:

s_{uv} = undrained shear strength from the vane,
T_{max} = maximum value of measured torque corrected for apparatus and rod friction,
D = vane diameter (Fig. 1),
H = height of vane (Fig. 1),
i_T = angle of taper at vane top (Fig. 1), and
i_B = angle of taper at vane bottom (Fig. 1).

9.1.3 The torque reading from the instrument may require use of a calibration constant for the torque measurement device.

9.2 *Peak Undrained Shear Strength*—Calculate the peak undrained shear strength, $(S_u)_{fv}$, from the maximum recorded torque for the first loading of the vane test in accordance with 9.1. (Note 6).

NOTE 6—The peak undrained shear strength from the field vane test needs to be multiplied by a vane correction factor (μ) to give a mobilizedfield value of undrained strength $(s_u)_{field}$ for geotechnical analysis. It is essential in reports to discern between raw field results and corrected data. See 5.3 and Appendix X1.

9.3 *Remolded Undrained Shear Strength, $(s_{ur})_{fv}$*—Calculate the remolded shear strength in accordance with 9.1, after

rotating the vane as specified in 8.7 and measuring the residual torque. The remolded shear stress can be reported as remolded undrained shear strength, $(S_{ur})_{fv}$,

9.4 *Sensitivity, S_T*—Calculate the sensitivity of the soil as follows:

$$S_{T\,fv} = (s_u)_{fv}/(s_{ur})_{fv} \quad (3)$$

where:
$S_{T\,fv}$ = sensitivity (dimensionless),
$(s_u)_{fv}$ = peak undrained shear strength, and
$(s_{ur})_{fv}$ = remolded undrained shear strength.

10. Report

10.1 For each vane test record the following observations:
10.1.1 Date of the test.
10.1.2 Boring or sounding number.
10.1.3 Size and shape of the vane (double tapered, single tapered, or rectangular).
10.1.4 Depth of the vane tip.
10.1.5 Depth of the vane tip below the housing or bottom of the hole.
10.1.6 Time from end of penetration to beginning of rotation.
10.1.7 Maximum torque reading, and intermediate readings if required for the undisturbed test.
10.1.8 Time to soil failure.
10.1.9 Peak undrained shear strength, $(s_u)_{fv}$ (9.2).
10.1.10 Remolded strength, number of revolutions (8.7)
10.1.11 Rate of remolding.
10.1.12 Maximum torque reading for the remolded test(s).
10.1.13 Remolded strength, $(S_{ur})_{fv}$ (9.3).
10.1.14 Friction determinations.
10.1.15 Sensitivy, $S_{T\ fv}$, for determination of sensitivity (9.4).
10.1.16 Notes on any deviations from standard test procedure.

10.2 *Summary Report*—The summary report will include information below. The report will include plots of the torque rotation data. The report shall also include summary plots and tables showing the strength data.

10.2.1 Description of the vane equipment and advancement methods, housed or not.
10.2.2 Description of the method of applying and measuring the torque.
10.2.3 Calculations, including rod friction measurements.
10.2.4 Notes on the resistance to pushing the vane.
10.2.5 Calibration information for the torque measurement device.

10.3 In addition, record the information that may be required in ASTM standard D 5435 Guide for Field Logging of Subsurface Explorations of Soil and Rock. This guide is used for logging explorations by drilling and sampling. Some examples of the information include:
10.3.1 Boring number.
10.3.2 Location.
10.3.3 Log of the soil conditions.
10.3.4 Reference elevation.
10.3.5 Method of making the hole.
10.3.6 Name of the drilling foreman.
10.3.7 Name of the supervising engineer.

11. Precision and Bias

11.1 *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.

11.1.1 Subcommittee D 18.02 is seeking any data from users of this method that might be used to make a limited statement on precision.

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

12. Keywords

12.1 clay; exploration; in-situ test; sensitivity; shear strength; undrained strength; vane shear

APPENDIX

(Nonmandatory Information)

X1. VANE CORRECTION FACTOR

X1.1 It is very important that the measured vane strength be corrected prior to use in stability analyses involving embankments on soft ground, bearing capacity, and excavations in soft clays (Bjerrum, 1972, 1973). The mobilized shear strength is given by:

$$\tau_{mobilized} = \mu_v\,(s_u)_{fv} \quad (X1.1)$$

where μ_v = empirical correction factor that has been related to plasticity index (PI) and/or liquid limit (LL) and/or other parameters based on back calculation from failure case history records of full-scale projects. The sensitivity, S_T, is based on the ratio of raw measured peak and remolded strengths and is not corrected.

X1.2 One proposed correction factor for field vane data is presented below. Other correction methods have been proposed. Additional information can be found in the references. The application of correction factors shall be performed by a qualified professional. The ASTM committee does not recommend or endorse any single method for adjusting the data. This information is presented to bring attention to the fact that a

correction factor of some method is normally required to raw vane shear data.

X1.2.1 Based on an extensive review of the factors and relationships affecting vane measurements in clays and silts with PI > 5 % recommends the following expression (Chandler, 1988):

$$\mu_v = 1.05 - b\,(PI)^{0.5} \quad \text{(X1.2)}$$

where the parameter b is a rate factor that depends upon the time-to-failure (t_f in minutes) in the actual failure (not in the field test) and given by:

$$b = 0.015 + 0.0075\ log\ t_f \quad \text{(X1.3)}$$

The combined relationships are shown in Fig. X1.1. For guidance, embankments on soft ground are normally associated with tt on the order of 10^4 minutes because of the time involved in construction using large equipment. For this case, Eq X1.2 becomes:

$$\mu_v = 1.05 - 0.045\,(PI)^{0.5} \quad \text{(X1.4)}$$

X1.2.2 Interestingly, the raw vane strength ratio (s_{uv}/σ_{vo}') has long been observed to increase with plasticity index (for example, Skempton, 1948). Conversely, the vane correction factor (μ_v) decreases with PI. The net effect is that the mobilized strength back calculated from failure case histories involving embankments, foundations, and excavations in soft clays is essentially independent of plasticity index (for example, Mesri, 1989). Aas, et.al.(1986) have proposed a correction method which uses (s_{uv}/σ_{vo}') as the independent variable rather than PI.

X1.2.3 Alternative correction factors are given based on compilations of back calculated failures of foundations, embankments, and excavations (Bjerrum, 1973), field load tests and laboratory data (Larsson, 1980), three-dimensional stability considerations (Azzouz, et al., 1983), laboratory shear data (Mesri, 1989), and oedometer data (Mayne & Mitchell, 1988), as well as effective stress analyses (Morris & Williams, 1993, 1994).

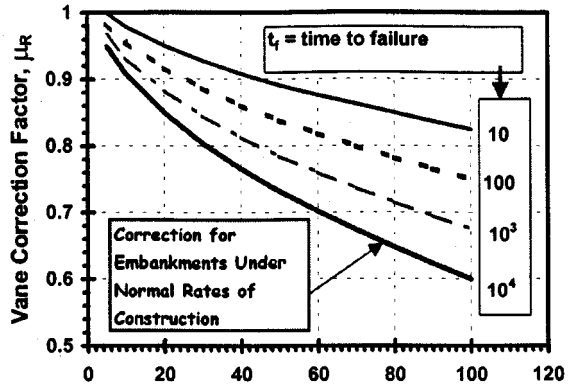


FIG. X1.1 Proposed Correction Factor to Raw Field Vane Shear Data from Plasticity Index (after Chandler, 1988)

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SUMMARY OF CHANGES

In accordance with committee D-18 policy, this section identifies the location of changes to this standard since the last edition, 1994, that may impact the use of this standard.

(1) Scope
Added 1.2 not applicable to marine testing, refer to ASTM STP 1014.
Added 1.3 references to drilling and sampling methods used in conjunction to Adopted SI units.
(2) Added section Referenced Documents and referred to related standards.
(3) Added Terminology pertinent to the standard, defined peak shear stress, strength, remolded shear strength, and sensitivity.
(4) Summary of Method
Removed discussion about the effects of rod friction and inclination; moved them to apparatus and procedure sections.
(5) Significance and Use
Added 5.3 Precaution that field vane strength, requires correction for geotechnical analysis.
Added 5.4 on use in sand and partial drainage precautions.
Added 5.5 on drilling methods, and hand vanes.
(6) Apparatus
Fig. 1—Added Bottom Tapered Field Vane.
Fig. 2—Added Vane Area Ratio.
Removed Table 1 - provided a range of allowable dimensions for vane blades (6.1).
6.1.2 added criteria for size selection.
6.1.3 added vane area ratio for allowable vane dimensions.
6.1.4 added advantage of tapered vane.
6.2 added information on the torque measurement apparatus.
6.2.2 Added section on hard copy or computer records.
6.3.1 Moved side thrust precautions from summary of method to apparatus/torque rods area.
6.4 Added friction coupling.
6.5 Added section on centralizers.
6.6 Added section on advancement equipment.
6.7 Added section on reaction casing.
6.8 Added section on vane housing system.
(7) Calibration
Added information on how and when to calibrate the torque measurement device.
(8) Procedure
Added 8.1 on locating drill/push equipment.
Added 8.2 to set reaction casing if needed.
Added 8.5, 8.5.1, 8.5.2, 8.5.2.1 explaining how friction determinations are made, using slip coupling or vane housing systems.
8.6 Changed speed range from 0.05 to 0.2 degrees/second. Require less than 5 minutes to failure. Note occurrences during testing.
8.8 Added section on taking tube samples after testing.
(9) Calculations
Added section 9.1.1 - simplified equation for rectangular vane H/D = 2.
Changed Section 9.1.2 - simplified equation for any shape vane.
Added section 9.2 - determination of peak shear stress and strength.
Added section 9.3 - determination of remolded shear stress and strength.
Added section 9.4 - determination of sensitivity.
Removed sections with complex vane constants - K value.
(10) Report
Added basic details required for each test.
Added section on summary report and summary report requirements.
Added reference to D 5434 on logging of subsurface investigations.

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Designation: D 2850 – 03

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:*

D 422 Method for Particle-Size Analysis of Soils[2]

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

D 854 Test Method for Specific Gravity of Soils[2]

D 1587 Method for Thin-Walled Tube Sampling of Soils[2]

D 2166 Test Methods for Unconfined Compressive Strength of Cohesive Soil[2]

D 2216 Test Method for Laboratory Determination of Water (Moisture) Content of Soil and Rock[2]

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[2]

D 4220 Practices for Preserving and Transporting Soil Samples[2]

D 4318 Test Method for Liquid Limit, Plastic Limit, and Plasticity Index of Soils[2]

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

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]

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 principal stress difference (deviator stress) at 15 % axial strain, whichever is obtained first during the performance of a test.

[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 Feb. 10, 2003. Published March 2003. Originally approved in 1970. Last previous edition approved in 1998 as D 2850 – 95(1999).

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

[3] *Annual Book of ASTM Standards*, Vol 04.09.

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

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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:

$$\epsilon = \Delta H/H_o \quad (1)$$

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:

$$A = A_o/(1 - \epsilon) \quad (2)$$

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:

$$\sigma_1 - \sigma_3 = P/A \quad (3)$$

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 %:

$$\Delta(\sigma_1 - \sigma_3) = 4E_m t_m \epsilon_1 / D \quad (4)$$

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:

$$E_m = FL/A_m \Delta L \quad (5)$$

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 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 (D2850–95(99)) tha may impact the use of this standard.

(1) New sections 1.3 and 1.3.1 were added to address significant digits. Remaining subsections were renumbered.
(2) Several sections were changed to comply with D18 SPM policy requirements: 12.1 and Summary of Changes.
(3) Practice D 6026 was added to the Referenced Documents Section.
(4) Permissive language was eliminated in Sections 5.1 and 5.3.
(5) Requirements for using significant digits for measurements and/or calculations were added as sections 1.3 and 8.1 and the number of required significant digits was changed from four to three in sections 7.2, 7.4, and 7.6.
(6) Section 8 was renumbered.
(7) Classification D 2487 and Practice D 2488 were eliminated from the Referenced Documetns section as those standards are not referenced in text.
(8) Section 9 was reformatted

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Designation: D 4318 – 00

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

This standard is issued under the fixed designation D 4318; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope *

1.1 These test methods cover the determination of the 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 Method D 2216). 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 acceptable metric 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 metric. The metric values given are for information only.

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

2. Referenced Documents

2.1 *ASTM Standards:*

C 702 Practice for Reducing Field Samples of Aggregate to Testing Size[2]

D 75 Practice for Sampling Aggregates[3]

D 420 Guide to Site Characterization for Engineering, Design, and Construction Purposes[4]

D 653 Terminology Relating to Soil, Rock, and Contained Fluids[4]

D 1241 Specification for Materials for Soil-Aggregate Subbase, Base, and Surface Courses[4]

D 2216 Test Method for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass[4]

D 2487 Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)[4]

[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.

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[2] *Annual Book of ASTM Standards,* Vol 04.02.

[3] *Annual Book of ASTM Standards,* Vol 04.03.

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

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

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D 3282 Practice for Classification of Soils and Soil-Aggregate Mixtures for Highway Construction Purposes[4]
D 3740 Practice for Minimum Requirements for Agencies Engaged in the Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction[4]
D 4753 Specification for Evaluating, Selecting, and Specifying Balances and Scales for Use in Soil, Rock, and Related Construction Materials Testing [4]
D 6026 Practice for Using Significant Digits in Geotechnical Data[5]
E 11 Specification for Wire-Cloth Sieves for Testing Purposes[6]
E 177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods[6]
E 691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method[6]

3. Terminology

3.1 *Definitions:*

3.1.1 The definitions of terms in this standard are in accordance with Terminology D 653.

3.2 *Description of Terms Specific to This Standard:*

3.2.1 *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.

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

3.2.3 *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.

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

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

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

3.2.6 *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.

3.2.7 *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.

3.2.8 *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 D 2487 and D 3282) and to specify the fine-grained fraction of construction materials (see Specification D 1241). 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 D 2487).

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

6. Apparatus

6.1 *Liquid Limit Device*—A mechanical device consisting of a brass cup suspended from a carriage designed to control its

[5] *Annual Book of ASTM Standards,* Vol 04.09.
[6] *Annual Book of ASTM Standards,* Vol 14.02.

drop onto a hard rubber base. 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 hard rubber base having a Type D Durometer hardness of 80 to 90, and 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 isolation of the base from the work surface, and having a Type A Durometer hardness no greater than 60 as measured on the finished feet attached to the base.

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 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 gage 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.

DIMENSIONS

LETTER	A △	B △	C △	E △	F	G	H	J △	K △	L △	M △
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 △	V	W	Z
MM	24	28	24	45	47 ± 1.0	3.8	13	6.5

△ 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

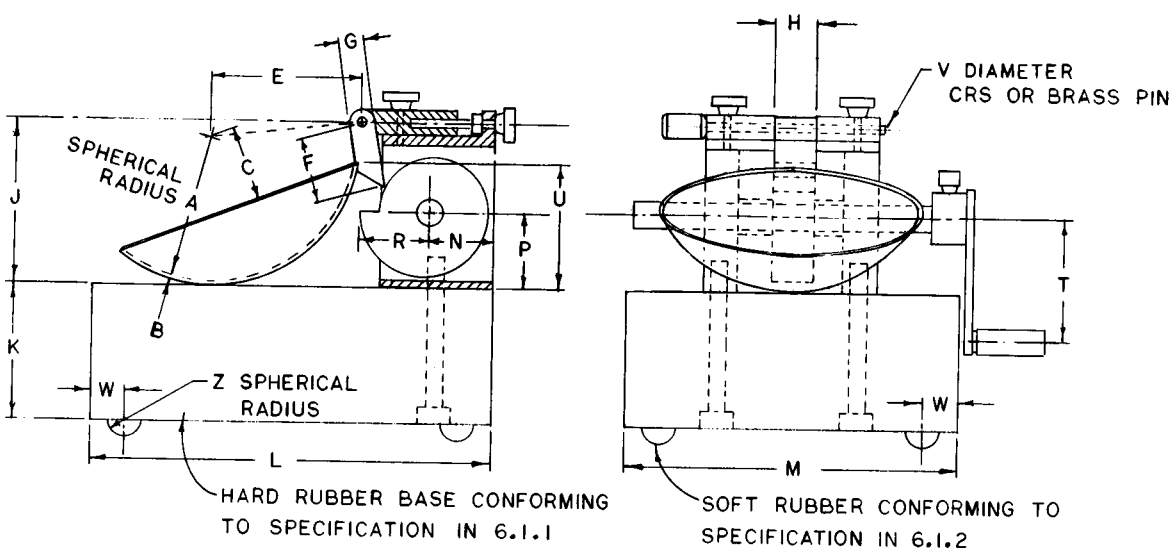


FIG. 1 Hand-Operated Liquid Limit Device

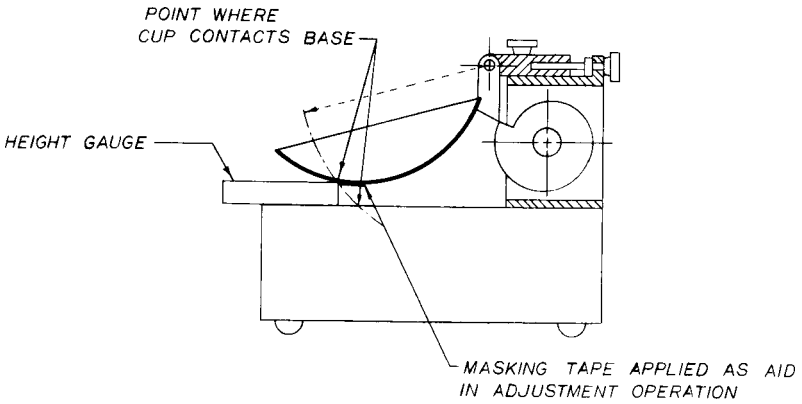


FIG. 2 Calibration for Height-of-Drop

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

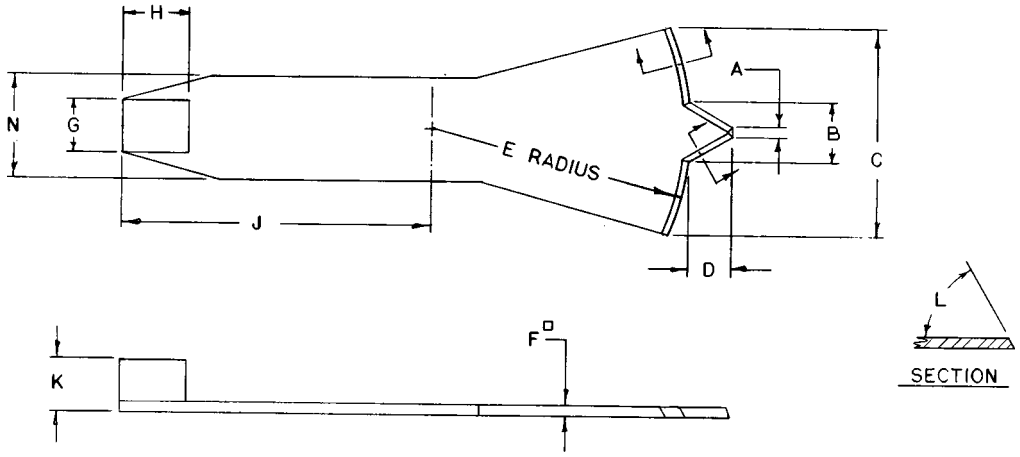


FIG. 3 Grooving Tool (Optional Height-of-Drop Gage Attached)

6.3 *Gage*—A metal gage 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 gage 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.

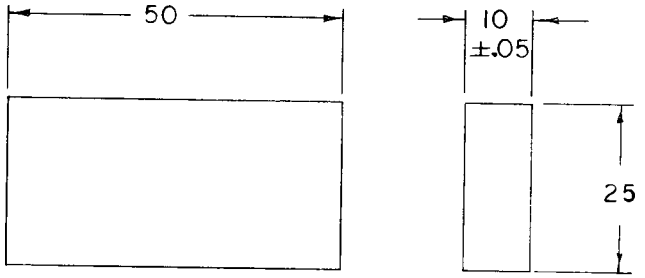
6.4 *Water Content Containers*—Small corrosion-resistant containers with snug-fitting lids for water content specimens. Aluminum or stainless steel cans 2.5 cm (1 in.) high by 5 cm (2 in.) in diameter are appropriate.

6.5 *Balance,* conforming to Specification D 4753, 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 at least 30



DIMENSIONS IN MILLIMETRES

FIG. 4 Height-of-Drop Gage

cm (12 in.) square by 1 cm (⅜ in.) thick 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.[7,8] 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 E 11 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.

8. Sampling and Specimen

8.1 Samples may be taken from any location that satisfies testing needs. However, Practices C 702, D 75, and D 420 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.

[7] The plastic limit-rolling device is covered by a patent (U.S. Patent No. 5,027,660).[7] 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.

[8] Bobrowski, L. J., Jr. and Griekspoor, D. M., "Determination of the Plastic Limit of a Soil by Means of a Rolling Device," *Geotechnical Testing Journal*, GTJODJ, Vol 15, No. 3, September 1992, pp. 284–287.

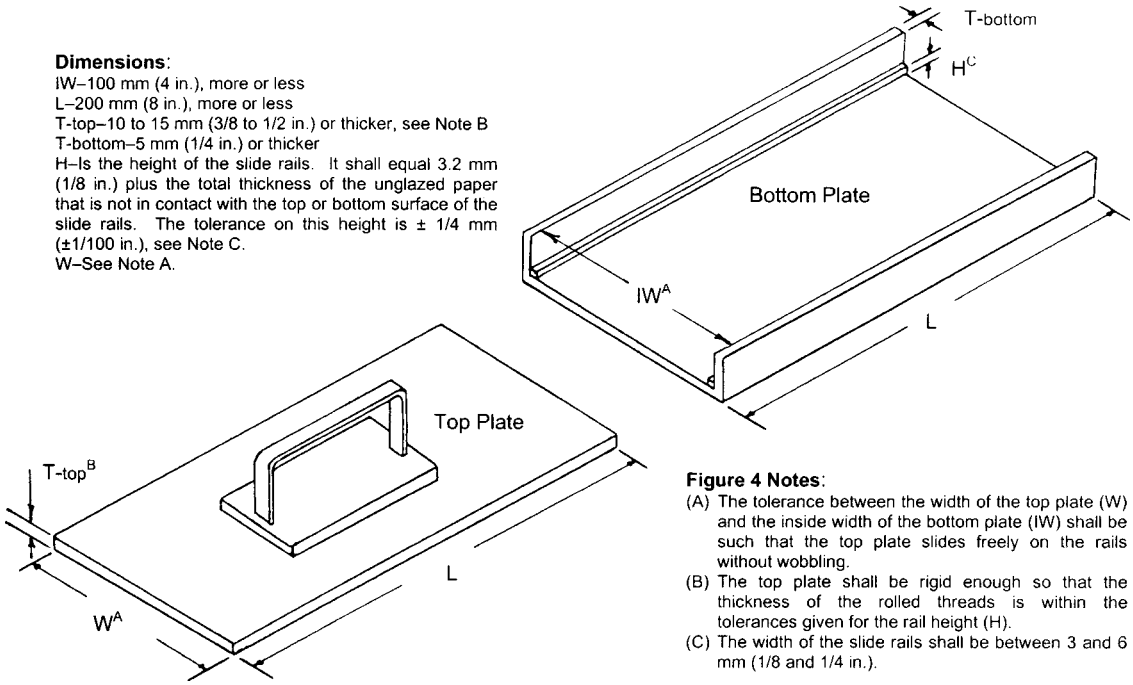


Figure 4 Notes:
(A) The tolerance between the width of the top plate (W) and the inside width of the bottom plate (IW) shall be such that the top plate slides freely on the rails without wobbling.
(B) The top plate shall be rigid enough so that the thickness of the rolled threads is within the tolerances 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

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 (⅜ 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.

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.

9.1.2 *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 gage 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 gage under the cup from the front, and observe whether the gage 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 gage in position against the tape and cup. If a faint ringing or clicking sound is heard without the cup rising from the gage, the adjustment is correct. If no ringing is heard or if the cup rises from the gage, readjust the height-of-drop. If the cup rocks on the gage 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,[9] 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 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 cup, and, if necessary, adjust its water content until the constancy 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

[9] S and S 595 filter paper available in 320-mm circles has proven satisfactory.

FIG. 6 Grooved Soil Pat in Liquid Limit Device

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.

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

FIG. 7 Soil Pat After Groove Has Closed

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 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 Method D 2216.

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 orientations. Repeat 11.2-11.5, and, 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. Otherwise, remix the entire specimen and repeat.

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

13.3 Determine water contents of 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

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

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):

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

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. 8). 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

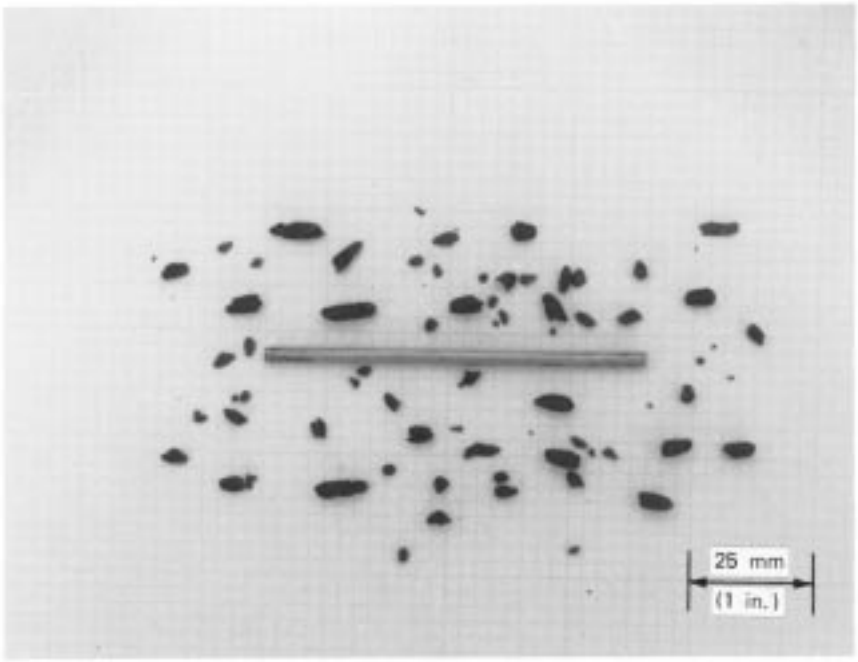


FIG. 8 Lean Clay Soil at the Plastic Limit

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 Method D 2216. 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 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; i.e., (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

19.1 Report the following information:

19.1.1 Sample identifying information,

19.1.2 Any special specimen selection process used, such as removal of sand lenses from undisturbed sample,

19.1.3 Report sample as air-dried if the sample was air-dried before or during preparation,

19.1.4 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,

19.1.5 Estimate of the percentage of sample retained on the 425-µm (No. 40) sieve, and

19.1.6 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.[10] 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 E 691, 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 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

[10] Supporting data are available from ASTM Headquarters. Request RR: D18-1013.

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 D 6026, 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 E 691 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 E 177. 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 D 6026. 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.

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

(1)	(2)	(3)			(4)			(5)		
Soil Type	Number of Test Laboratories	Average Value (Percentage Points)			Standard Deviation (Percentage Points)			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.

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 E 691 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 D 2487. 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.

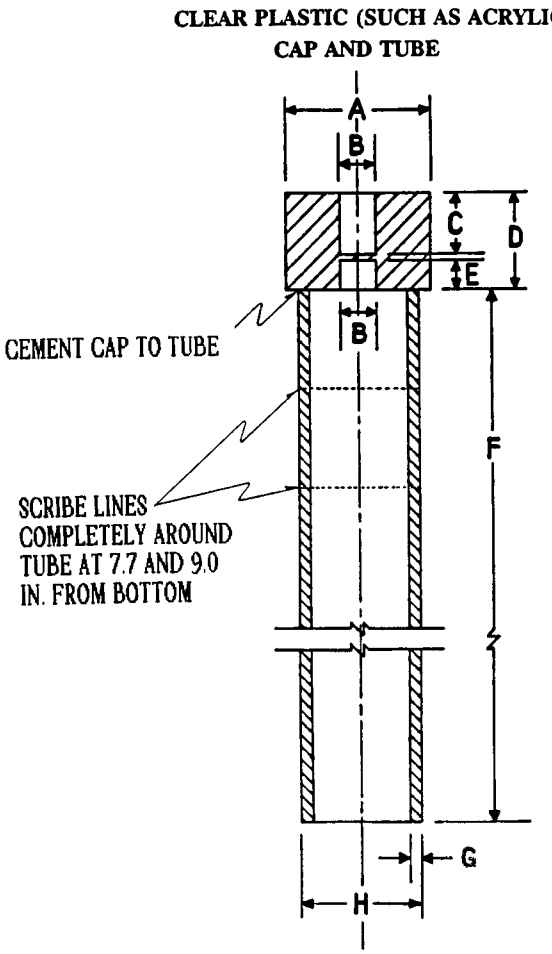


TABLE OF MEASUREMENTS

DIMENSION	DESCRIPTION	ENGLISH, in.	METRIC, 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

SUMMARY OF CHANGES

Committee D18 has identified the location of selected changes to this standard since the last issue (1998) that may impact the use of this standard.

(*1*) Replaced “procedure” with “method,” when the topic covers how one is to perform a task.
(*2*) In Scope covering “units,” clarified that the standard units for resilience tester are in inch-pound, not metric.
(*3*) Where applicable, replaced “weight” with “mass” or reworded to remove such terms as “weight,” “weighing,” or “weigh.”
(*4*) Where applicable, replaced “natural” as an adjective to water content with such terms as “its” or “as-sampled.”
(*5*) In Apparatus, under 6.6, “storage container” was changed to “mixing and storage container” and subsection reworded to indicate this container/dish may be used to mix the soil. Remaining sections in the standard, where applicable, were reworded to indicate “storage dish” may also be the “mixing dish.”
(*6*) In Section 8, changed title to include “Specimen,” and where applicable reworded to distinguish between the sample and the specimen before processing using the wet or dry preparation method.
(*7*) Under Preparation of Test Specimen: The subsections covering the wet and dry preparation methods were reworded to include the required number of blows for Method A and B. In addition, used the term “material” instead of soil or sample, whenever applicable, and replaced “grains” with “particle.”.
(*8*) Under One-Point Liquid Limit, Method B, Section 13 on Preparation of Test Specimen was removed since the information given in that section was moved to 10.1.2.4.
(*9*) In the calculation sections, defined that the calculated test result is rounded to the nearest whole number.
(*10*) References to Practice C 670 were deleted in text, and references to Practices D 3740, D 6026, E 177, and E 691 were incorporated.
(*11*) At the end of the Significance and Use section, a new Note 1 was added referencing Practice D 3740 in accordance with D18 policy, and all subsequent notes were renumbered.
(*12*) Section 20.1 on Precision was revised completely.
(*13*) In Table 1, corrected the factor for 20 number of drops.
(*14*) Appendix X1 was changed to Annex A1, and the scribe

line at “8.0” in Fig. A1.1 was changed to “7.7.”

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Appendix B

Standard Operating Procedures (SOPs)

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SOP No. 1

Soil Boring Installation and Soil Sampling Procedures

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Standard Operating Procedure No. 1: Soil Boring Installation and Soil Sampling Procedures

I. Scope and Application

This standard operating procedure (SOP) describes the field sampling procedures to install soil borings and collect soil samples. Soil samples may be collected through a variety of mechanisms, including the driven casing drilling method or a direct-push technique. In situations where physical site features limit the use of drill rigs, soil borings will be completed with a hand-driven or portable power auger depending on the required depth and subsurface material.

Samples of subsurface material encountered while drilling soil borings will typically be collected continuously to the required depth of the boring, or as directed by the supervising geologist. The sampling method employed will be the American Society for Testing and Materials (ASTM) D1586 – Standard Test Method for Penetration Test and Split-Barrel Sampling of Soils (Annual Book of ASTM Standards, Volume 04.08).

Personnel will also be responsible for documenting drilling events in the field notebook. The drilling contractor will be responsible for obtaining accurate and representative samples, informing the supervising geologist of changes in drilling pressure and loss of circulation, and keeping a separate general log of soils encountered, including blow counts (i.e., the number of blows from a soil sampling drive weight [140 pounds] required to drive the split-spoon sampler in 6-inch increments).

II. Equipment List

The following materials, as required, will be available during soil sampling:

- Health and safety equipment (as required in the *Revised Health and Safety Plan* [Revised HASP]) (Blasland, Bouck & Lee, Inc. [BBL], 2003);
- Cleaning equipment;
- All drilling equipment required by ASTM D1586;
- Appropriate sample containers and forms; and
- Field notebook.

The following materials, as required, will be available during surficial soil sampling:

- Health and safety equipment (as required by the Revised HASP [BBL, 2003]);
- Cleaning equipment;
- Appropriate sample containers and forms;
- Hand-operated soil sampling kit (split-spoon);
- Stainless steel bucket auger;
- Brass push rod;

- Spatula or knife;
- Hand spade;
- Stainless steel scoop;
- Stainless steel spoon;
- 6-foot rule; and
- Field notebook.

III. Health and Safety Considerations

Refer to Revised HASP (BBL, 2003).

IV. Soil Boring Installation Procedures

In conjunction with the use of driven casing methodologies, soil cores will be collected using standard 2-inch by 2-foot split-spoons driven by a 140-pound hammer or standard Shelby tubes, unless otherwise specified. The split-spoons or Shelby tubes will be advanced to the depth specified in the project-specific work plan. The sampling method employed will be ASTM D1586.

Direct-push drilling methods may also be used to collect soil cores. Examples of this technique include the Diedrich ESP vibratory probe system or AMS Power Probe™ dual tube system. Environmental probe systems typically use a hydraulically-operated percussion hammer. Depending on the equipment used, the hammer delivers 140 to 350 foot pounds of energy with each blow. The hammer, operated at 1,200 blows per minute, provides the force needed to penetrate very stiff/medium dense soil formations. The hammer simultaneously advances an outer steel casing that contains a disposable plastic liner that is used to collect soil samples.

V. Subsurface Soil Sampling Procedures

1. As samples are collected, qualified personnel will describe each soil sample on the Boring Log (Attachment 1-1) for the following parameters:

    - Soil type;
    - Color;
    - Percent recovery;
    - Moisture content;
    - Texture;
    - Grain size and shape;
    - Consistency; and
    - Miscellaneous observations.

2. Sample containers will be labeled, stored onsite, and transported to the appropriate testing laboratory. The sampling method employed will be the ASTM D1587 – Thin-Walled Tube Sampling of Soils for Geotechnical Purposes. Label all sample containers with the following:

- Site;
- Project number;
- Boring number;
- Sample interval;
- Date;
- Time of sample collection;
- Horizontal position in 1983 State Plane Coordinate System; and
- Initials of sampling personnel.

VI. Surficial Soil Sampling Procedures

Soil samples will be collected using a hand-driven split-spoon sampler, a stainless steel bucket auger, or a spade and scoop as determined by the field team and depending on the subsurface material. Samples of material encountered during this operation will be collected in 12-inch increments as indicated in the respective work plan.

The following procedures will be employed to collect surficial soil samples:

1. If the sample location is a grassed area or an area that exhibits overlying material (i.e., gravel, leaves, roots), the sod or overlying material should be removed and the underlying soil should be collected. The sod refers to the grass and dense root matter below the grass, including the soil within the dense root matter. Replace the sod following sample collection.

2. Secure one representative sample from the appropriate depth and place into a suitable sample jar.

3. Label all sample containers with the following:

    - Site;
    - Project number;
    - Location number;
    - Depth of sample;
    - Date;
    - Time of sample collection;
    - Horizontal position in 1983 State Plane Coordinate System; and
    - Initials of sampling personnel.

4. Record all appropriate information in the field notebook and on the proper forms.

VII. Soil Sample Compositing

In certain instances (e.g., duplicate sample collection), representative soil samples from several depth increments may be composited into one sample for subsequent analyses. In such instances, the following protocols will be used to support the performance of composite sample collection and analysis:

1. As soil samples from individual sample depth increments (e.g., 2-foot depth increments) are collected and one representative sample is placed into a glass sample jar.

2. The remainder of the soil samples will be placed into a clean, stainless steel bowl for subsequent compositing with other samples from the specified composite depth interval.

VIII. Survey

A field survey control program will be conducted using standard instrument survey techniques to document the boring, surficial soil, or floodplain sampling location and elevation. Generally, to accomplish this, a local control baseline will be set up. This local baseline control can then be tied into the appropriate vertical and horizontal datum of the North American Vertical Datum (NAVD) of 1988 and the 1983 State Plane Coordinate System.

IX. Field Cleaning Procedures

The sampling equipment is to be cleaned prior to the start of sampling activities, between samples, and after completing sampling activities.

X. References

BBL. 2003. *Revised Health and Safety Plan* (Revised HASP). Hudson River PCBs Superfund Site. Prepared for General Electric Company, Albany, NY.

Attachment 1-1

Boring Log

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Date Start/Finish: **Time Start/Finish:** **Drilling Company:** **Driller's Name:** **Drilling Method:** **Bit Size:** **Auger Size:** **Rig Type:** **Sampling Method:**	**Northing:** **Easting:** **Casing Elevation:** **Water Depth:** **Borehole Depth:** **Surface Elevation:** **Geologist:**	**Boring ID:** **Client:** General Electric **Location:** Hudson River

DEPTH ELEVATION	Sample Run Number	Sample/Int/Type	Recovery (feet)	Blows / 6 Inches	N - Value			Geologic Column	Stratigraphic Description	Remarks
0										
5										
10										
15										

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SOP No. 2

Barge Location Setup

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Standard Operating Procedure No. 2: Barge Location Setup

I. Scope and Application

This standard operating procedure (SOP) describes the procedures for positioning/maneuvering to collect soil samples. Barge can be positioned by an attached motor or by a tug/crew boat. In situations where physical site features limit the use of drill rigs, soil borings will be completed with a hand-driven or portable power auger depending on the required depth and subsurface material.

Personnel will also be responsible for documenting drilling events in the field notebook.

II. Equipment List

The following materials, as required, will be available during barge positioning/maneuvering:

- Health and safety equipment (as required in the *Revised Health and Safety Plan* [Revised HASP]) (Blasland, Bouck & Lee, Inc. [BBL], 2003);
- Cleaning equipment;
- Calculator;
- Real-Time Kinematics (RTK) Differential Global Positioning System (DGPS);
- Surveying level rod;
- 50-foot measuring tape attached to an 8-inch steel plate (similar to lead lines); and
- Field notebook.

III. Health and Safety Considerations

Refer to Revised HASP (BBL, 2003).

IV. Barge Location Setup Procedures

Prior to drilling operations, maneuver the sampling vessel to within 5 feet of the pre-programmed target coordinates for each sample location. Secure the vessel in place using spuds and/or anchors. Record in the field notebook where the actual location from which the core was collected and target location.

1. Qualified personnel will note the date and time of all recordings and will describe each position on the Boring Log (Attachment 2-1) for the following parameters:

    - Date;
    - Time;
    - Horizontal position (Datum: North American Datum [NAD] 1983 NY East Zone);
    - Vertical position (Datum: North American Vertical Datum [NAVD] 1988;) and

- Other observations.

2. Using the on-board RTK DGPS unit, maneuver the sampling vessel to within 5 feet of the pre-programmed target coordinates for each sample location. Secure the vessel in place using spuds and/or anchors. Record in the field notebook where the actual location from which the core was collected and target location.

3. Determine the water depth by using a tape measure with a weight attached to the end for areas with low flow velocity. For areas of high flow velocity, use a standard survey rod, taking care to make sure that it is vertical in the water column and not forced into the river bottom. Record the water depth to the hundredth position (i.e., 10.21 feet). Also, water depth reading can be taken down the barrel of the casing to be used.

4. Using the DGPS system, record the water surface elevation (stage in feet). Note that the water surface elevation needs to be recorded to the hundredth position (i.e., 120.21 feet).

V. Survey

A field survey control program will be conducted using standard instrument survey techniques to document the positioning and maneuvering of barges to sampling location and elevations. Generally, to accomplish this, a local control baseline will be set up. This local baseline control can then be tied into the appropriate vertical and horizontal datum NAVD of 1988 and the NAD 1983 State Plane Coordinate System).

VI. Field Cleaning Procedures

The measuring equipment is to be cleaned prior to the start of activities, between, and after completing activities.

VII. References

BBL. 2003. *Revised Health and Safety Plan* (Revised HASP). Hudson River PCBs Superfund Site. Prepared for General Electric Company, Albany, NY.

Attachment 2-1

Boring Log

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Date Start/Finish: **Time Start/Finish:** **Drilling Company:** **Driller's Name:** **Drilling Method:** **Bit Size:** **Auger Size:** **Rig Type:** **Sampling Method:**	**Northing:** **Easting:** **Casing Elevation:** **Water Depth:** **Borehole Depth:** **Surface Elevation:** **Geologist:**	**Boring ID:** **Client:** General Electric **Location:** Hudson River

DEPTH ELEVATION	Sample Run Number	Sample/Int/Type	Recovery (feet)	Blows / 6 Inches	N - Value			Geologic Column	Stratigraphic Description	Remarks
0										
5										
10										
15										

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SOP No. 3

Decontamination Procedure

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Standard Operating Procedure No.3: Decontamination Procedure

I. Scope and Application

This standard operating procedure (SOP) describes the procedures for decontamination of sampling equipment. Drill casing will be decontaminated prior to initial use at the site and at the completion of the field activities. Non-disposable sampling equipment (such as hand augers, split-spoon samplers, stainless steel bowls and spoons, etc.) will be decontaminated between sample locations.

II. Equipment List

The following materials, as required, will be available during decontamination procedures:

- Health and safety equipment (as required in the *Revised Health and Safety Plan* [Revised HASP]) (Blasland, Bouck & Lee, Inc. [BBL], 2003);
- Tap water;
- Non-phosphate soap solution; and
- Scrub brush.

III. Health and Safety Considerations

Refer to Revised HASP (BBL, 2003).

IV. Decontamination Procedure

Since only geotechnical sampling is proposed for this study, a modified decontamination procedure has been set forth for the supplemental engineering data collection (SEDC) effort. Drill casing will be decontaminated prior to initial use at the site and at the completion of the field activities. Non-disposable sampling equipment (such as hand augers, split-spoon samplers, stainless steel bowls and spoons, etc.) will be decontaminated between sample locations, according to the following procedures:

1. Tap water rinse;
2. Manual scrub with non-phosphate soap solutions;
3. Tap water rinse; and
4. Air dry.

The equipment will be decontaminated at the sampling location, and all decontamination water will be contained and disposed of properly as described in the *Quality Assurance Project Plan* (QAPP) (QEA and ESI, 2002).

V. References

BBL. 2003. *Revised Health and Safety Plan* (Revised HASP). Hudson River PCBs Superfund Site. Prepared for General Electric Company, Albany, NY.

QEA and ESI. 2002. *Quality Assurance Project Plan* (QAPP). Hudson River PCBs Superfund Site. Prepared for General Electric Company, Albany, NY.

SOP No. 4

Infrastructure Documentation

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Standard Operating Procedure No. 4: Infrastructure Documentation

I. Scope and Application

This standard operating procedure (SOP) describes the procedures for recording and documentation of infrastructure located within and adjacent to the dredge area. Data will consist of a collection of vertical/horizontal dimensions and geographic location of all infrastructures (e.g., bridges, utility clearances, bulkheads, piers, dams, locks, water intake/outfalls, roads, houses, etc.) located within and adjacent to the proposed dredge areas.

II. Equipment List

The following materials, as required, will be available during infrastructure documentation procedures:

- Health and safety equipment (as required in the *Revised Health and Safety Plan* [Revised HASP]) (Blasland, Bouck & Lee, Inc. [BBL], 2003);
- Survey level rod;
- Real-Time Kinematics (RTK) Differential Global Positioning System (DGPS);
- Calculator;
- 300-foot measuring tape;
- Digital camera; and
- Field notebook.

III. Health and Safety Considerations

Refer to Revised HASP (BBL, 2003).

IV. Infrastructure Documentation Procedure

Infrastructure Located Within and Adjacent to the River

Identify pre-designated infrastructure located on water (e.g., bridge abutment, piers, water intake/outfalls, docks, locks dams, etc.) using pre-programmed target coordinates for each infrastructure location. Prior to measurement, maneuver the vessel as close as possible to infrastructure. Secure the vessel in place using anchors. Record in the field notebook where the actual location from which the measurement was collected and target location.

1. Qualified personnel will note the date and time of all recordings and will describe each infrastructure on the Infrastructure Documentation Log (Attachment 4-1) for the following parameters:

    - Infrastructure identification;
    - Date;

- Time;
- Horizontal position (Datum: North American Datum [NAD] 1983 New York [NY] East Zone);
- Vertical position (Datum: North American Vertical Datum [NAVD] 1988);
- Water surface elevation around infrastructure;
- Dimensions of structure (length, width, and depth);
- Photo number and description; and
- Other observations.

2. Using a hand-held RTK DGPS, identify all points on the infrastructure (e.g., perimeter of infrastructure, corners, mid-points, etc.) at the water surface of the river utilizing a RTK unit.

3. Using a measuring tape/survey rod, identify all dimensions (e.g., length, width, depth, center, mid-point, etc.) of the infrastructure.

4. Photograph infrastructure from all sides utilizing a digital camera. Each photo will be identified by a photo log number and a brief description of photo location and orientation.

Infrastructure Located on Land

Identify pre-designated infrastructure located on land (e.g., roads/highways, houses/structures, trees/landscaping, sea walls, etc.) using pre-programmed target coordinates for each infrastructure location. Record in the field notebook where the actual location from which the measurement was collected and target location.

1. Qualified personnel will note the date and time of all recordings and will describe each infrastructure on the Infrastructure Documentation Log (Attachment 4-1) for the following parameters:

   - Infrastructure identification;
   - Date;
   - Time;
   - Horizontal position (Datum: NAD 1983 NY East Zone);
   - Vertical position (Datum: NAVD 1988);
   - Water surface elevation closest to infrastructure;
   - Dimensions of structure (length, width, and depth);
   - Photo number and description; and
   - Other observations.

2. Using a hand-held RTK DGPS unit, identify all points on the infrastructure (e.g., perimeter of infrastructure, corners, mid-points, etc.) and the water surface elevation on the river closest to the infrastructure utilizing an RTK unit.

3. Using a measuring tape/survey rod, identify all dimensions (e.g., length, width, depth, center, mid-point, etc.) of the infrastructure.

4. Photograph infrastructure from all sides utilizing a digital camera. Each photo will be identified by a photo log number and a brief description of photo location and orientation.

Vertical Clearance

Identify pre-designated bridge using pre-programmed target coordinates for each infrastructure location. Prior to measurement, maneuver the vessel as close as possible under the lowest point of each span across the river. Secure the vessel in place using anchors. Record in the infrastructure log where the actual location from which the measurement was collected and target location.

1. Qualified personnel will note the date and time of all recordings and will describe each infrastructure on the Infrastructure Documentation Log (Attachment 4-1) for the following parameters:

    - Infrastructure identification;
    - Date;
    - Time;
    - Number of spans and abutments;
    - Horizontal position (Datum: NAD 1983 NY East Zone);
    - Vertical position (Datum: NAVD 1988);
    - Water surface elevation closest to infrastructure;
    - Dimensions of structure (length, width, and depth);
    - Photo number and description; and
    - Other observations.

2. Using a hand-held RTK DGPS, identify all points on the infrastructure (e.g., perimeter of infrastructure, corners, mid-points, etc.) and the water surface elevation on the river closest to the infrastructure utilizing a RTK unit.

3. Using a measuring tape/survey rod, identify all dimensions (e.g., length, width, depth, center, mid-point, etc.) of the infrastructure.

4. Photograph infrastructure from all sides utilizing a digital camera. Each photo will be identified by a photo log number and a brief description of photo location and orientation.

V. References

BBL. 2003. *Revised Health and Safety Plan* (Revised HASP). Hudson River PCBs Superfund Site. Prepared for General Electric Company, Albany, NY.

Attachment 4-1

Infrastructure Documentation Log

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Infrastructure Documentation Log

Surveying Company:	***Northing:***	***Infrastructure ID:***
Surveyor's Name:	***Easting:***	***Infrastructure Number:***
Date:	***Water Surface Elevation:***	***River Mile:***
Time:		

Dimensions of Infrastructure

Shape:
Description:
Length (ft):
Width (ft):
Depth (ft):
Diameter (ft):

Span Number	*Span Location*	*Span Description*	*Vertical Clearance (ft) at lowest point in span*

Photo Description

photo number	*photo description*

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Remarks:

Infrastructure Documentation Log

Sketch of Infrastructure:

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SOP No. 5

Boat-Mounted Current Velocity Profiling Surveys

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Standard Operating Procedure No. 5: Boat-Mounted Current Velocity Profiling Surveys

I. Scope and Application

This standard operating procedure (SOP) applies to boat-mounted current velocity profiling surveys of River Sections 1 and 2 of the Hudson River PCBs Site, as defined by the February 2002 Record of Decision (ROD) issued by the United States Environmental Protection Agency (USEPA) (USEPA, 2002), and of the "Land Cut" section of the Champlain Canal that runs outside of the river between the Fort Miller Dam (Lock 6) and Thompson Island Dam - HRM 186 to 189. This SOP describes the procedures that the designated subcontractor will use to conduct boat-mounted current velocity profiling surveys during the 2003 - 2004 field season of the GE Hudson River Design Support Sediment Sampling and Analysis Program (SSAP), as described in the *Sediment Sampling and Analysis Program – Field Sampling Plan* (SSAP-FSP) (QEA, 2002) and *Supplemental Field Sampling Plan* (Supplemental FSP) (QEA, 2003).

The objective of the boat-mounted current velocity profiling survey is to collect river velocity data to be used for the design of in-river structures that may be used for dredging-related activities (e.g., silt curtains, sheetpile walls, etc.).

II. Equipment and Supplies

Equipment and supplies needed for the boat-mounted current velocity profiling survey include:

- Shallow draft survey vessel;
- Navigational charts and permits;
- RD Instruments 1,200 kHz Workhorse Monitor Acoustic Doppler Current Profiler (ADCP);
- Real-Time Kinematic (RTK) control monuments and Differential Global Positioning System (DGPS) navigation equipment;
- Marine communications equipment;
- Electronic data acquisition equipment;
- Electronic data storage equipment;
- Field logs and charting paper;
- Boat supplies (e.g., fuel, safety equipment); and
- Personnel supplies (e.g., protective clothing).

II a. Survey Vessel

The designated subcontractor will conduct the boat-mounted current velocity profiling survey from a 21-foot flat-bottom Carolina Skiff with a fully enclosed cabin and dual outboard engines. The boat is equipped with a starboard side mount for RD Instruments ADCP.

II b. Navigation Equipment

Navigational control monuments for SSAP survey operations have been established along the Upper Hudson River at the Troy Lock, Champlain Canal Locks 1 through 7, and along Rt. 4 north of Stillwater. Each control monument has known coordinates and elevation referenced to North American Datum (NAD) of 1983 and North American Vertical Datum (NAVD) of 1988, respectively, and is located such that DGPS receivers will have clear visibility of the sky from approximately 15 degrees above the horizon in all directions.

The designated subcontractor will employ Trimble 7400 Msi DGPS receivers to acquire navigation data based on DGPS satellites and the shore-based control monuments. Differential correctors determined at the control stations will be transmitted to the survey vessel, where they will be used by the onboard receiver using RTK On-The-Fly (OTF) software to determine the accurate position of the DGPS antenna in both the horizontal and vertical planes. These data will be logged on-board at one-second intervals for the duration of the project. Data quality parameters will also be logged and monitored by the on-board navigator, with flags put on all data points which do not meet the quality limits set. The specified horizontal accuracy for this system is +/- 2 cm when satellite configuration is sufficient. Where coverage is insufficient, as determined by DGPS filters and navigational software flags, either additional control stations will be added or - for small gaps in coverage - the navigation data will be interpolated between points of adequate coverage based on boat speed and heading.

II c. RD Instruments Acoustic Doppler Current Profiler

In-situ current velocity data will be collected using an RD Instruments ADCP. This unit, mounted on the starboard side of the survey vessel directly under the DGPS antenna in a look-down configuration, will map the flow of the river in real-time as the survey vessel is maneuvered along selected cross-river transects within each area of interest. Current velocity data will be collected twice along each transect, once in an east-west direction and repeated in the opposite west-east direction. These data are uploaded and displayed on the navigational computer in real-time, allowing the field crew to observe a vector-based presentation of the flow instantaneously. To collect data, the designated subcontractor's field crew will pilot the survey vessel across each transect collecting a current velocity profile of the water column as they go.

Current velocity data will be compiled with a vertical interval of ½-meter and a horizontal resolution of 10 meters. The boat-mounted ADCP data will be reduced to ASCII listings of current speed and direction versus depth and x/y or latitude/longitude position.

II d. Data Acquisition and Processing Equipment

Coastal Oceanographics' software package "HYPACK Max" will be used for trackline design, navigation, trackline control, and RTK DGPS data logging. The real-time boat-mounted ADCP data will be processed using RD Instruments specialized software program, (e.g., WinRiver Version 1.09.002, etc.) to generate tabular ASCII data containing vessel position, current speed, and current direction at ½-meter vertical intervals and at a horizontal spacing of 10 meters. Data will be presented as formatted ASCII listings of current speed and direction versus position and depth and as current vector plots of the vertically averaged flow. Data acquisition equipment, software, and file formats are summarized in Table 5-1, below.

Table 5-1. Summary of Boat-Mounted ADCP Data Collection/Processing Equipment and Software

Equipment Type	Manufacturer	Model	Data File Format
OTF DGPS Receiver	Trimble	7400 Msi	Logged by HYPACK and ISIS
Navigation Software and Sounding Data Collection Platform	Coastal Oceanographics	HYPACK Max	HYPACK RAW
RD Instruments ADCP	RD Instruments	Workhorse 1,200 khz	Logged by WinRiver
Data Processing Software	Coastal Oceanographics	HYPACK Max	XYZ, DXF, TIFF
CAD Software	AutoCAD	Release 14	DXF, DWG

III. Survey Procedures

The designated subcontractor will conduct the boat-mounted ADCP survey in River Sections 1 and 2. The following survey procedures will be used:

1. Before leaving the dock, the survey crew will check to make sure all navigation and instrument systems are working properly. Calibrate and set navigation instruments based on the instrument-specific SOPs. Prepare survey equipment for start of daily survey operations, including: deployment of RD Instruments ADCP into water, measurement of survey equipment offsets, and other required pre-survey activities.
2. Navigate to the coordinates of the first transect. Coastal Oceanographics' "HYPACK Max" will be used for trackline design, navigation, trackline control, and RTK DGPS data logging.
3. Align survey vessel along transect and confirm heading and equipment operation. Start data acquisition and commence boat-mounted current velocity survey along transect at a vessel speed of 4 knots or less. Current velocities will be collected using a look-down RD Instruments ADCP. The ADCP will collect velocity data at ½-meter vertical intervals and at a 10-meter horizontal resolution. Data will be logged by the WinRiver computer.
4. Note relevant observations and changes in operational procedures on the field log. These may include: coordinates of observed obstructions or artifacts, areas where interferences or other conditions limit survey resolution, etc.
5. At the end of each transect, confirm successful data acquisition and storage, and navigation and equipment calibrations and settings. Log time and coordinates at end of each transect line surveyed.
6. Navigate to next transect and repeat steps 2 through 5 for collecting current velocity data along each transect. Maintain a safe operating distance (as determined by boat operator) from lock gates, dams, and other vessels between transects.
7. Back up the computer data and check for error flags periodically during the survey.
8. Output all notes and electronic target files to an ASCII file and store with the raw records. All raw survey data and information (e.g., field notes, instrumentation frequencies) must be documented electronically or in a field notebook. Back-up copies of raw electronic data and copies of field logbooks will be made at the end of each survey day.

IV. Quality Assurance/Quality Control (QA/QC)

The designated subcontractor's personnel will follow the guidance of the *Quality Assurance Project Plan* (QAPP) (QEA and ESI, 2002) and the OSI *Quality Management Plan* (OSI, 2002b). The designated subcontractor's personnel will follow in-house SOPs for data transfer and transformation that ensure both the integrity of the original dataset and the quality of post-processed data. Confidence checks and calibration procedures will be performed daily, or as needed, to ensure proper equipment functionality and data quality. The following sections describe QA/QC procedures for the survey equipment.

IV a. Positioning Systems Confidence Checks

The designated subcontractor shall initially verify the accuracy of the positioning system by occupying a survey monument set for this project. Once verified to this monument, the designated subcontractor shall establish an accessible checkpoint at a location(s) where the vessel will be docked. Using this checkpoint, the positioning system's accuracy will be verified at the beginning and end of each day of field operations.

IV b. ADCP Operational Confidence Checks

The RD Instruments ADCP will be checked at the beginning of each survey day using the instrument's internal software/firmware QA/QC tests. In addition, all ADCP cross-river transects will be run twice, once in each direction. These two datasets will allow cross-verification of the in-situ velocity vectors.

V. Data Processing and Reporting

The designated subcontractor will use in-house SOPs for processing field survey data into useful maps for interpretation. Data processing and review will be accomplished employing "HYPACK Max," WinRiver, and MatLab software packages. The processing flow will include review of layback, heading, altitude, and navigation. Navigation will be recomputed with sensor layback applied. Each line will be reviewed for data quality, sensor height, and contact identification and correlation. All corrections and offsets to the raw data will be applied in "HYPACK Max" during post-processing.

Information gathered during the current velocity survey will be output as ASCII engineering listings and as vector plots of current velocity on the project base sheets using AutoCAD at an appropriate scale and resolution. The designated subcontractor will submit the current velocity data, along with interpretive text summarizing survey procedures and results, to QEA and GE within 45 days of the completion of the current velocity survey.

VI. References

QEA. 2003. *Supplemental Field Sampling Plan* (Supplemental FSP). Hudson River PCBs Superfund Site. Prepared for General Electric Company, Albany, NY.

QEA. 2002. *Sediment Sampling and Analysis Program - Field Sampling Plan* (SSAP-FSP). Hudson River PCBs Superfund Site. Prepared for General Electric Company, Albany, NY.

QEA and ESI. 2002. *Quality Assurance Project Plan* (QAPP). Hudson River PCBs Superfund Site. Prepared for General Electric Company, Albany, NY.

OSI. 2002a. *Manual of Standard Operating Procedures – Geophysical Surveys of the Hudson River PCBs Site*. Prepared for General Electric Company. July 2002.

OSI. 2002b. *Quality Management Plan*. July 2002.

Office of Costal Survey. 1998. *Field Procedures Manual for Hydrographic Surveying*. National Oceanic and Atmospheric Administration, Office of Coastal Survey. March 1998.

USEPA. 2002. *Hudson River PCBs Site - Record of Decision and Responsiveness Summary* (ROD). New York, NY.

SOP No. 6

Modified Calibration of Hydrographic Survey Equipment

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Standard Operating Procedure No. 6: Modified Calibration of Hydrographic Survey Equipment

I. Scope and Application

This standard operating procedure (SOP) describes the procedures for verification of vertical accuracies of hydrographic survey equipment, above those stated in the United States Army Corps of Engineers (USACE) manual titled *Engineering and Design - Hydrographic Surveying* (EM 1110-2-1003) (USACE, 2002). The intent of this SOP is not to replace EM 1110-2-1003, but rather provide additional steps to produce a hydrographic survey that has a vertical accuracy of +/- 0.25 feet (currently the USACE manual allows for a vertical accuracy of +/- 0.5 feet for electronic data collection methods). SOPs for single-beam hydrographic surveys have already been provided under the *Quality Assurance Project Plan* (QAPP) (QEA and ESI, 2002) previously developed for the Sediment Sampling and Analysis Program (SSAP). The SOPs for multi-beam surveying will be in accordance with the USACE manual EM 1110-2-1003.

II. Personnel Qualifications

A Certified Inland Hydrographer will be present during survey data collection and data processing.

III. Equipment List

The following equipment will be used when implementing this SOP:

- Shallow draft survey vessel;
- Navigational charts and permits;
- RD Instruments acoustic Doppler current profiler (ADCP);
- Differential global positioning system (DGPS) navigation equipment and Real-Time Kinematics (RTK) control monuments;
- Marine communications equipment;
- Electronic data acquisition equipment;
- Electronic data storage equipment;
- Field logs and charting paper;
- Boat supplies (e.g. fuel, safety equipment), and
- Personnel supplies (e.g. protective clothing).

IV. Health and Safety Considerations

Refer to the *Revised Health and Safety Plan* (Revised HASP) (Blasland, Bouck & Lee, Inc. [BBL], 2003).

V. Calibration for Single-Beam and Multi-Beam Hydrographic Surveys

1. Determine the appropriate survey line spacing based on the water depth within the proposed dredge area. For single-beam surveys, survey lines will not be spaced greater than 15 feet. Note that during survey operations, the captain will not deviate/veer from the targeted survey transect more than 10 feet either side (port or starboard).

2. Perform hand probing in the proposed dredge area and/or review probing information previously presented in the *Sediment Sampling and Analysis Program – Year 1 – Data Summary Report* (Year 1 DSR) (QEA, 2003) to determine hardness of the river bottom. This process will be repeated in each potential dredge area. This information will be used to aid in determining the hardness of the river bottom during lead-line soundings.

3. Perform necessary set-up and calibration (bar check, calibration for speed of sound in the water column, etc.) as specified in the QAPP (QEA and ESI, 2002) and the USACE survey manual (USACE, 2002) (for both survey techniques).

   Note that calibration procedures will be performed three times a day to account for change in water temperature as well as reduction in vessel draft due to fuel consumption.

   Note that each survey line will be run in two directions (i.e., if the proposed dredge area has a north to south orientation, surveys will be run from east to west and west to east).

4. Manual depth measurement techniques (lead-line) will be collected following collection of electronic survey data as a tool to verify the accuracy of the digital soundings. Lead-line soundings will be spaced equally at 50-foot increments along every other targeted transect. The soundings (water depth) will be recorded electronically, as well as the position of the sounding. The sounding will be collected directly under the antenna that collects the position from the satellites and the differential correction signal from the shore-based unit.

5. Three comparisons will be performed on the survey data collected (for each individual proposed dredge area):

   - The survey lines run from east to west and west to east (for each transect) and will be overlaid on one another in cross-section view. Vertical differences will be noted. Note that for multi-beam surveys, cross-sections will be generated at an interval no greater than 15 feet for cross section comparison.

   - A difference plot will be generated of the two datasets (a comparison of survey lines run east to west and west to east for both electronic survey techniques). The difference plot will be queried for differences that are greater than +/- 0.25 feet.

   - Lead-line soundings will be overlaid electronically (in plan view for targeted transects where lead-line soundings were conducted). A comparison will be made of the soundings collected electronically (both sets east to west and west to east).

If a particular area/transect does not correspond with the lead-line soundings, that particular area/transect will have to be re-surveyed and steps 3 through 5 performed again. Steps 1 through 5 will be repeated for each proposed dredge area.

The goal of this comparison process is to provide/collect survey data that do not exceed a vertical error of +/- 0.25 feet.

VI. Data Recording and Management

As specified in the QAPP (QEA and ESI, 2002).

VII. Quality Assurance

As specified in the QAPP (QEA and ESI, 2002).

VIII. References

BBL. 2003. *Revised Health and Safety Plan* (Revised HASP). Hudson River PCBs Superfund Site. Prepared for General Electric Company, Albany, NY.

QEA. 2003. *Sediment Sampling and Analysis Program – Year 1 – Data Summary Report* (Year 1 DSR). Hudson River PCBs Superfund Site. Prepared for General Electric Company, Albany, NY.

QEA and ESI. 2002. *Quality Assurance Project Plan* (QAPP). Hudson River PCBs Superfund Site. Prepared for General Electric Company, Albany, NY.

USACE. 2002. *Engineering and Design - Hydrographic Surveying* (EM 1110-2-1003).

Appendix C

Sample Handling and Custody Requirements

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Appendix C – Sample Handling and Custody Requirements

Field Activities Sample Custody

The primary objective of sample custody procedures is to create an accurate written record which can be used to trace the possession and handling of samples from the moment of their collection, through analysis, until their final disposition.

A sample (or sample container) will be considered under custody if:

- It is in the Field Sampling Manager's (or his designate's) possession;
- It is in the Field Sampling Manager's (or his designate's) view, after being in the Field Sampling Manager's (or his designate's) possession;
- It was in the Field Sampling Manager's (or his designate's) possession and the Field Sampling Manager (or his designate's) locked it up; or
- It is placed in a designated secure area by the individual who is maintaining custody.

Samples will be collected from each split-spoon on the vessels at the time of sampling and be transferred to individual wide-mouth, 16-ounce glass jars for the geotechnical analyses. All necessary sample containers will be provided by the drilling subcontractor and received by the field personnel. After a given sample has been collected, a self-adhesive, waterproof label will be affixed to each container. An example label is provided on Figure C-1. At a minimum, the sample label will contain:

- Field sample identification number;
- Date and time collected;
- Custodian's initials; and
- Analytical category.

The analytical categories include GEOTEC or STOR. The categories were chosen based on the fact that those samples in different categories will go to the geotechnical laboratory for analysis or be held for potential future geotechnical analysis.

A field log (Figure C-2) will be used to document custody of the split-spoon samples from the time they are collected until the samples are delivered to the field sample processing area. Custody of the samples will be transferred by the processing area personnel by a release and acceptance signature, as indicated on the field log (Figure C-2). The field log transfer of the samples will terminate transfer of the samples to the processing area where sample custody will begin. A copy of the field log forms will be maintained on file at the sample processing area. Custody for samples collected from sample processing will be maintained by the field personnel collecting the samples. The field personnel are responsible for documenting each sample transfer and maintaining custody of samples until they are shipped or delivered by courier to the laboratory or stored for future testing.

To insure proper chain-of-custody (COC) is not broken, an initialed custody seal will be placed over the lid opening. A laboratory supplied and initialed COC will be used to document the transfer of sample containers from the site to the geotechnical laboratory.

A field COC record will accompany the samples to their destination. An example of the field COC records is provided in Figure C-3. Field COC records may be prepared either using a computerized sample tracking and COC program that will be integral to the project database or via hand or preprinted COC forms. The sampling personnel will properly relinquish the samples on the field COC record. These record forms will be sealed in a plastic bag to protect them against moisture. The shipping containers will then be sealed utilizing custody seals that will be initialed by the field personnel or designate. All sample containers will be delivered to the analytical laboratory by either direct courier or 24-hour delivery courier (i.e., United Parcel Service) at the end of each day's sample processing activities.

Laboratory Receipt and Custody

Once samples are received at the laboratory, the field COC record is completed and signed by the individual Laboratory Sample Custodian. The Laboratory Sample Custodian will check the sample jar labels against the corresponding information listed on the field Chain-of-Custody records and note any discrepancies. Additionally, the laboratory sample receipt personnel will note any damaged or missing sample containers. Any

discrepancies in sample identifications, sample analysis information, or any indication that samples are missing upon receipt at the laboratory will be communicated to the Field Sampling Manager within 24 hours of sample receipt so that appropriate corrective action can be determined and implemented.

After the sample receipt information is checked and recorded, sample analysis information will be entered into the individual Laboratory Information Management System (LIMS) (or equivalent). Each sample will be provided a unique laboratory identification number and the analysis tests requested on the COC records entered into the LIMS. After the required information has been entered into the LIMS, the Laboratory Sample Custodian will initiate an internal laboratory COC. The internal COC will document the transfer of samples from the storage location to the analyst for analysis and subsequently through final disposition at the laboratory. At a minimum, the internal COC will include client identification, laboratory sample number, sample matrix, signatures for relinquishing and receiving samples, and reasons for the change in custody (procedure to be performed).

All completed field and laboratory COC records will be provided in the laboratory analysis data package as part of the required deliverable report.

Geotechnical samples do not require temperature preservation, as these samples will be stored at room temperature. Disposal of unused raw sample volumes, sample extracts, and sample digestates will be in accordance with each laboratory's waste management procedures. Disposal of raw samples will occur after 14 days from the date the analysis report (full data package) was issued.

Sample Storage Procedures

GE will store those samples collected as part of the SEDC Program, but not analyzed by the geotechnical laboratory. Samples will be stored in the original sample collection jar (e.g., the 16-ounce wide mouth jar, etc.). Samples collected during the geotechnical drilling program will only be stored until the Project Manager determines that the necessary geotechnical analyses have been conducted.

Stored geotechnical samples will be stored in a controlled manner (i.e., dry storage away from direct sunlight) at room temperature. A label identical to that placed on the original sample will be used to identify the stored sample.

Hudson River Design Support Sediment Sampling Program

Field Sample ID:		RS1-9392-WT001-084090
Date Collected:	9/19/02	
Time Collected:	11:39	**AROCLOR**
Custodian Initials:	LML	

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EXAMPLE SAMPLE LABEL

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FIGURE C-1

HUDSON RIVER SEDIMENT SAMPLING AND ANALYSIS PROGRAM

Coring Field Log

Relinquished by:_____ Date: _____ Time: _____ Sampler:_____

Received by:_____ Date: _____ Time: _____ Weather:_____

Core ID	Date	Time	Northing	Easting	Water Depth (ft)	Probing Depth (in)	Sediment Type	Sediment Description	Sample Type **	Core Recovered	Tube Material *	Penetration (in)	Recovery (in)
										☐			
										☐			
										☐			
										☐			
										☐			
										☐			
										☐			
										☐			
										☐			
										☐			
										☐			

* Tube Material: A = Aluminum, L = Lexan

** Sediment Type: C = Core, G = Grab

Date Printed: 7/17/02

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EXAMPLE FIELD LOG FORM

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FIGURE C-2

ENVIRONMENTAL SAMPLE CHAIN OF CUSTODY

COC ID:
Sample Custodian: LML
Lab:

Client: General Electric Company **Project:** Hudson River Design Support Sediment Sampling Program

COC Sample Number	Field Sample ID	QA/QC	MS / LD	Date Processed	Time Processed	Media*	# Containers	Aroclor PCB (GEHR6662)	137Cs (gamma spectroscopy)	Moisture Content (ASTM D2216-98)	Bulk Density (USACE EM-1110-2-1906)	Total Organic Carbon (Lloyd Kahn)	Geotechnical Parameters Grain Size (ASTM D422) Atterberg Limits (ASTM D4318-00) Specific Gravity (ASTM D854-00) USCS Classification (ASTM D2487)	Disposal Parameters TCLP Metals (6010B/7470A-TCLP) TCLP Volatiles (8260B-TCLP) TCLP Semivolatiles (8270C-TCLP) TCLP Pesticides (8081A-TCLP) TCLP Herbicides (8151A-TCLP) Ignitability (1010 40 CFR Chapter 7)	Dioxins/Furans (EPA 1613)	Homolog PCB (GEHR6580)	Total RCRA Metals (6010B/7471A-RCRA)
001			☐			S	1	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
002			☐			S	1	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
003			☐			S	1	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
004			☐			S	1	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
005			☐			S	1	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
006			☐			S	1	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
007			☐			S	1	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
008			☐			S	1	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
009			☐			S	1	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
010			☐			S	1	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

Comments:

Relinquished by:	Received by:	Relinquished by:	Received by:	Relinquished by:	Received by:
Signature	Signature	Signature	Signature	Signature	Signature
Print Name	Print Name	Print Name	Print Name	Print Name	Print Name
Company	Company	Company	Company	Company	Company
Date/Time	Date/Time	Date/Time	Date/Time	Date/Time	Date/Time

Date Printed: 9/27/2002 * S= SEDIMENT *COC TYPE: ARCHIVE* *Page 1 of 2*

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ENVIRONMENTAL SAMPLE CHAIN OF CUSTODY

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FIGURE C-3

Appendix D

Backfill Source Log

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Backfill Source Log

Company:	***Backfill Source Name:***
Name:	***Backfill Source Contact:***
Date:	***Backfill Source Phone #:***
Time:	***Backfill Source Address:***

Backfill Source Information:

	Distance & Location to Hudson River		
Transportation Type(s) Available from Backfill Source	***Distance (miles)***	***River Mile***	***Soil Classification***

Type(s) of Material	***Quantity of Material (cubic yards)***	***Description***

Photo Description

photo number	***photo description***

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