RETURN TO TOC

SECTION IV. SPECIFIC-GRAVITY-OF-SOLIDS DETERMINATION (ASTM D 854-92)

The specific gravity of a solid substance is the ratio of the weight of a given volume of material to the weight of an equal volume of water (at 20°C). In effect, it tells how much heavier (or lighter) the material is than water. For exact analysis, the specifications require distilled or demineralized water and all measurements of water and solids should be made at stated temperatures. In dealing with soils testing, the value of specific gravity is necessary to compute the soil's void ratio and for determining the grain-size distribution in hydrometer analysis.

SPECIFIC GRAVITY OF SOIL OR SOLIDS

The term specific gravity of soil actually refers to the specific gravity of the solid matter of the soil, which is designated G_s. The specific gravity of solids is normally only applied to that fraction of a soil that passes the No. 4 sieve. Generally, geotechnical engineers need the soil's specific gravity to perform additional testing of that soil. In these cases there may be a different soil fraction used when performing this test. For example, the resulting specific-gravity value of soil from this test using a –10 sample is applicable to hydrometer analysis while the determination of the zero-air-voids curve in laboratory soils-compaction testing uses the specific gravity from the –4 sample.

A soil's specific gravity largely depends on the density of the minerals making up the individual soil particles. However, as a general guide, some typical values for specific soil types are as follows:

- The specific gravity of the solid substance of most inorganic soils varies between 2.60 and 2.80.
- Tropical iron-rich laterite, as well as some lateritic soils, usually have a specific gravity of between 2.75 and 3.0 but could be higher.
- Sand particles composed of quartz have a specific gravity ranging from 2.65 to 2.67.
- Inorganic clays generally range from 2.70 to 2.80.
- Soils with large amounts of organic matter or porous particles (such as diatomaceous earth) have specific gravities below 2.60. Some range as low as 2.00.

SPECIFIC-GRAVITY TEST

Take particular care to obtain representative samples for a specific-gravity test. It is easier to begin the test with an oven-dried sample. However, some soils, particularly those with a high organic content, are difficult to rewet. Test these at their natural water content and determine the oven-dried weight at the end of the test.

PURPOSE

Perform this test to determine the specific gravity of solids (which will be used to assist in the hydrometer-analysis test) and to calculate the zero-air-voids curve for compaction results.

EQUIPMENT

Perform the specific-gravity test in a laboratory environment, using the following items (see *Figure 2-35*):

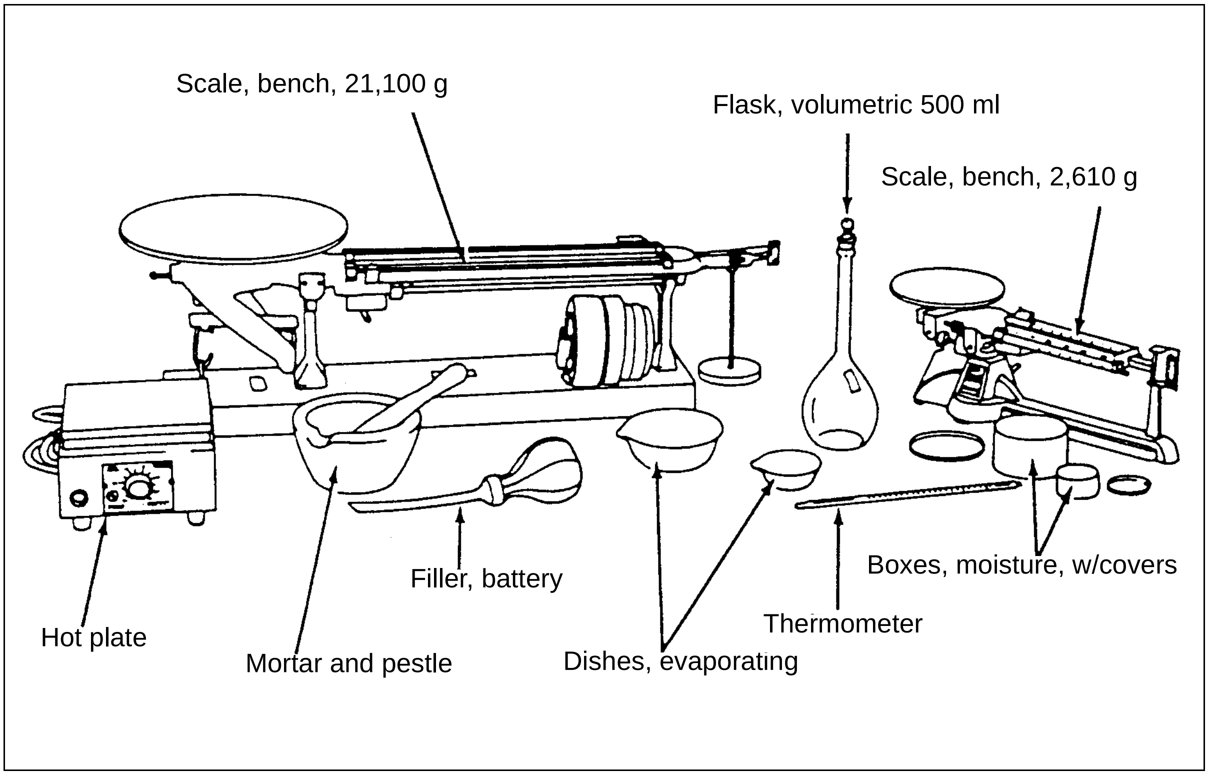


Figure 2-35. Apparatus for determining specific gravity of soils

- A pycnometer; volumetric flask (500-milliliter capacity).
- A laboratory oven.
- Heat-resistant gloves.
- Balance scales sensitive to 0.01 gram.
- Pudding pans.
- A waterbath.
- A thermometer.
- A battery-filler syringe.
- A No. 4 sieve (for general specific-gravity results).

- A No. 10 sieve (when results are used for hydrometer analysis).
- Graph paper.
- A pencil.
- A french curve.
- Cloth towels.
- Paper towels.
- A hot plate.
- DD Form 1208.
- A spatula.
- An evaporating dish.
- Distilled water.
- A calculator.
- A pail.

STEPS

Perform the following steps to determine the soil's specific gravity:

Step 1. Calibrate the pycnometer (volumetric flask). If a calibration graph has already been prepared for this pycnometer and will be used for the determination procedures, go to step 2.

a. Weigh a clean, dry pycnometer to the nearest 0.01 gram. Record this information, W_b, on DD Form 1208 *(see Figure 2-36)*. Additionally, record the basic information concerning the specimens being tested and the pycnometer/flask number.

b. Fill the pycnometer with room-temperature distilled water. Ensure that the bottom of the meniscus is even with the calibration mark.

c. Weigh the pycnometer plus water. Record this information, W_{bw}, on the form.

d. Use the thermometer to determine the water temperature to the nearest whole degree, T_i. Record the temperature on the form.

e. Create a graph or table for the pycnometer being used (if additional specific-gravity determinations are to be made).

NOTE: This graph helps in determining values of W_{bw} for any desired water temperatures and eliminates the need to calibrate the pycnometer for each test. The graph can be developed by using the following equation for various temperatures, plotting the temperatures against the weight of the pycnometer and water, and drawing a smooth curve through the plotted points:

SPECIFIC-GRAVITY TESTS

1. PROJECT ENGINEER CENTER EXPANSION		2. DATE 1 DEC 99
3. BORING NUMBER 5-C-1	4. JOB NUMBER 16-P-T	5. EXCAVATION NUMBER 5-C

6. SPECIFIC GRAVITY OF SOLIDS (G_s)

FLASK CALIBRATION DATA	a. FLASK NUMBER	b. CLEAN, DRY WEIGHT, W_b	c. FLASK + WATER WEIGHT, W_{bw}	d. OBSERVED TEMPERATURE, T_i
	#2A	171.05 Grams	667.88 Grams	25 °C

e. SAMPLE OR DETERMINATION NUMBER		5-C-1		
DETERMINATION DATA	f. DISH NUMBER	2A		
	g. WEIGHT OF DISH + DRY SOIL (Grams)	308.48		
	h. WEIGHT OF DISH (Grams)	269.83		
	i. WEIGHT OF DRY SOIL, W_s (Grams)	38.65		
	j. WEIGHT OF FLASK + WATER + IMMERSED SOIL, W_{bws} (Grams)	692.05		
	k. TEMPERATURE OF WATER, T_x (°C)	23°		
	l. CALCULATED WEIGHT OF FLASK + WATER AT T_x, W_{bw} (Grams)	668.12		
	m. CORRECTION FACTOR FOR T_x, K	0.9993		
n. SPECIFIC GRAVITY OF SOLIDS	$G_s = \frac{W_s K}{W_s + W_{bw} - W_{bws}}$	2.62		

7. APPARENT (G_a) AND BULK (G_m) SPECIFIC GRAVITY

a. SAMPLE OR SPECIMEN NUMBER				
b. TEMPERATURE OF WATER AND SOIL (°C) (must be within 23 ±1.7°C)				
c. TARE + SATURATED SURFACE - DRY SOIL				
DETERMINATION DATA	d. TARE			
	e. SATURATED SURFACE - DRY SOIL, *(B)*			
	f. (WIRE BASKET + SOIL) IN WATER			
	g. WIRE BASKET IN WATER			
	h. SATURATED SOIL IN WATER, *(C)*			
	i. TARE AND DRY SOIL			
	j. TARE			
	k. DRY SOIL, *(A)*			
l. APPARENT SPECIFIC GRAVITY	$G_a = (A) / (A - C)$			
m. BULK SPECIFIC GRAVITY	$G_m = (A) / (B - C)$			
n. BULK SPECIFIC GRAVITY, SATURATED SURFACE DRY (SSD)	$G_m = (B) / (B - C)$			

SAMPLE

8. REMARKS

9. TECHNICIAN *(Signature)*	10. COMPUTED BY *(Signature)*	11. CHECKED BY *(Signature)*
EACN Pineda, AP	EACN Pineda, AP	SSG Dobbs WD

DD FORM 1208, DEC 1999 PREVIOUS EDITION IS OBSOLETE.

Figure 2-36. Sample DD Form 1208

$$W_{bw}\ (\textit{for specified temperature}, T_x) = \left[\frac{\rho_w(T_x)}{\rho_w(T_i)} \times \left[(W_{bw}\ \textit{at}\ T_i) - W_b\right]\right] + W_b$$

where—

ρ_w (T_x) = density of water identified by temperature (T_x) (see Table 2-7)

ρ_w (T_i) = density of water identified by temperature (T_i) (see Table 2-7)

W_{bw} = weight of pycnometer and water, in grams

W_b = weight of pycnometer, in grams

T_i = observed/recorded temperature of water, in °C

T_x = any other desired temperature, in °C

Table 2-7. Relative density of water and correction factor (K) at various temperatures

Temp °C	Relative Density	Correction Factor (K)
18.0	0.99862	1.0004
19.0	0.99843	1.0002
20.0	0.99823	1.0000
21.0	0.99802	0.9998
22.0	0.99780	0.9996
23.0	0.99757	0.9993
24.0	0.99733	0.9991
25.0	0.99708	0.9988
26.0	0.99682	0.9986
27.0	0.99655	0.9983
28.0	0.99627	0.9980
29.0	0.99598	0.9977
30.0	0.99568	0.9974
31.0	0.99537	0.9971
32.0	0.99505	0.9968
NOTE: Data obtained from ASTM. Correction factor, K, is found by dividing the relative density of water at the test temperature by the relative density of water at 20°C.		

A completed graph using the above formula for the following data can be seen in *Figure 2-37*.

Calibration data:

W_{bw} = 656.43

W_b = 158.68

T_i = 24°C

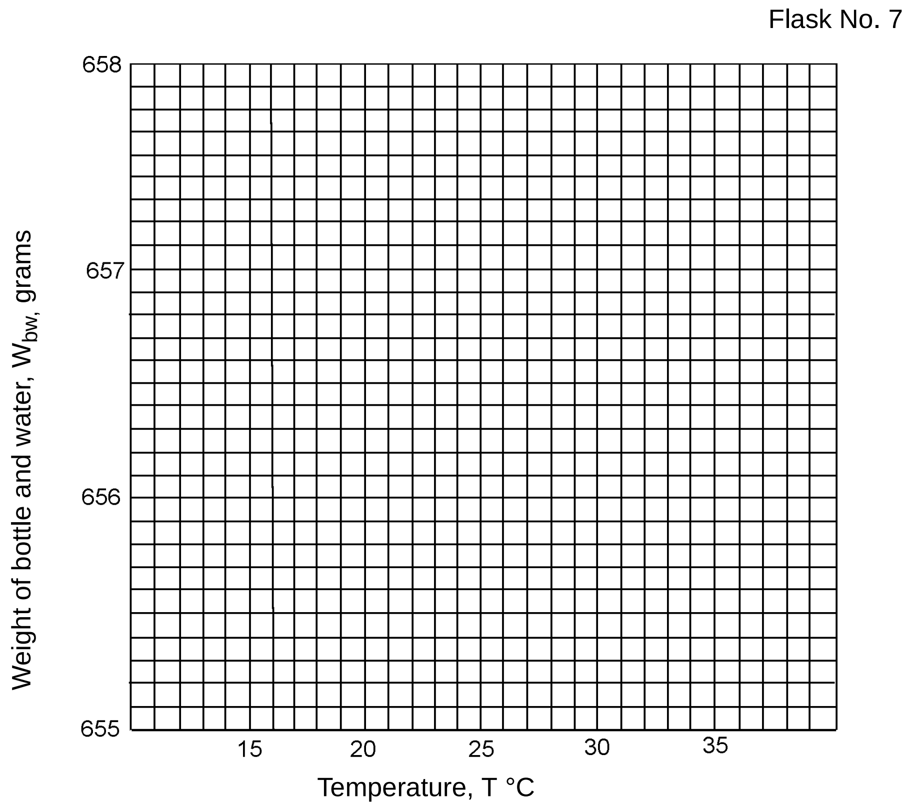


Figure 2-37. Calibration curve for a volumetric flask

Computed data:

T_x of 20°C yields W_{bw} of 656.88

T_x of 23°C yields W_{bw} of 656.55

T_x of 26°C yields W_{bw} of 656.17

T_x of 29°C yields W_{bw} of 655.75

T_x of 32°C yields W_{bw} of 655.29

A complete data table can be created from the formula above for each temperature expected to prevail during testing.

Step 2. Obtain a soil sample for testing. Separate the given sample over a No. 4 sieve to obtain at least a 100-gram sample passing the sieve or over a No. 10 sieve to obtain a 20-gram sample. Since this test method is only concerned with the sample passing the appropriate sieve used, discard the material retained on the sieve.

Step 3. Prepare the sample for testing.

NOTE: To determine the specific gravity of solids, the sample may be at its natural water content or oven-dried. Soils with a high organic content or with fines that are low compressible are difficult to rewet after having been oven-dried. These soils should be tested at their natural water content first and the oven-dried weight determined at the end of the test.

a. Record all identifying information about the sample on the form (see *Figure 2-36, page 2-65*).

b. Place the –4 or –10 sample into the evaporating dish.

c. Perform the following procedures for soil at natural water content or moisture; otherwise, go to step 3d:

(1) Add distilled water to the sample and mix to a slurry.

(2) Transfer the slurry to the pycnometer and add distilled water until the pycnometer is about three-fourths full.

d. Perform the following procedures for an oven-dried soil sample:

(1) Oven-dry the sample to a constant weight at a temperature of 110° ± 5°C. Allow the sample to cool and weigh it to the nearest 0.01 gram. Record the weight on the form as the weight of the dish and dry soil (in block 6g).

(2) Transfer the dried sample to the volumetric flask. Take care to avoid the loss of any particles.

(3) Fill the flask three-fourths full with distilled water and allow it to soak for 12 hours.

(4) Weigh the empty, dry evaporating dish. Record the weight on the form as the weight of the dish (block 6h).

Step 4. Process the sample through the test method.

a. Remove entrapped air by bringing the solution to a slow, rolling boil for 10 minutes while occasionally rolling the pycnometer to assist in the removal of the air (ensure that no loss of material occurs while boiling). Cool the sample to room temperature.

b. Fill the pycnometer with distilled water until the bottom of the meniscus is level with the calibration mark.

c. Dry the outside and thoroughly remove any moisture adhering to the neck of the pycnometer.

d. Weigh the pycnometer and its contents to the nearest 0.01 gram. Record this amount on the form as the weight of the flask and water and immersed soil (W_{bws}).

e. Shake the flask immediately after weighing (putting its contents in suspension) and determine the water temperature at middepth to the nearest whole degree, T_x. Record this amount on the form.

f. Determine the dry unit weight for soil processed at natural moisture content as follows:

(1) Transfer the soil solution from the flask to a preweighed pudding pan. Record the weight in block 6h. Use care when transferring all the grains of soil.

(2) Oven-dry the sample to a constant weight at a temperature of 110° ± 5°C. Allow the sample to cool. Weigh and record the weight on the form in block 6g as the weight of the dish and dry soil.

Step 5. Compute the results on DD Form 1208 (see *Figure 2-36, page 2-65*).

a. Compute the weight of the dry soil (W_s) by subtracting the weight of the dish from the weight of the dish and dry soil. Record it on the form.

b. Determine the weight of the flask and water (W_{bw}) by plotting the temperature of the water (T_x) obtained in step 4e (block 6k) on the calibration curve obtained in step 1. Record the result on the form. If the calibration curve and graph were not produced, use the formula as indicated in step 1e and record the result on the form.

c. Determine the correction factor (K) by locating the temperature of the water (T_x) (obtained in step 4e [block 6k]) in *Table 2-7, page 2-66*; read across to the correction factor column, and record it on the form as the correction factor K (for T_x).

d. Compute the specific gravity of solids (G_s) to two decimal places. Record the amount on the form using the following formula:

$$G_s = \frac{W_s K}{W_s + W_{bw} - W_{bws}}$$

APPARENT AND BULK SPECIFIC GRAVITY

The specific gravity of solids is not applied to coarse particles because they normally contain voids from which air cannot be displaced unless the particles are ground into finer particles so as to eliminate the voids. Thus, when dealing with coarser particles, it is more convenient to work with the apparent specific gravity of the particle mass or to determine the bulk specific gravity. Test methods for these determinations are listed in Chapters 3 and 4.

The apparent specific gravity is designated G_a and is the ratio of the weight in air of a unit volume of the impermeable portion of aggregate to the weight in air of an equal volume of distilled water, both at a stated temperature. The impermeable portion of a porous material, such as most large soil grains, includes the solid material plus impermeable pores or voids within the particles. This test method is applicable to the testing of fine and coarse aggregates (see Chapters *3* and 4).

The bulk specific gravity is designated G_m and is the ratio of the weight in air of a unit volume of aggregate (including permeable and impermeable voids in the particles, but not the voids between the particles) to the weight of an equal volume of distilled water at a stated temperature. This test method is applicable to the testing of soils with fine and coarse aggregates (see Chapters *3* and 4).

SECTION V. GRAIN-SIZE ANALYSIS AND DISTRIBUTION (ASTM D 422-63 AND ASTM 2217-85)

Soil particles, also referred to as grains, are discussed in Section I of this chapter, with some consideration of the effects of particle characteristics on the physical properties of soils. The use of grain size and grain-size distribution in soil classification and visual-manual tests—and their use for field identification—are also covered in Section I. Although estimates of grain size of coarser materials may be made in this way, the accurate determination of the grain-size distribution or gradation of coarse-soil fractions requires a grain-size analysis.

Grain-size analysis, which is among the oldest of soil tests, is used in soils classification and as part of the specifications of soil for airfields, roads, earth dams, and other soil-embankment construction. The standard grain-size-analysis test determines the relative proportions of different grain sizes as they are distributed among certain size ranges, which is referred to as particle-size or grain-size distribution. This is accomplished in two steps:

- A screening process (a sieve analysis, which is also called a mechanical analysis) for particle sizes retained on the No. 200 sieve.
- A sedimentation process (a hydrometer analysis) for particle sizes smaller than the No. 200 sieve.

NOTE: Previous test methods presented the sieve analysis and the hydrometer analysis as two separate test methods, and a combination of these analyses was referred to as a combined analysis. ASTM employs a different method for particle-size analysis which includes both methods (ASTM D 422-63). This single method also references the test method specific to wet preparation of soil samples (ASTM D 2217-85). These test methods provide for minor modifications to allow the end user to obtain results specific to the purpose of the test. The following test method is a product of this modification. It allows for easier identification of the USCS classification.

Performing just the sieve-analysis portion of this test method may yield sufficient information to classify a soil type and therefore not require the hydrometer analysis. However, the hydrometer analysis will ensure a more accurate depiction of the soil gradation as well as provide necessary information required to determine the soil's frost susceptibility.

SIEVE ANALYSIS (MECHANICAL ANALYSIS)

The accurate completion of the sieve-analysis test will produce the percent of gravel, sand, and fines of the material. The most accurate process for this test method is to wash the material over the sieves; this will give a more accurate percent of fines. It is possible the test will also provide sufficient information to calculate the coefficient of uniformity and the coefficient of curvature.

PURPOSE

Perform this test to determine the grain-size distribution or the gradation of a soil or aggregate for the portion of the material that is larger than the No. 200 sieve. The results of this test should assist in the soil-classification process.

EQUIPMENT

Use the following items to perform this test (see *Figure 2-38*):

- A calculator.
- DD Form 1206 or an equivalent form.
- DD Form 1207.
- Beam scales.

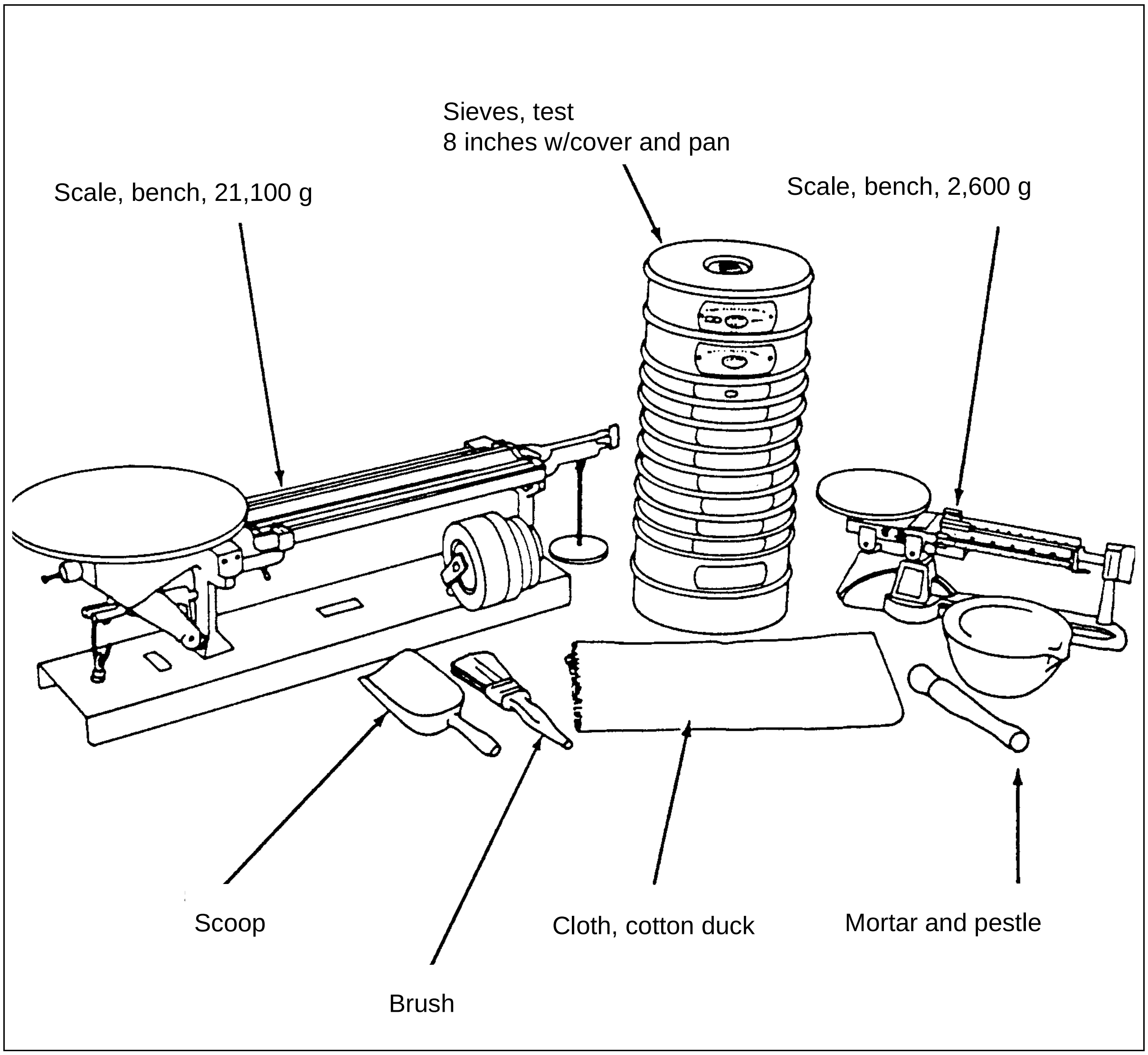


Figure 2-38. Equipment for sieve analysis

- Balance scales sensitive to 0.1 gram and 0.01 gram.
- A scoop.
- A brush.
- A sieve shaker.
- A nest of sieves including, as a minimum, the following sizes: 2 inches, 1.5 inches, 1 inch, 3/4 inch, 3/8 inch, No. 4, No. 10, No. 16, No. 30, No. 40, No. 50, No. 100, and No. 200.
- A pan.
- A cover.
- A mortar.
- A rubber-covered pestle.
- Pudding pans.
- Paper.
- A pencil.
- A french curve.
- A splitter (if available).
- Canvas (in a laboratory environment).
- A laboratory oven.
- Heat-resistant gloves.
- A battery-filler syringe.
- Distilled water.

STEPS

Perform the following steps to determine the grain-size distribution:

Step 1. Prepare the soil sample.

a. Spread out and air-dry the soil sample.

b. Break up the aggregate particles thoroughly with fingers or with the mortar and pestle.

c. Obtain a representative sample for testing by using a sample splitter or by quartering. The sample size recommended for sieve analysis depends on the particle size. Obtain the required minimum sample as listed in *Table 2-8*.

Step 2. Record all identifying information about the sample (such as the project name, excavation number, sample number, description of sample, and date [blocks 1 through 7]) on DD Form 1206 (see *Figure 2-39, page 2-74*).

Step 3. Oven-dry the material at 110°C ± 5° until a constant weight is obtained. Allow the sample to cool.

Step 4. Weigh the oven-dried sample and record the weight on the form (block 8) to the nearest gram as the weight of the original sample.

Table 2-8. Representative soil samples for grain-size analysis

Maximum Particle Size		Minimum Sample Weight (g)
in	mm	
3/8 (No. 4)	9.5 (No. 4)	500
3/4	19.0	1,000
1	25.4	2,000
1 1/2	38.1	3,000
2	50.8	4,000
3	76.2	5,000

Step 5. Check “No” in block 9 and enter 0 in blocks 10 and 11 if only a dry sieve is to be performed, then proceed to step 10. If the sample will be prewashed, check “Yes” in block 9 and proceed to step 6.

Step 6. Place the sample in a clean container and cover the sample completely with water. Allow the sample to soak until the adhering and lumpy particles are completely disintegrated. This process may take 2 to 24 hours.

Step 7. Wash the sample over a No. 200 sieve into a 2 x 2 concrete pan until all –200 material has been washed through. If the sample contains an appreciable amount of coarse particles, combine the No. 4 and No. 200 sieves. Take care not to overload the No. 200 sieve. If necessary, transfer the sample in increments (this process may take up to 6 different pans and as long as 8 hours).

Step 8. Process the +200 material. Oven-dry the washed +200 material at 110°C ± 5° until a constant weight is obtained and allow the material to cool. Record the weight on the form to the nearest tenth of a gram (block 10).

Step 9. Process the –200 material.

a. Allow the –200 material to settle in the pan until the surface water becomes clear (16 to 24 hours).

b. Decant the surface water (using a siphon or a syringe), ensuring that the settled material is not disturbed.

c. Use a trowel to transfer as much of the material as possible from the pan to the pudding pans.

d. Rinse the remainder of the material from the 2 x 2 pans to the pudding pans with as little water as possible.

e. Oven-dry the washed –200 material and determine the total –200 sample weight to the nearest tenth of a gram. Record this weight on the form (block 11). Retain this material for use in the hydrometer analysis.

Step 10. Select a nest of sieves to accommodate the largest particle size of the soil being tested, ensuring that all material will pass through the largest sieve. As a minimum, the following sieves sizes will be used (up to the largest

GRAIN-SIZE ANALYSIS (SIEVE METHOD)

1. PROJECT ENGINEER CENTER EXPANSION		2. DATE 1 DEC 99
3. JOB NUMBER 16-P-T	4. EXCAVATION 5-C	5. DATE COMPLETED 5 DEC 99
6. NOTES ABOUT SAMPLE/DESCRIPTION RED IN COLOR, VERY FINE SANDS		7. SAMPLE NUMBER 5-C-1
		8. ORIGINAL SAMPLE WEIGHT 4404.7
9. PREWASHED X YES ☐ NO	10. + #200 SAMPLE WEIGHT, WASHED 2814.2	11. - #200 SAMPLE WEIGHT, WASHED 1569.7

12. SIEVE SIZE	13. SIEVE WEIGHT	14. SIEVE-SAMPLE WEIGHT	15. WEIGHT RETAINED	16. CUMULATIVE WEIGHT RETAINED	17. PERCENT RETAINED	18. PERCENT PASSING
2"	584.5	584.5	0	0	0	100
1 1/2"	713.6	797.3	83.7	83.7	1.9	98.1
3/4"	577.2	738.2	161.0	244.7	3.7	94.4
1/4"	540.4	1168.4	628.0	872.7	14.3	80.1
#4	506.7	624.5	117.8	990.5	2.7	77.4
#16	464.3	826.9	417.6	1408.1	9.5	67.9
#30	595.6	820.0	224.4	1632.5	5.1	62.7
#40	402.0	634.3	232.3	1864.8	5.3	57.4
#60	533.5	966.4	432.9	2297.7	9.9	47.6
#80	351.4	655.2	303.8	2601.5	6.9	40.6
#100	265.2	328.9	63.7	2665.2	1.5	39.2
#200	347.1	460.7	113.6	2778.8	2.6	36.6

19. TOTAL WEIGHT RETAINED IN SIEVES *(Sum of column 15)*	2778.8	24. ERROR *(8-23)* 4404.7 -4381.4 23.3	25. ERROR IN PERCENTAGE $\left(\frac{24}{8}\right) \times 100 =$ $\frac{23.3}{4404.7} \times 100 = 0.5\%$
20. WEIGHT SIEVED THROUGH #200 *(Weight in pan)*	32.9		
21. WASHING LOSS *(8 - [10+11])*	26.8		
22. TOTAL WEIGHT PASSING #200 SIEVE *(20+11)*	1602.6		
23. TOTAL WEIGHT OF FRACTIONS *(19+22)*	4381.4		

26. PERCENT GRAVEL *(% G)*	27. PERCENT SAND *(% S)*	28. PERCENT FINES *(% F)*	29. DECIMAL FINES *(% F ÷ 100)*
22.6%	40.8%	36.6%	0.366

30. REMARKS

USCS SC w/GRAVEL

31. TECHNICIAN *(Signature)*	32. COMPUTED BY *(Signature)*	33. CHECKED BY *(Signature)*
PV2 Dishman	PV2 Dishman	SSG Dobbs

DD FORM 1206, DEC 1999 PREVIOUS EDITION IS OBSOLETE.

Figure 2-39. Sample DD Form 1206

particle size): 2 inches, 1.5 inches, 1 inch, 3/4 inch, 3/8 inch, No. 4, No. 10, No. 16, No. 30, No. 40, No. 50, No. 100, and No. 200.

Step 11. Record the weight of each sieve selected on the form to the nearest tenth of a gram (column 13), and arrange the sieves in a nest with the smallest sieve size on the bottom. Weigh and place a pan on the bottom.

Step 12. Cover the sample. If the sample was prewashed, place only the +200 material onto the top sieve of the nest and place a cover over it. If the sample was not prewashed, place the entire sample on the top sieve of the nest and place a cover over it.

Step 13. Place the nest of sieves and the sample in the sieve shaker and shake for 10 to 15 minutes (see *Figure 2-40*).

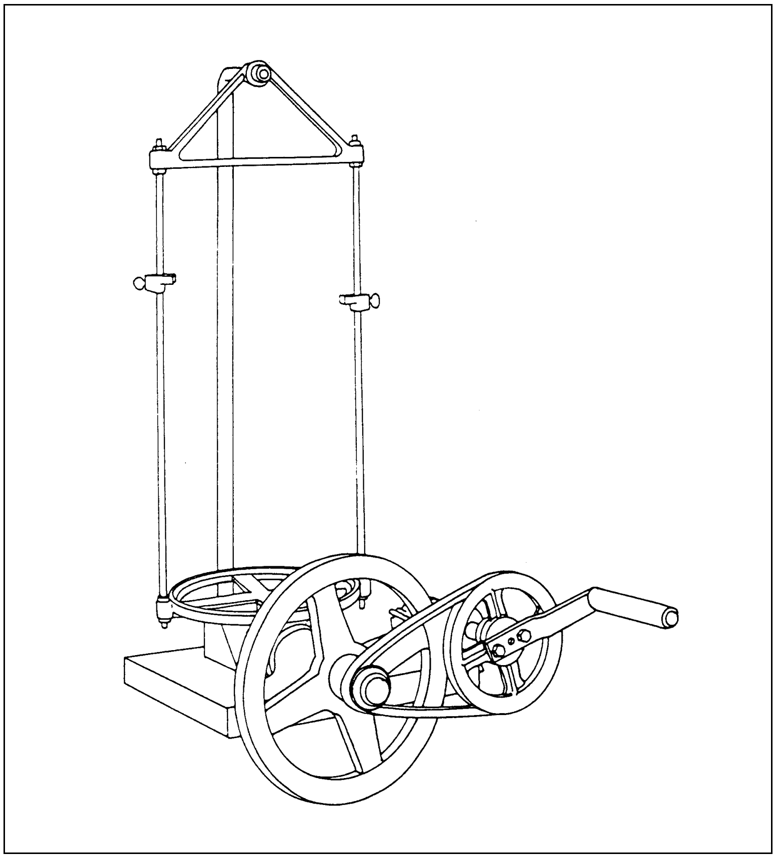


Figure 2-40. Hand-operated sieve shaker

Step 14. Remove the cover of the sieve nest after the shaking has been completed.

Step 15. Record the weight of each sieve with the retained sample (starting with the top sieve (see *Figure 2-41, page 2-76*) on the form (column 14).

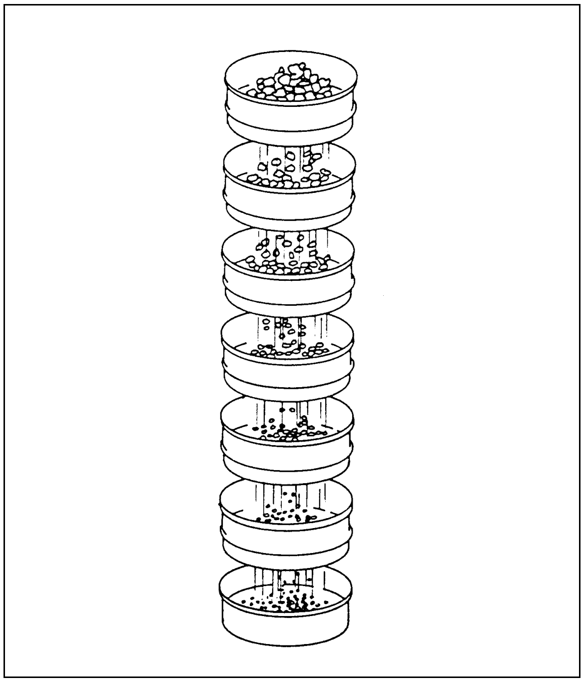


Figure 2-41. Testing sieves stacked large to small

Step 16. Determine the weight of the material retained on each sieve by subtracting the weight of the sieve from the weight of the sieve and retained sample (columns 14 through 13). Record this weight as the weight retained (column 15).

Step 17. Add the weights retained on all sieves and record as total weight retained in sieves (block 19).

Step 18. Weigh the pan with the material passing the No. 200 sieve. Subtract the weight of the pan (from step 11) and record this as the weight sieved through No. 200 (block 20).

Step 19. Complete blocks 21 through 25 of the form using the formulas provided on the sheet. If the error of percentage is 1 percent or greater, rerun the test.

Step 20. Compute the cumulative weight retained (column 16) for each sieve by adding the weight retained to the previous cumulative weight retained with the starting point being 0.

Step 21. Compute the percent retained (column 17) for each sieve by dividing the weight retained by the total weight of fractions as follows:

$$\frac{column\ 15}{block\ 23} \times 100$$

Step 22. Compute the percent passing for each sieve size by subtracting the cumulative weight retained from the total weight of fractions and dividing by the total weight of fractions as follows:

$$column\ 18 = \frac{block\ 23 - column\ 16}{block\ 23} \times 100$$

Step 23. Determine the percentages for gravel, sand, and fines. Record the information on the form.

- Gravel is the material retained on the No. 4 sieve.
- Sand is the material passing the No. 4 sieve and retained on the No. 200 sieve.
- Fines are the material passing the No. 200 sieve.

Step 24. Prepare DD Form 1207 (see *Figure 2-42, page 2-78*).

a. Record the identifying information for the sample in the remarks block.

b. Use the sieve-analysis data to plot (on DD Form 1207) the sieve size and the percentage passing the sieve.

c. Using a french curve, connect the plotted points to form a smooth, free-flowing curve (the grain-size distribution curve, *Figure 2-42*).

d. Determine the coefficient of uniformity (C_u).

NOTE: The grain size, in millimeters, which corresponds to 10 percent passing on the grain-size-distribution curve, is called Hazen's effective size. It is designated by the symbol D_{10}. If the grain-size-distribution curve extends to or below 10 percent passing, then the C_u can be determined. The uniformity coefficient is the ratio between the grain diameter, in millimeters, corresponding to 60 percent passing (D_{60}) and 10 percent passing on the curve. Use the following formula and record on the form:

$$C_u = \frac{D_{60}}{D_{10}}$$

If D_{10} cannot be determined using the data from the sieve analysis, a hydrometer analysis may be required to obtain information about the smaller size grains and to extend the distribution curve to make it more complete.

e. Determine the coefficient of curvature (C_c) by using D_{60} and D_{10} as previously discussed and D_{30}, the grain diameter, in millimeters, corresponding to 30 percent passing on the grain-size-distribution curve. These numbers are used in the following formula and recorded on the form:

$$C_c = \frac{(D_{30})^2}{(D_{60} \times D_{10})}$$

NOTE: The values for D_{60}, D_{10}, and D_{30} are obtained by going to the percent passing by weight on the left vertical scale, then moving horizontally across to the right until the grain-size-distribution curve is intercepted, and then vertically down to the horizontal axis where the diameter of the material is read in millimeters. See *Figure 2-42,* for the completed gradation chart.

Step 25. Determine the gradation by using the abbreviated information listed below. Record the information on the form.

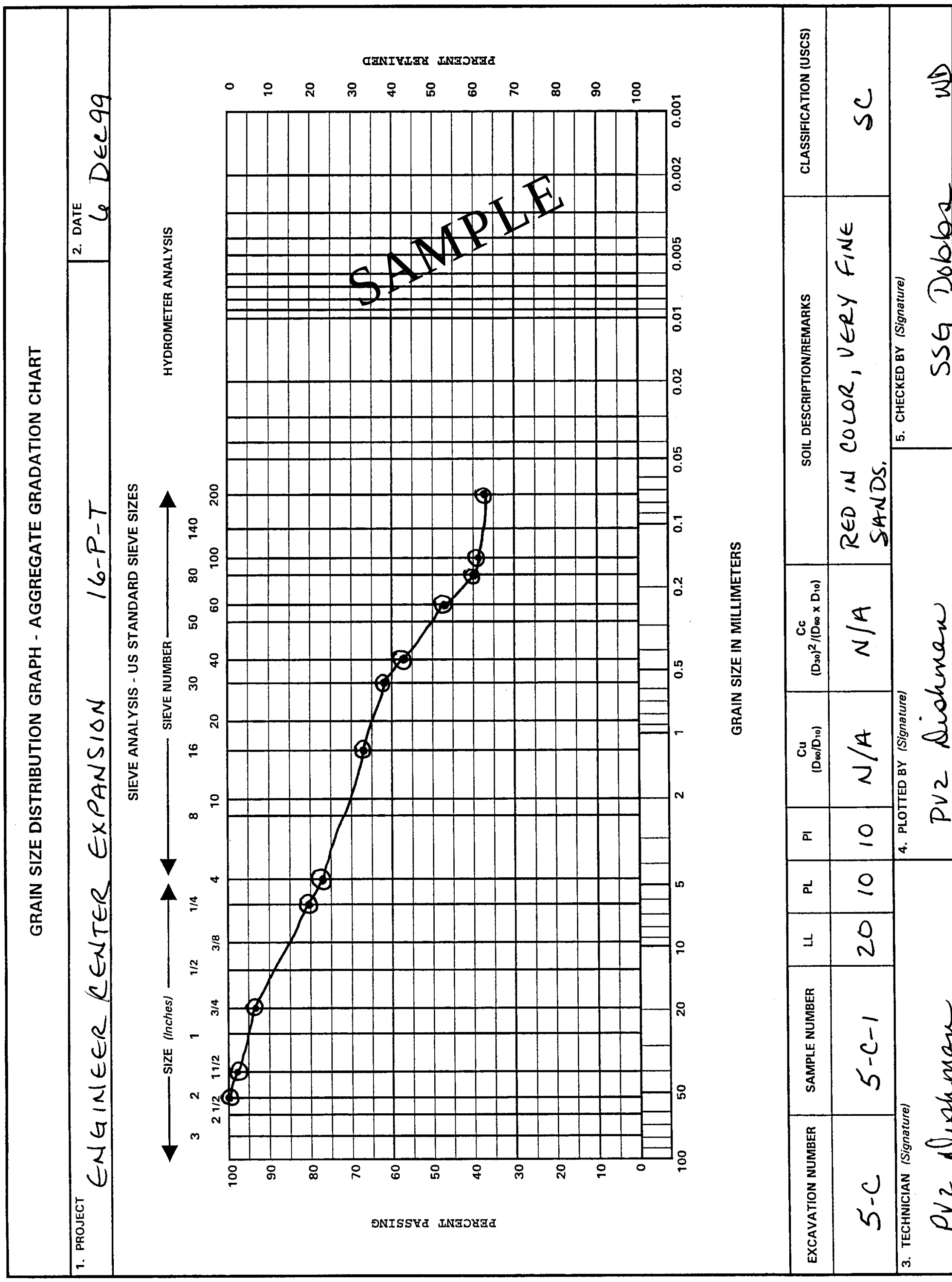


Figure 2-42. Sample DD Form 1207

a. The soil is well-graded (W) when all of the following apply:

- C_u is greater than 4 if the soil is predominantly gravel and greater than 6 if the soil is predominantly sand.
- C_c is at least 1.0 but not more than 3.0 for both gravel and sand.

An indicator of a well-graded soil is a smooth curve plotted for grain-size distribution. The curve must not have any horizontal or vertical portions and must be continuous.

b. The soil is poorly graded (P) if any of the above criteria is not fulfilled.

HYDROMETER ANALYSIS

Hydrometer analysis is based on Stokes' law, which relates the terminal velocity of a free-falling sphere in a liquid to its diameter—or, in simpler terms, the larger the grain size, the greater its settling velocity in a fluid. It is assumed that Stokes' law can be applied to a mass of dispersed soil particles of various shapes and sizes. Larger particles settle more rapidly than smaller ones. The hydrometer analysis is an application of Stokes' law that permits calculating the grain-size distribution in silts and clays, where the soil particles are given the sizes of equivalent spherical particles.

The density of a soil-water suspension depends on the concentration and specific gravity of the soil particles. If the suspension is allowed to stand, the particles gradually settle out of the suspension and the density decreases. The hydrometer is used to measure the density of the suspension at a known depth below the surface. The density measurement, together with knowledge of specific gravity of the soil particles, determines the percentage of dispersed soil particles in suspension at the time and depth of measurement.

The depth at which the measurement is made is found by calibrating the hydrometer. Stokes' law is used to calculate the maximum equivalent particle diameter for the material in suspension at this depth and for the elapsed time of settlement. A series of density measurements at known depths of suspension and at known times of settlement give the percentages of particles finer than the diameters given by Stokes' law. Thus, the series of readings will reflect the amount of different sizes of particles in the fine-grained soils. The particle diameter (D) is calculated from Stokes' equation using the corrected hydrometer reading.

PURPOSE

Perform the hydrometer analysis to determine the grain-size distribution of the –200 material in a soil, to assist in determining the frost susceptibility of a soil, and to provide data needed to calculate the coefficient of uniformity and coefficient of curvature.

EQUIPMENT

Perform the hydrometer analysis in a laboratory environment using the following items:

- A hydrometer.
- A laboratory oven.

- Heat-resistant gloves.
- Balance scales sensitive to 0.1 gram and 0.01 gram.
- A thermometer.
- A timing device with a second hand.
- A No. 200 sieve.
- A battery-filler syringe.
- Distilled water.
- A dispersing agent.
- Pudding pans.
- Two graduated glass cylinders (1,000-milliliter) with cap.
- DD Form 1207.
- DD Form 1794.
- A calculator.
- Paper.
- A pencil.
- A grease pencil.
- Graph paper.
- A straightedge.
- A mechanically operated stirring device with a dispersion cup.

STEPS

Perform the following steps for the hydrometer analysis:

Step 1. Prepare the sample.

a. Obtain the –200 sample as prepared in the sieve analysis. The size of the –200 sample varies according to the type of soil being tested. Approximately 100 grams are required for sandy soils and 50 grams for silty or clayey soils. Place the sample in a dish and add distilled water until the sample is submerged.

b. Determine the amount and type of dispersing agent that will be used during the test. Record it on DD Form 1794 (blocks 9 and 10) (see *Figure 2-43*). The dispersing agents shown in *Table 2-9, page 2-82,* are listed in approximate order of effectiveness. They have been found to be satisfactory for most types of soils. In most instances, 15 milliliters of a dispersing-agent solution is adequate to control flocculation (the adherence of fine soil grains to each other in clusters while in suspension). An additional 15 milliliters can be added a second or third time if flocculation continues.

c. Add the predetermined amount of dispersing agent to the soaking soil sample and allow the sample to soak at least 16 hours.

GRAIN-SIZE ANALYSIS (HYDROMETER METHOD)

1. PROJECT ENGINEER CENTER EXPANSION		2. DATE 6 DEC 99
3. BORING NUMBER 5-C	4. SAMPLE OR SPECIMEN NUMBER 5-C-1	5. CLASSIFICATION SC
6. DISH NUMBER 4-A	7. GRADUATE NUMBER #3	8. HYDROMETER NUMBER/TYPE *(151H/152H)* 359557
9. DISPERSING AGENT USED SODIUM HEXAMETAPHOSPHATE		10. QUANTITY 15 ML
11. COMPOSITE CORRECTION 0.5	12. DECIMAL FINES *(Block 29, DD Form 1206)* 0.366	13. SPECIFIC GRAVITY OF SOLIDS *(Block 6n, DD Form 1208)* G_s = 2.62

14. TIME	15. ELAPSED TIME, *(T)* *minutes*	16. ACTUAL HYDROMETER READING *(R¹)*	17. CORRECTED READING *(R)*	18. TEMP *(°C)*	19. TEMPERATURE AND SPECIFIC GRAVITY CONSTANT *(K)*	20. EFFECTIVE DEPTH *(L)*	21. PARTICLE DIAMETER *(D), mm*	22. PERCENT FINER a. PARTIAL	22. PERCENT FINER b. TOTAL
0930	0								
0931	1	45.0	45.5	26	0.01272	8.8	0.0377	93.3	34.1
0932	2	43.0	43.5	26	0.01272	9.1	0.0271	89.2	32.6
0935	5	38.5	39.0	26	0.01272	9.9	0.0178	79.9	29.2
0945	15	23.5	24.0	26	0.01272	12.4	0.0115	49.2	18.0
1000	30	18.5	19.0	25	0.01286	13.2	0.0084	38.9	14.2
1030	60	15.0	15.5	25	0.01286	13.7	0.0060	31.8	11.6
1130	120	13.0	13.5	25	0.01286	14.0	0.0043	27.7	10.1
1330	240	11.0	11.5	25	0.01286	14.3	0.0031	23.6	8.6
0930	1440	8.5	9.0	24	0.01301	14.8	0.0012	18.4	6.7

WEIGHT *(Grams)*		
	23. DISH + DRY SOIL	324.90
	24. DISH	275.62
	25. DRY SOIL *(W_s)*	49.28

The particle diameter (D) is calculated from Stokes' equation using the corrected hydrometer reading. Use the following formula to solve for particle diameter (D): $D = K\sqrt{L/T}$

Corrected hydrometer reading (R) = actual hydrometer reading (R^1) + composite correction

W_s = Oven-dry weight (in grams) of soil used for hydrometer analysis

Hydrometer graduated in specific gravity (151H)

Partial Percent Finer $= \left[\dfrac{G_s}{G_s - 1} \times \dfrac{100{,}000}{W_s}\right] (R - 1)$

Total Percent Finer = Partial Percent Finer x Decimal fines (Block 12)

0.366

Hydrometer graduated in grams per liter (152H)

$\dfrac{(R)(a)}{W_s} \times 100$

(a = specific gravity of solids correction factor)

a = 1.01

SAMPLE

26. REMARKS

RED IN COLOR, VERY FINE SANDS

FROST GROUP: F 4

27. TECHNICIAN *(Signature)*	28. COMPUTED BY *(Signature)*	29. CHECKED BY *(Signature)*
PVT Butler	PVT Butler	SFC McKimmey

DD FORM 1794, DEC 1999 PREVIOUS EDITION IS OBSOLETE.

Figure 2-43. Sample DD Form 1794

Table 2-9. Dispersing agents

Dispersing Agent	Stock Solution		Manufacturer
	Concentration	Grams Per Liter	
Sodium tripolyphosphate	0.4N	29	Blockson Chemical Co, Joliet, IL
Sodium polyphosphate	0.4N	36	Blockson Chemical Co, Joliet, IL
Sodium tetraphosphate (Quadrofos)	0.4N	31	Rumford Chemical Works, Rumford, NJ
Sodium hexametaphosphate (Calgon)	0.4N	41	Calgon Co, Pittsburgh, PA

Step 2. Determine the type of hydrometer. If the hydrometer scale ranges from 1.000 to 1.038, it is a Type 151H and measures specific gravity of the suspension. If the scale ranges from 0 to 60, it is a Type 152H and measures grams per liter of the suspension. The dimensions for both hydrometers are the same.

Step 3. Determine the composite correction.

NOTE: Before performing the hydrometer test, a composite correction for hydrometer readings must be determined to correct for items that tend to produce errors in the test.

The first of these items needing correction is the meniscus reading. 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.

The second of these items needing correction is a result of using a dispersing agent in the water to control flocculation. This leads to errors in the analysis. While the dispersing agent assists in keeping the soil grains from adhering to each other, it also increases the specific gravity of the fluid used.

The net amount of the correction for the two corrections required is designated as the composite correction.

a. Place about 500 milliliters of distilled water in a graduated cylinder.

b. Place the amount of dispersing agent that was used in step 1 in the cylinder and mix well.

c. Add additional distilled water to the cylinder to reach the 1,000-milliliter mark.

d. Place the hydrometer in the cylinder and allow it to settle for 20 to 25 seconds. Read the hydrometer at the top of the meniscus formed on the stem. For the Type 151H hydrometer, the composite correction is the difference between this reading and 1. For the Type 152H hydrometer, the composite correction is the difference between the reading and 0.

e. Record the composite correction in block 11 of the form *(Figure 2-43, page 2-81)*.

f. Remove the hydrometer from the dispersing-fluid cylinder and place it in a second cylinder filled with distilled water.

NOTE: From this point forward, all hydrometer readings will be taken from the top of the meniscus.

Step 4. Perform the hydrometer test.

a. Record all identifying information for the sample, dispersing agent, quantity used, and composite correction on the form.

b. Obtain the decimal fines from the original soil sample from DD Form 1206. Record it on DD Form 1794 (block 12).

c. Obtain the specific gravity of solids (G_s) of the soil sample from DD Form 1208. Record it on DD Form 1794 (block 13).

d. Empty and thoroughly rinse the graduated cylinder containing the dispersing solution from step 3.

e. Transfer the soaked sample to a dispersion cup, using distilled water to wash any residue from the dish into the cup. Add distilled water to the cup until the water surface is 3 inches below the top of the cup. Place the cup in the dispersing machine and mix silts and sands for 5 minutes, low-plasticity clay for 7 minutes, and high-plasticity clay for 9 minutes.

f. Transfer the mixed solution to the clean 1,000-milliliter graduated cylinder, using distilled water to wash any residue from the cup into the cylinder. Add distilled water until the 1,000-milliliter volume mark is reached.

g. Place the rubber cap over the open end of the cylinder. Turn the cylinder upside down and back for a period of 1 minute to complete the agitation of the slurry.

NOTE: The number of turns during this minute should be about 60, counting the turn upside down and back as two turns. If any soil remains at the bottom of the cylinder during the first few turns, it should be loosened by vigorous shaking of the cylinder while it is in the inverted position.

h. After shaking the cylinder for 1 minute, place it on a level and sturdy surface where it will not be disturbed. Remove the cap and start the timer. Remove any foam that has formed during agitation by lightly touching it with a bar of soap.

i. Immerse the hydrometer slowly into the liquid 20 to 25 seconds before each reading. Take the actual hydrometer reading (R1) at 1 and 2 minutes of elapsed time. As soon as the 1- and 2-minute readings are taken, carefully remove the hydrometer and place it in the second cylinder of pure distilled water using a spinning motion. Record the reading on the form (block 16).

j. Place a thermometer in the solution. Record the temperature reading, in centigrade, to the nearest whole degree. Record on the form (block 18).

NOTE: It is extremely important to obtain accurate temperature readings. The soil hydrometer is calibrated at 20°C. Variations in temperature from this standard temperature produces inaccuracies in the actual hydrometer readings. These inaccuracies will be compensated for later during the computations.

k. Repeat steps 4i and 4j for the remainder of the required readings. Take readings at the following intervals: 5, 15, and 30 minutes and 1, 2, 4, and 24 hours. After each reading, remove the hydrometer, place it in the hydrometer of distilled water, and obtain the temperature reading. Record the information on the form for each reading.

Step 5. Determine the dry weight of the sample by carefully washing all of the sample into a preweighed pudding pan or dish (block 24). Oven-dry the sample, allow it to cool, and determine and record the weight of the sample and the pan or dish (block 23).

Step 6. Determine the weight of the dry soil by subtracting the weight of the pan from the weight of the pan and dry soil. Record this information on the form as the weight of the oven-dried soil (W_s) used for hydrometer testing (block 25).

Step 7. Compute the results on DD Form 1794 (see *Figure 2-43, page 2-81*).

a. Column 17. Obtain the corrected reading (R) by adding the actual hydrometer reading (column 16, R1) and the composite correction (block 11) and record the sum on the form.

$$R = R^1 + \text{composite correction}$$

b. Column 19. Obtain the temperature versus specific gravity constant (K) from *Table 2-10*. Record it on the form.

NOTE: Although typical specific-gravity values are listed in Table 2-10, there may be cases when a soil type falls above or below this range of values. In these situations the value of K must be computed using the following formula:

$$K = \sqrt{\frac{30\eta}{G_s - 1}}$$

where—

η ***= coefficient of viscosity of the liquid (water) in poises (varies with changes in temperature)***

G_s ***= Specific gravity of solids for the material being tested***

c. Column 20. Obtain the effective depth (L) for each corrected reading (column 17) by using *Table 2-11, page 2-86,* and record on the form.

Table 2-10. Values of K for use in Stokes' equation for computing particle diameter

Temp °C	Specific Gravity of Solids (G_S)								Coeff of Viscosity (η)
	2.50	2.55	2.60	2.65	2.70	2.75	2.80	2.85	
16	0.01505	0.01481	0.01458	0.01435	0.01414	0.01394	0.01374	0.01355	0.00001133
17	0.01486	0.01462	0.01439	0.01417	0.01396	0.01376	0.01356	0.01338	0.00001104
18	0.01467	0.01443	0.01420	0.01399	0.01378	0.01358	0.01339	0.01321	0.00001076
19	0.01449	0.01426	0.01403	0.01382	0.01361	0.01342	0.01323	0.01305	0.00001050
20	0.01432	0.01408	0.01386	0.01365	0.01345	0.01326	0.01307	0.01289	0.00001025
21	0.01414	0.01391	0.01369	0.01348	0.01328	0.01309	0.01291	0.01273	0.00001000
22	0.01397	0.01374	0.01353	0.01332	0.01312	0.01294	0.01275	0.01258	0.00000976
23	0.01381	0.01358	0.01337	0.01316	0.01297	0.01278	0.01260	0.01243	0.00000953
24	0.01365	0.01342	0.01321	0.01301	0.01282	0.01263	0.01246	0.01229	0.00000931
25	0.01349	0.01327	0.01306	0.01286	0.01267	0.01249	0.01232	0.01215	0.00000910
26	0.01334	0.01312	0.01292	0.01272	0.01253	0.01235	0.01218	0.01201	0.00000890
27	0.01319	0.01298	0.01277	0.01258	0.01239	0.01221	0.01204	0.01188	0.00000870
28	0.01305	0.01283	0.01263	0.01244	0.01225	0.01208	0.01191	0.01175	0.00000851
29	0.01290	0.01269	0.01249	0.01230	0.01212	0.01194	0.01178	0.01162	0.00000832
30	0.01276	0.01255	0.01235	0.01217	0.01199	0.01181	0.01165	0.01149	0.00000814

d. Column 21. Determine the particle diameter (D) corresponding to a given hydrometer reading on the basis of Stokes' equation:

$$D = K\sqrt{\frac{L}{T}}$$

where—

D = diameter of the sphere, in millimeters

K = constant depending on temperature of suspension and specific gravity of soil particles; values of K can be obtained from Table 2-10 (entered in column 19)

L = distance from the surface of the suspension to the level at which the density of the suspension is being measured, in centimeters (effective depth) (entered in column 20)

T = interval of time from beginning of sedimentation to the taking of the reading, in minutes (entered in column 15)

e. Column 22a. Compute the partial percent finer. To compute the percent of particle diameters finer than that corresponding to a given hydrometer reading, use the following formulas based on the hydrometer type and record the results on the form:

(1) Hydrometer type 151H:

$$\text{Partial percent finer} = \frac{G_S}{G_S - 1} \times \frac{100,000}{W_S} \times (R - 1.0)$$

Table 2-11. Values of effective depth for hydrometer analysis

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

(2) Hydrometer type 152H:

$$Partial\ percent\ finer\ =\ \frac{R \times a}{W_S} \times 100$$

where—

G_s = *specific gravity of solids*

W_s = *oven-dried weight of soil (in grams) used for hydrometer analysis*

R = *Corrected hydrometer reading (with composite correction applied)*

a = *Correction factor from Table 2-12, to be applied to the reading for Type 152H*

Table 2-12. Specific-gravity correction factors applied to hydrometer 152H for computing partial percent finer

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

f. Compute the total percent finer for each hydrometer reading and record it on the form using the formula—

Total percent finer = partial percent finer x decimal fines (block 12)

PRESENTATION OF RESULTS

Plot the grain-size distribution on DD Form 1207 using the particle diameters (D, grain-size, in millimeters) and the total percent finer (percent passing) and connect the plotted points with a smooth curve (see *Figure 2-44, page 2-88*).

Read the curve on the form and determine if 3 percent or more of the particles are smaller than 0.02 millimeter in diameter; if so, the soil is frost susceptible.

Frost-susceptible soils are listed in four groups in the order of increasing susceptibility (see *Table 2-13, page 2-89*).

Soils in group F-4 have high frost susceptibility. Record the frost-susceptibility group for the soil type in block 27 of DD Form 1794 (see *Figure 2-43, page 2-81*).

This curve can be used to determine the coefficient of uniformity (C_u) and the coefficient of curvature (C_c).

The data in the example shown on DD Form 1794 (*Figure 2-43, page 2-81*) is plotted on DD Form 1207 to give an example of such a curve for a mixed soil (see *Figure 2-44*). For this soil, the diameter corresponding to 60 percent passing (D_{60}) is 0.5 millimeter. The diameter corresponding to 10 percent passing (D_{10}) is 0.0045 millimeter. Hence, the coefficient of uniformity is as follows:

$$C_U = \frac{D_{60}}{D_{10}} = \frac{0.5}{0.0045} = 111.11$$

The diameter for 30 percent passing (D30) is 0.024 millimeters. Thus, the coefficient of curvature is as follows:

$$C_C = \frac{(D_{30})^2}{D_{60} \times D_{10}} = \frac{(0.024)^2}{0.5 \times 0.0045} = \frac{0.000576}{0.00225} = 0.256$$

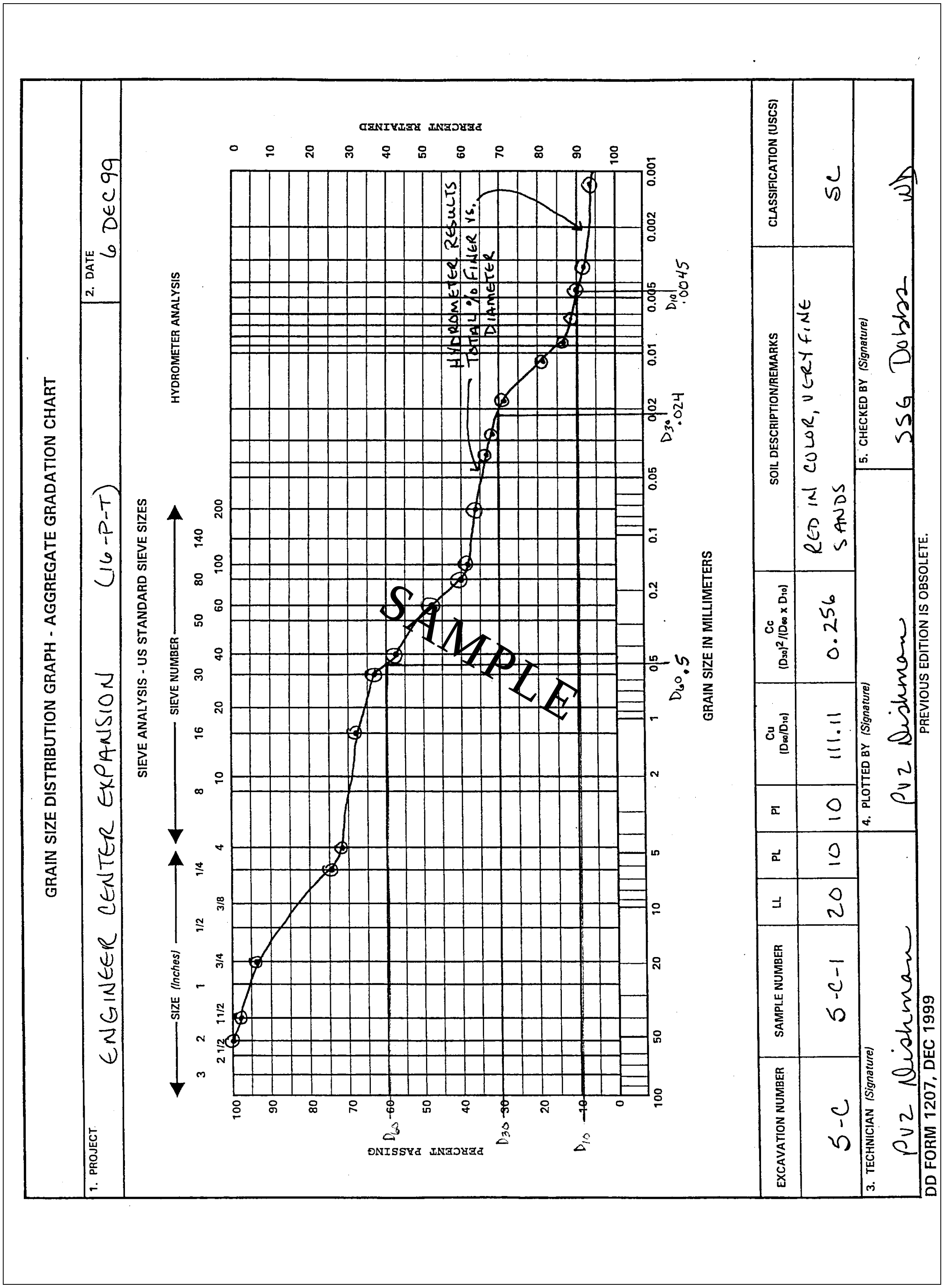


Figure 2-44. Sample DD Form 1207

Table 2-13. Frost-susceptibility groups for typical soil types

Frost Group	Kind of Soil	Percentage Finer Than 0.02 mm by Weight	Typical Soil Types Under USCS
NFS	(a) Gravels (e $\geq$ 0.25) crushed stone or rock	0 to 3	GW, GP
	(b) Sands (e $\leq$ 0.30)	0 to 3	SW, SP
	(c) Sands (e > 0.30)	3 to 10	SP
S-1	(a) Gravels (e < 0.25) crushed stone or rock	0 to 3	GW, GP
	(b) Gravelly soils	3 to 6	GW, GP, GW-GM, GP-GM, GW-GC, GP-GC
S-2	Sandy soils (e $\leq$ 0.30)	3 to 6	SW, SP, SW-SM, SP-SM, SW-SC, SP-SC
F-1	Gravelly soils	6 to 10	GW-GM, GP-GM, GW-GC, GP-GC
F-2	(a) Gravelly soils	10 to 20	GM, GC, GM-GC
	(b) Sands	6 to 15	SM, SC, SW-SM, SP-SM, SW-SC, SP-SC, SM-SC
F-3	(a) Gravelly soils	Over 20	GM, GC, GM-GC
	(b) Sands, except very fine silty sands	Over 15	SM, SC, SM-SC
	(c) Clays, PI > 12		CL, CH, ML-CL
F-4	(a) All silts		ML, MH, ML-CL
	(b) Very fine sands	Over 15	SM, SC, SM-SC
	(c) Clays, PI < 12		CL, ML-CL
	(d) Varved clays and other fine-grained, banded sediments		CL or CH layered with ML, MH, SM, SC, SM-SC, or ML-CL

NOTE: e = void ratio

SECTION VI. LIQUID LIMIT, PLASTIC LIMIT, AND PLASTICITY INDEX DETERMINATION (ASTM D 4318-95A)

Clays and some other fine-grained soils exhibit plasticity if the proper amount of water is present in the soil. A plastic soil is one that can be deformed beyond the point of recovery without cracking or change in volume. Such soils can be remolded. The LL is the greatest water content that the material may contain and still remain plastic. More water causes it to become a thick liquid. The PL is the lowest water content that the material may contain for plastic behavior. With less water, the soil becomes brittle and breaks into fragments if remolding is attempted. The PI is the numerical difference between the LL and the PL:

$$PI = LL - PL$$

A large PI indicates a very plastic soil; a small PI denotes a soil having little plasticity. As water content decreases below the PL, the soil mass shrinks and becomes stiffer. The shrinkage limit is the water content where, with further drying, shrinkage stops. Since there is no sharp distinction between the liquid, plastic, and brittle solid states of consistency, standardized procedures have been established for determining the LL and the PL. These consistency limits, as well as the shrinkage limit, are called the Atterberg limits. Since the primary tests in this section determine only the LLs and PLs and do not include tests for the shrinkage limits, they are not identified as the Atterberg limits.

Research with large numbers of clay soils was used to establish the soil plasticity chart for laboratory classification of fine-grained soils. The LL and PI values are coordinates that locate a particular soil sample on the chart. The region on the chart in which the sample falls gives the classification based on the behavioral characteristics of the particular soil.

Take particular care when performing the test methods described below. Some soils, particularly those with a high organic content, can provide inconsistent readings or drastic differences between an oven-dried sample and a sample at natural moisture content. Conduct the test below on samples of natural moisture content. Determine the moisture content at the end of the test.

LL DETERMINATION

A soil's LL is the water content expressed as a percentage of the weight of the oven-dried soil at the boundary between the liquid and the plastic states and reported as a whole number. This boundary is arbitrarily defined by a standard test method. The test is performed on two halves of a prepared soil specimen in an LL device. The LL is determined when the soil halves flow together along a distance of 13 millimeters when the cup is dropped or jarred exactly 25 times from a height of 1 centimeter. This rate of drop is 1.9 to 2.1 drops per second.

PURPOSE

Perform this test to assist in classifying the soil by determining the LL from three moisture-content samples.

EQUIPMENT

Perform this test in a laboratory environment using the following items (see *Figure 2-45*):

- A balance scale sensitive to 0.01 gram.
- An LL device and a grooving tool (see *Figure 2-46, page 2-92*).
- A No. 40 sieve.
- Pudding pans.
- A ground-glass plate (at least 30 centimeters square by 1 centimeter thick) for mixing soil and rolling PL threads.
- A plastic bag.
- A calculator.
- Moisture-determination tares.

- Paper.
- A pencil.
- A grease pencil.
- DD Form 1209.
- Gummed labels.
- A spatula.
- A straightedge.
- A mortar with a rubber-tipped pestle.
- A laboratory oven.
- Heat-resistant gloves.
- Distilled water.

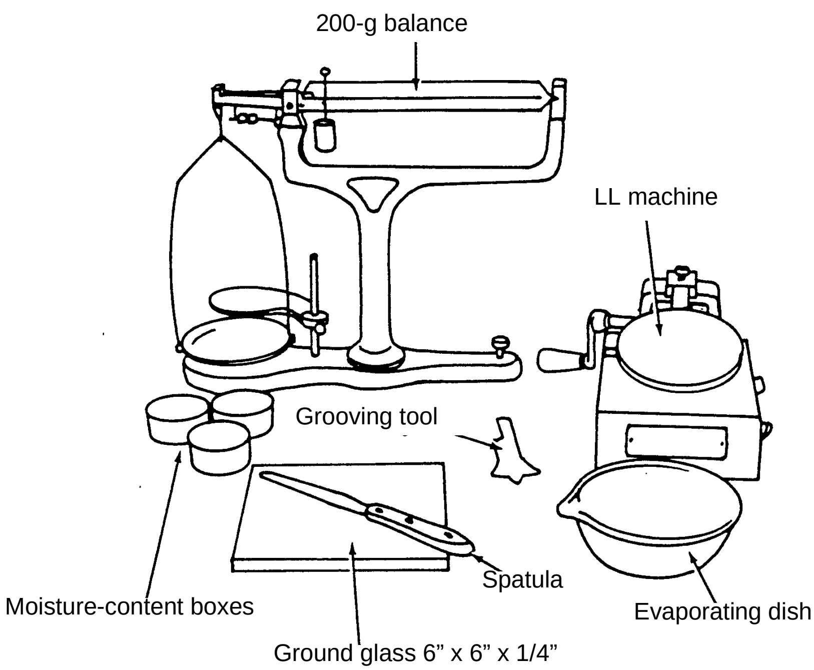


Figure 2-45. Equipment for the LL and PL tests

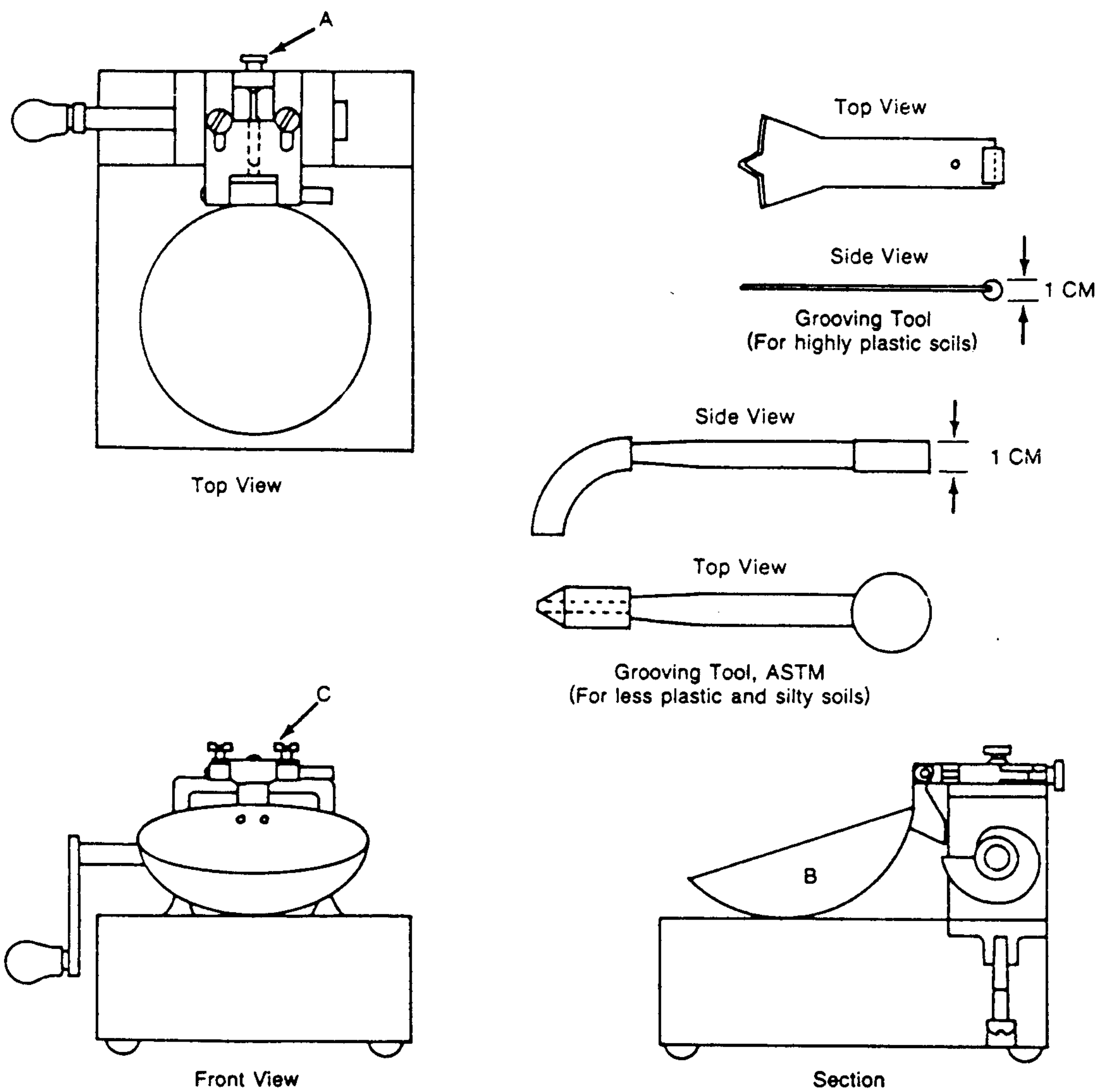


Figure 2-46. LL device with grooving tools

STEPS

Perform the following steps to determine the LL:

Step 1. Prepare the soil sample.

a. Sieve the soil sample (at natural moisture content) over the No. 40 sieve to obtain a sufficient quantity of at least 250 grams.

b. Perform the following steps if little or no material is retained on the No. 40 sieve, otherwise go to step 1c:

(1) Collect 200 to 250 grams of –40 material for testing.

(2) Mix the material with distilled water until the water content is slightly below the LL or about a peanut butter consistency. The goal is to have the material fall in the 25- to 35-blow range for the first test.

(3) Place the mixture in a plastic bag, making it airtight for at least 16 hours (overnight) so the moisture content can become consistent throughout the sample. Remix the material thoroughly before testing.

c. Perform the following steps if material is retained on the No. 40 sieve:

(1) Place the –40 material in a plastic bag, making it airtight to maintain its natural moisture content.

(2) Soak the coarse material retained on the No. 40 sieve (the soaking time is variable).

(3) Rub the colloidal material from the surfaces of the large particles until they are clean, placing the fines in suspension.

(4) Pour off the suspended fines slowly into another pan, being careful not to pour off the coarse material.

(5) Add clean water to the coarse material and repeat the wash process until the water poured off is sufficiently clear to indicate that the majority of fines that were put in suspension have been poured off.

(6) Remove the excess water from the pan containing the suspended fines after the fines have settled by decantation and evaporation. Do not oven-dry or add chemical substances to speed dry or hasten the settlement.

(7) Oven-dry the coarse material that has been soaked and washed.

(8) Sieve the oven-dried coarse material over the No. 40 sieve.

(9) Combine the –40 material obtained from steps 1c(1) and 1c(8) with the decanted material from step 1c(6). If the combined material is too moist, air-dry it until the water content is slightly below the LL. If the combined material is too dry, add small quantities of water until the water content is slightly below the LL (peanut butter consistency).

(10) Place the combined mixture in a plastic bag, making it airtight for at least 16 hours (overnight) so the moisture content can become consistent throughout the sample. Remix the material thoroughly before testing.

Step 2. Inspect the LL device before testing.

a. Ensure that the pin connecting the cup is not worn (which would permit side play).

b. Ensure that the screws connecting the cup to the hanger arm are tight.

c. Check the cup for wear. If a groove has developed from use, replace it.

d. Check the contact between the cup and the base. If a dent can be felt in the base or flat on the cup, replace or repair it.

e. Check the grooving tool for wear.

f. Check the height of the drop of the cup so that the point on the cup that comes in contact with the base (not the lowest point of the cup) rises to a height of 1 centimeter. Use the gauge on the handle of the grooving tool to assist in this measurement. The height of the drop must be 1 centimeter. Use the thumbscrew at the rear of the device to make an adjustment.

Example: The following is one procedure which could be used to aid in checking and adjustments:

1. 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, place a piece of carbon paper on the base and allow the cup to drop several times to mark the contact spot.

2. Attach the cup to the device, and turn the crank until the cup is raised to its maximum height.

3. Slide the height gauge under the cup from the front, and observe whether the gauge contacts the cup or the tape. If the tape and cup are both contacted, the height of drop is approximately correct. If not, adjust the cup until simultaneous contact is made.

4. Check the adjustment by turning the crank at 2 revolutions per second while holding the gauge in position against the tape and cup. If a faint ringing or clicking sound is heard without the cup rising from the gauge, the adjustment is correct. If no ringing is heard or if the cup rises from the gauge, readjust the height of drop. If the cup rocks on the gauge during this step, the cam-follower pivot is excessively worn and the worn parts should be replaced.

5. Remove the tape after completion of adjustments.

Step 3. Perform the LL test.

a. Obtain about 50 grams of the 200- to 250-gram prepared sample, and place in an airtight container for use in the PL test.

b. Record all identifying information for the sample on DD Form 1209 (see *Figure 2-47*).

c. Label and preweigh three empty moisture-determination tares. Record the weight on the form as the weight of the tare.

d. Place 20 to 25 grams of the thoroughly mixed sample into the brass cup, and level it off with a maximum depth of 1 centimeter (see *Figure 2-48, page 2-96*).

e. Divide the soil sample in the cup with a grooving tool so that a clean, sharp groove is formed. Hold the cup with the cam follower upward and draw the grooving tool, with the beveled edge forward, through the specimen downward away from the cam follower (see *Figure 2-49, page 2-96)*. Use more than one stroke to make the groove, but no more than six, cleaning the grooving tool's cutting edge after each stroke. Avoid tearing the side of the groove. Replace the soil sample in the cup, and regroove if

LIQUID- AND PLASTIC-LIMITS DETERMINATION

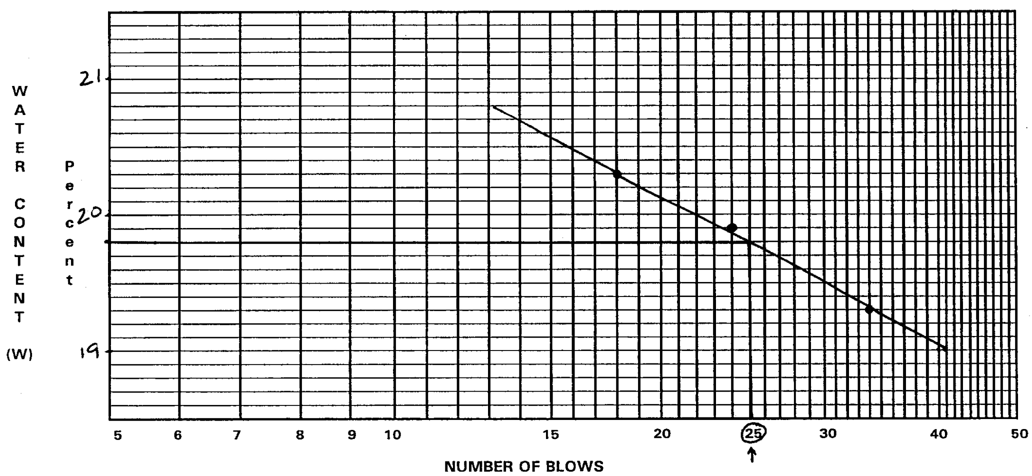
1. PROJECT	2. DATE
ENGINEER CENTER EXPANSION	3 DEC 99

3. EXCAVATION NUMBER	4. JOB NUMBER	5. SAMPLE NUMBER
5-C	16-P-T	5-C-1

6. LIQUID LIMIT, LL

RUN NUMBER	1	2	3			
TARE NUMBER	1-L	2-L	3-L			
a. WEIGHT OF WET SOIL + TARE	30.63	23.65	25.01			
b. WEIGHT OF DRY SOIL + TARE	28.50	22.22	23.54			
c. WEIGHT OF WATER $W_w = a - b$	2.13	1.43	1.47			
d. WEIGHT OF TARE	17.48	15.04	16.30			
e. WEIGHT OF DRY SOIL $W_s = b - d$	11.02	7.18	7.24			
WATER CONTENT $w = \frac{W_w}{W_s} \times 100$	19.3	19.9	20.3			
NUMBER OF BLOWS	34	24	18			

SAMPLE



7. PLASTIC LIMIT, PL

RUN NUMBER	~~5~~	6	7	8		
TARE NUMBER	~~5-P~~	6-P	7-P	8-P		
a. WEIGHT OF WET SOIL + TARE	~~23.86~~	23.27	24.07	23.59		8.3
b. WEIGHT OF DRY SOIL + TARE	~~23.42~~	22.61	23.46	22.98	MEAN =	9.3 (+/-1)
c. WEIGHT OF WATER $W_w = a - b$	~~0.44~~	0.66	0.61	0.61		10.3
d. WEIGHT OF TARE	~~17.35~~	15.80	17.38	16.92		
e. WEIGHT OF DRY SOIL $W_s = b - d$	~~6.07~~	6.81	6.08	6.06		
WATER CONTENT $w = \frac{W_w}{W_s} \times 100$	~~7.2~~	9.7	10.0	10.1		
PLASTIC LIMIT, PL (Average w)	9.9					

8. REMARKS		
FINES = CL	LL =	20
	PL =	10
PLASTIC LIMIT TARE 5-P NOT USED. POSSIBLE ERROR. NOT +/- 1%	(LL - PL) PI =	10

9. TECHNICIAN (Signature)	10. COMPUTED BY (Signature)	11. CHECKED BY (Signature)
SGT Glasper	SGT Glasper	SSG Dobbs WD

DD FORM 1209, DEC 1999 PREVIOUS EDITION IS OBSOLETE.

Figure 2-47. Sample DD Form 1209

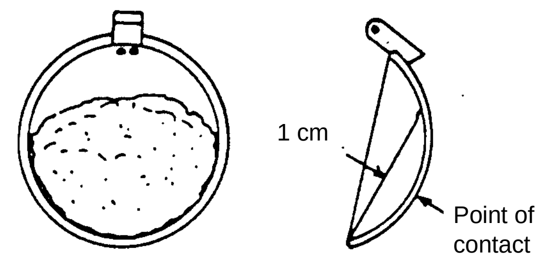


Figure 2-48. Leveling sample in the cup

the side tears. With some sandy and highly organic soils, it is impossible to draw the grooving tool through the specimen without tearing the sides of the groove. In such cases, the groove should be made with a spatula, using the grooving tool only for a final check of the groove (see *Figure 2-50)*.

Figure 2-49. Holding cup and grooving tool

f. Attach the cup to the device; ensure that the height of the drop is 1 centimeter.

g. Turn the crank of the device at a rate of two revolutions per second. Count the blows until the two halves of the soil make contact at the bottom of the groove along a distance of 13 millimeters (see *Figure 2-51*).

h. Record the number of blows to close the groove for 13 millimeters.

i. Obtain 5 to 10 grams of soil from the cup to determine the moisture content. Take the sample perpendicular to the groove from the edge of the cup and through the portion that has closed in the bottom of the groove. Place the sample in the preweighed moisture-determination tare, and

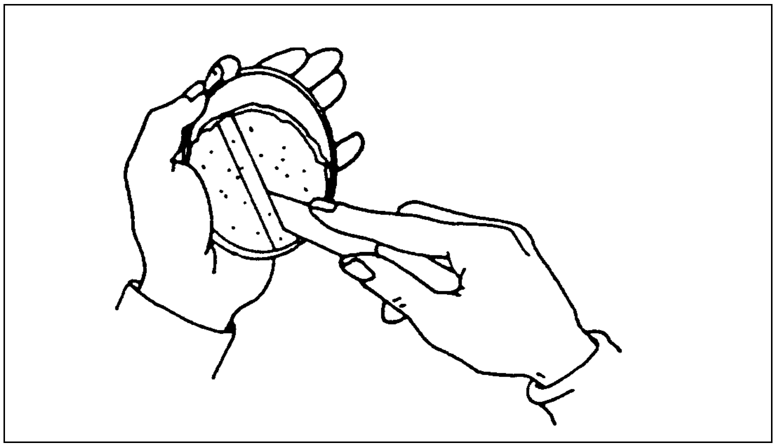


Figure 2-50. Cutting groove with spatula in sandy soil

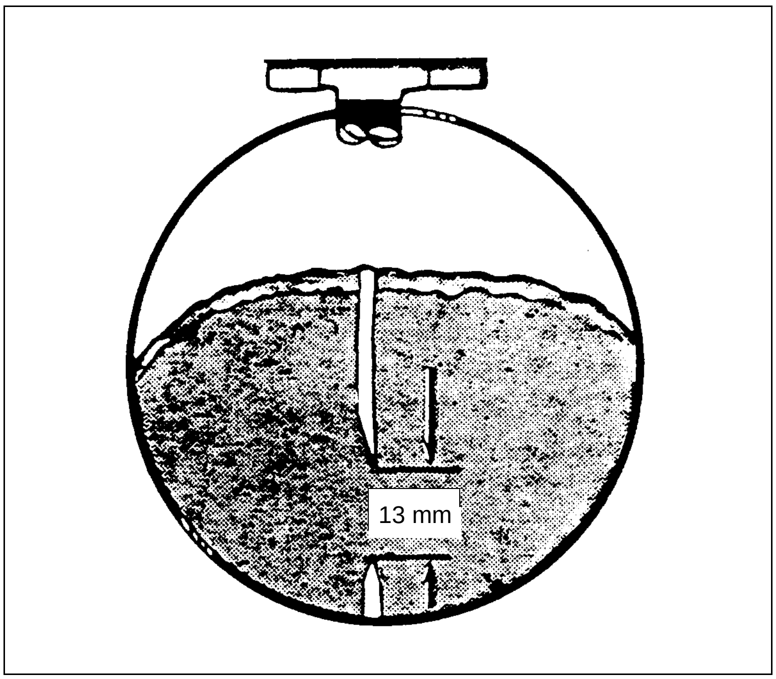


Figure 2-51. Soil coming into contact

cover it with a lid. Weigh it and record the weight on the form as the weight of the wet soil and the tare.

j. Transfer the soil remaining in the cup to the mixing dish. Wash and dry the cup and the grooving tool.

NOTE: It is recommended that one of the trials be for a closure requiring 25 to 35 blows, one for a closure between 20 and 30 blows, and one for a closure requiring 15 to 25 blows.

k. Remix the entire soil specimen, adding a little water to increase the water content of the soil and decrease the number of blows required to close the groove. Repeat steps 3d through 3j for at least two additional trials producing a successively lower number of blows to close the groove.

l. Oven-dry the water-content samples, allow them to cool, and reweigh them. Record the weight on the form as the weight of the dry soil and the tare.

m. Compute the weight of the water (W_w) by subtracting the weight of the dry soil and the tare from the weight of the wet soil and the tare. Record the weight on the form.

n. Compute the weight of the dry soil (W_s) by subtracting the weight of the tare from the weight of the dry soil and the tare. Record the weight on the form.

o. Record the water content for each specimen by computing the formula—

$$w = \frac{W_w}{W_s} \times 100$$

NOTE: All weighing should be accurate to 0.01 gram and water contents computed in percent to one decimal place.

p. Plot the water-content points on the semilog graph on the form (water versus number of blows) and draw a straight line (flow line) representative of the three or more points.

q. Determine the LL by interpreting the graph where the flow line intersects the 25-blow line. Record the LL to the nearest whole number.

PL DETERMINATION

The PL of a soil is the water content, expressed as a percentage of weight of oven-dried soil, at which the soil begins to crumble when rolled into a thread 3.2 millimeters in diameter. About 50 grams of material is required for the PL test. Prepare the sample and set it aside while preparing for the LL test.

PURPOSE

Perform this test to assist in classifying the soil by determining the PL moisture content to within ± 1 percent.

EQUIPMENT

Perform this test in a laboratory environment using the same equipment listed in the LL determination test.

STEPS

Perform the following steps to determine the PL:

Step 1. Label and preweigh two empty moisture-determination tares. Record the weight on DD Form 1209 as the weight of the tare.

Step 2. Obtain the 50-gram sample set aside during step 3a of the LL test. Reduce the water content, if required, to obtain a consistency with which the soil can be rolled without sticking to the hands by spreading or mixing continuously on the glass plate. The drying process may be accelerated by air-drying only.

Step 3. Select a portion of about 2 grams (marble size) from the 50-gram mass and form the test specimen into an ellipsoidal mass. Roll it on a finely-ground glass plate with the fingers or palm of the hand to a uniform thread diameter of 3.2 millimeters, taking no more than 2 minutes (see *Figure 2-52*).

NOTE: The rate of rolling should be between 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 soil.

Step 4. Remold the sample and roll it again to 3.2 millimeters diameter, repeating the rolling and remolding process until the total sample crumbles, before reaching the 3.2-millimeters-diameter thread (see *Figure 2-53, page 2-120*).

NOTE: All of the sample may not crumble at the same time. If the thread breaks into smaller lengths, roll each of these lengths to 3.2 millimeters. Continue the rolling and remolding process until the sample can no longer be remolded and rolled to the 3.2-millimeter thread without totally breaking up.

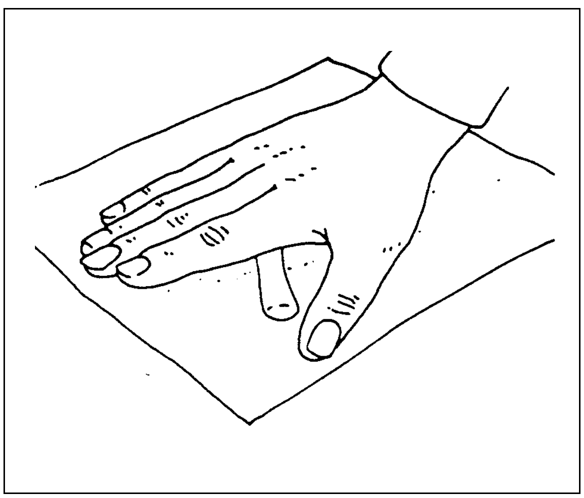


Figure 2-52. Rolling a soil specimen, PL test

Step 5. Collect and place the crumbled portions into a preweighed moisture-determination tare and cover it with the lid.

Step 6. Repeat steps 3 through 5 until the crumbled threads in the moisture-determination tare weigh at least 6 grams.

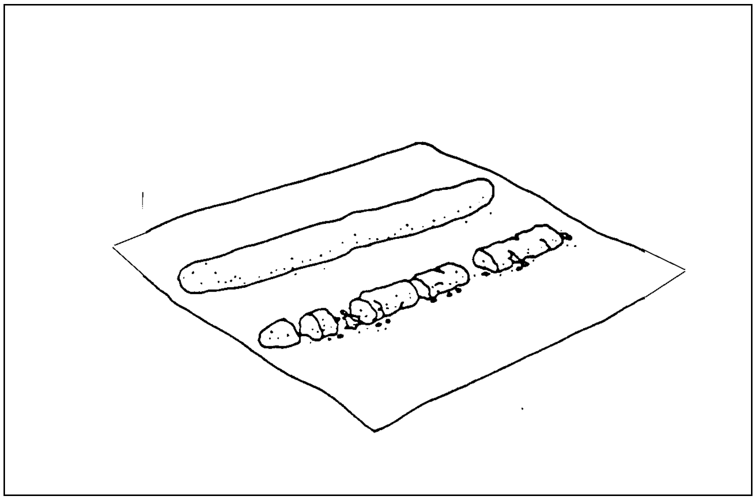


Figure 2-53. Rolled threads, crumbled and uncrumbled

Step 7. Repeat steps 3 through 6 to obtain a second moisture-determination tare of at least 6 grams of material.

Step 8. Weigh the moisture-determination tares with the crumbled threads, and record the weights on the form as the weight of the wet soil and the tare.

Step 9. Determine the water content by following steps 3l through 3o (page 2-118) of the LL test.

Step 10. Determine the average water content of the samples and record to the nearest tenth as the PL. When determining the average water content, the individual tests must be within ± 1 percent of the mean. Any individual tests that do not meet this requirement will not be used. If none of the individual tests meet this requirement, then additional testing is required.

PI DETERMINATION

Compute the PI and record it on the form using the following formula:

$$PI = LL - PL$$

Classify the soil by plotting the LL versus the PI on the plasticity chart as follows (see *Figure 2-54*):

- The material plotted on or above the A line is classified as clay, and the material plotted below the A line is classified as silt.
- The material plotted on or to the right of the 50 percent line has a high LL (H), and the material plotted to the left of the 50 percent line has a low LL (L).
- The upper, or U, line is an approximate upper boundary. Although not impossible, any results plotted above this line should be considered suspect and the tests should be rechecked.

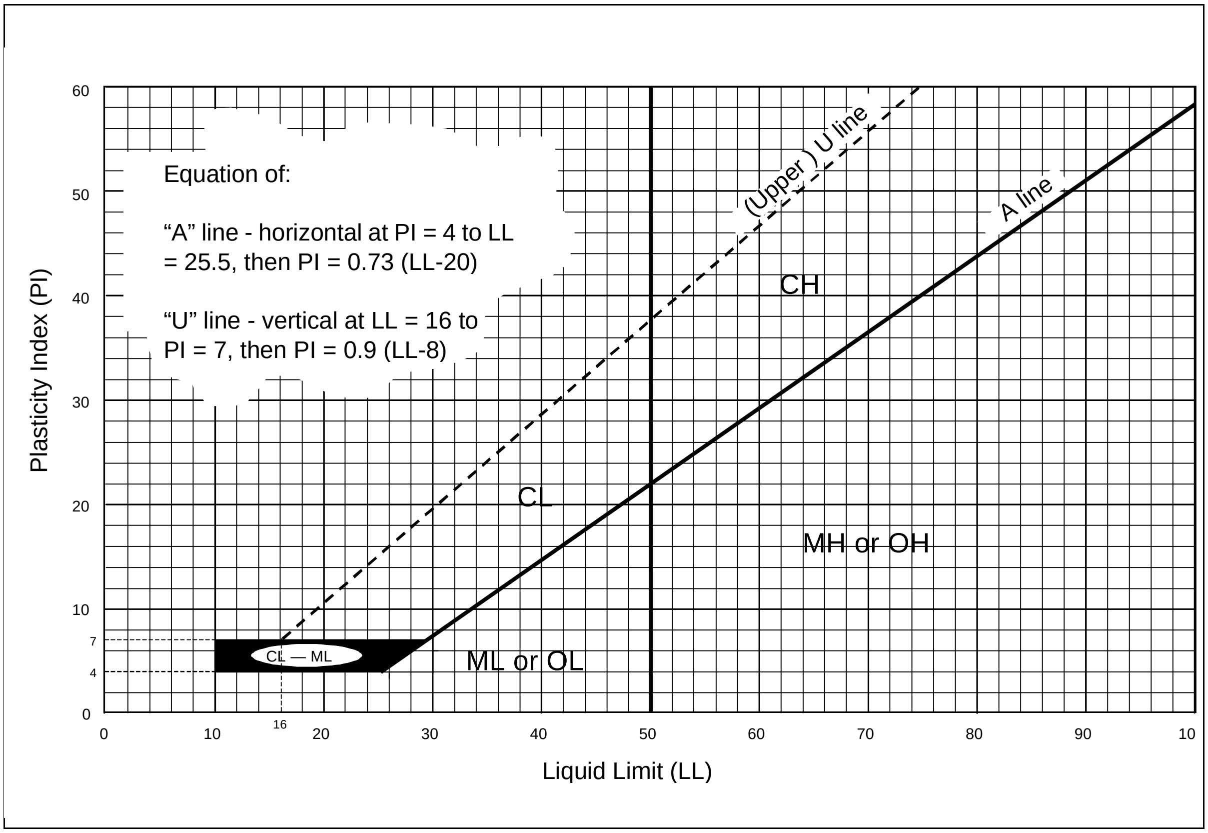


Figure 2-54. USCS plasticity chart

SECTION VII. LABORATORY COMPACTION CHARACTERISTICS OF SOIL USING MODIFIED EFFORT (COMPACTION TEST) (ASTM D 1557-91)

Compaction is one of the basic construction procedures involved in building subgrades and bases for roads and airport pavements, embankments, earthen dams, and similar structures. Compaction is the process of increasing the amounts of solids per unit volume of soil by mechanical means. This increase in density has an important effect in improving such soil properties as strength, permeability, and compressibility.

The amount of compaction is quantified in terms of the soil's density (dry unit weight). Usually, soil can be compacted best (and thus a greater density achieved) if only a certain amount of water is added. In effect, water acts as a lubricant, allowing soil particles to be packed together better. However, if too much water is added, a lesser density will result because the excess water separates the soil particles. Therefore, for a given compactive effort, there is a particular moisture content at which dry density is greatest and compaction is best. This moisture content is the OMC, and the associated dry density is called the maximum dry density (MDD).

COMPACTION TEST

In the field, compaction is accomplished by rolling or tamping with special equipment or by the passing of construction equipment. Laboratory compaction usually is accomplished by placing the soil in a cylinder of known volume and dropping a tamper of known weight onto the soil from a known height for a given number of blows. The amount of work done to the soil per unit volume of soil in this dynamic compaction procedure is called compactive effort. Each compactive effort for a given soil has its own OMC. As the compactive effort is increased, the maximum density usually increases and the OMC decreases.

Before performing the compaction test, the grain-size analysis must be determined (see Section V). This test method provides three alternative testing procedures. The procedure used shall be as indicated in the project specifications for the type of material being tested. If no procedure is clearly specified, the selection should be based on follow-on testing requirements (such as the CBR) and the material gradation.

PURPOSE

Perform compaction tests in the laboratory to determine such soil properties as the effect of varying percentages of water on dry density, the maximum density obtainable under a given compactive effort, and the OMC.

- Procedure A. This procedure uses the 4-inch mold on only the soil passing the No. 4 sieve when the overall representative sample has no more than 20 percent of the material by weight retained on the No. 4 sieve. The number of blows per layer for this procedure is 25 and the number of layers is 5. **NOTE: Materials that meet these gradations may also be tested using procedures B or C.**
- Procedure B. This procedure uses the 4-inch mold on only the soil passing the 3/8-inch sieve when the overall representative sample has more than 20 percent of the material by weight retained on the No. 4 sieve and 20 percent or less is retained on the 3/8-inch sieve. The number of blows per layer for this procedure is 25 and the number of layers is 5. **NOTE: Materials that meet these gradations may also be tested using procedure C.**
- Procedure C. This procedure uses the 6-inch mold on only the soil passing the 3/4-inch sieve when the overall representative sample has more than 20 percent of the material by weight retained on the 3/8-inch sieve and less than 30 percent is retained on the 3/4-inch sieve. The number of blows per layer for this procedure is 56 and the number of layers is 5.

NOTE: Previous testing methods incorporated a mix of standards that have since been rescinded. The current standard for this test is ASTM D 1557-91. This test procedure standardizes the use of the 4-inch (Proctor) and 6-inch (CBR) molds. The compaction effort at 56 blows is about the same as used in previous test methods (CE 55). This test method is applicable only to soils containing 30 percent or less by weight of material retained on the 3/4-inch sieve.

EQUIPMENT

Perform the compaction test using the following items:

- Cylinder molds (use one of the following molds, depending on the soil sample being processed):
  - — Proctor mold; 4-inch (4.0-inch inside diameter and 4.584-inch inside height having an internal volume of 0.0333 cubic foot), having an extension collar (2.375 inches high) and a detachable metal baseplate.
  - — CBR mold; 6-inch (6-inch inside diameter and 7-inch inside height), having an extension collar (2 inches high) and detachable metal baseplate. The mold should also have a metal spacer disk (5.94-inch inside diameter and 2.416 inches thick) for use as a false bottom in the mold during testing. When the spacer disk is in place in the bottom of the mold, the internal volume of the mold (excluding extension collar) shall be 0.075 cubic foot.
- A compacting hammer or tamper. A sliding-weight type compacting tamper, having a 2-inch-diameter steel striking face, a 10-pound mass, and an 18-inch fall.
- A No. 4 sieve.
- A 3/8-inch sieve.
- A 3/4-inch sieve.
- A balance scale sensitive to 0.01 gram.
- A balance scale sensitive to 1.0 gram.
- Moisture tares.
- A soils oven.
- Filter paper.
- A large spoon.
- A large knife.
- A steel straightedge.
- A calculator.
- DD Form 1210.
- DD Form 1211.

The amount of material (field sample) required for the compaction test depends on the test procedure being used and the field sample's moisture content. The following are guidelines for the amount of soil required for the test procedures:

- Procedures A and B: Use about 35 pounds of dry soil or at least 50 pounds of moist soil.

- Procedure C: Use about 75 pounds of dry soil or at least 100 pounds of moist soil.

STEPS

Perform the following steps for the compaction test:

Step 1. Determine the test procedure to be used.

- If the CBR design and tests are to be developed for this project, do not use this method. See Section IX for procedures to be used for CBR.
- If CBR is not a factor, determine the test procedure by evaluating the gradation criteria of the procedures listed above (A, B, or C) with column 17 (percent retained) on DD Form 1206.

Step 2. Prepare the soil sample.

a. Dry the sample until it can be easily crumbled under a trowel. Drying may be done by air-drying or by using a drying apparatus, provided the temperature of the sample does not exceed 60°C.

b. Break up the sample thoroughly, but not in such a manner as to reduce the size of the individual particles.

c. Sieve the sample over a No. 4 (procedure A), 3/8-inch (procedure B), or 3/4-inch sieve (procedure C). When preparing the material by passing it over the 3/4-inch sieve for compaction in the 6-inch mold, break up aggregates sufficiently to at least pass the 3/8-inch sieve. This facilitates the distribution of water throughout the soil in later mixing.

d. Separate from the sample 5 equal portions representing each point desired on the compaction curve. The size of each sample for one mold is about 2,700 grams for procedures A and B or 6,800 grams for procedure C. Retain all excess soil sample.

Step 3. Adjust the water content.

NOTE: The water-content adjustments in this step are designed to provide approximations of the OMC. In no way should these approximations be used for or be interpreted as the actual moisture content. Exact moisture determinations will be conducted in a later step.

a. Establish the assumed or approximate OMC.

(1) Place exactly 100 grams of the excess soil sample in a dish.

(2) Add 5 milliliters of water to the sample and mix thoroughly. The approximate OMC is typically achieved so that when the soil is squeezed in the palm, it will adhere together on its own but it will break cleanly into two separate pieces without either piece shattering when bent. Usually this will be slightly less than the PL.

(3) Add small amounts of water (in milliliters), remembering to record the amounts added, until the approximate OMC is achieved. Do not confuse the approximate OMC with the actual moisture content of this soil, which will be determined in a later step. For purposes of conducting the test method, the approximate OMC will be the amount

of water, in milliliters, added to the sample. (For example, if only 8 milliliters of water was added to achieve the approximate OMC, then the approximate OMC is 8.0 percent. This works in approximating because 1 milliliter of water is about equal to 1 gram. By adding weight to an original sample of 100 grams, no mathematical calculations are required.)

b. Determine the moisture-content range. This range is the approximated OMC ±4. (For example, if you have determined that the approximated OMC is 8.0 percent, then the -4 is 4.0 percent and the +4 is 12.0 percent. This identifies the moisture-content range as 4.0 to 12.0 percent.)

c. Use the following formula to determine the amount of water to add to each of the 5 samples to obtain the desired approximate (-4, -2, OMC, +2, +4) moisture contents:

$$\textit{water (in milliliters) to add} =$$
$$\textit{weight of sample (in grams)} \times \textit{desired percent (decimal format)}$$

For example, to determine the water to add to obtain the approximated OMC for a sample of 6,804 grams (using procedure C)—

$$6,804 \times 0.08 = 544.3 \textit{ milliliters}$$

Perform the same calculations to determine the water to add for the remaining samples for the required moisture-content range. The examples below illustrate this calculation for the remaining samples, taking into consideration that not all the sample weights will be exactly the same (6,804 grams):

(-4) 4.0% moisture for a sample at 6,815 grams: $6,815 \times 0.04 = 272.6$ *milliliters*

(-2) 6.0% moisture for a sample at 6,800 grams: $6,800 \times 0.06 = 408.0$ *milliliters*

(+2) 10.0% moisture for a sample at 6,822 grams: $6,822 \times 0.10 = 682.2$ *milliliters*

(+4) 12.0% moisture for a sample at 6,810 grams: $6,810 \times 0.12 = 817.2$ *milliliters*

d. Add the water figured from the formulas for each of the 5 desired moisture contents (-4, -2, OMC, +2, and +4) and mix thoroughly to ensure even distribution of water throughout the sample.

e. Place each sample in an airtight container and allow to stand for the minimum period of time indicated below:

- For GW, GP, SW, and SP soil types, there is no minimum standing period of time.
- For GM and SM soil types, a minimum of 3 hours standing time is required.
- For all other soil types, a minimum of 16 hours standing time is required.

Step 4. Record all identifying information such as the project, the excavation number, and other pertinent data on DD Form 1210 (see *Figure 2-55, page 2-106*).

LABORATORY COMPACTION CHARACTERISTICS OF SOIL (COMPACTION TEST)

1. PROJECT: ENGINEER CENTER EXPANSION
2. EXCAVATION NUMBER: 5-C
3. SAMPLE NUMBER: 5-C-1
4. DATE: 10 DEC 99
5. LAYERS/BLOWS PER LAYER: 5 / 56
6. WEIGHT OF TAMPER *(lb)*: 10 lb
7. HEIGHT OF DROP *(in)*: 18 in
8. SPECIFIC GRAVITY OF SOLIDS, G_s: 2.62
9. DIAMETER OF MOLD *(in)*: 6 in
10. VOLUME OF SOIL SAMPLE *(cu ft)*: ☐ 0.0333 cu ft ☒ 0.0750 cu ft

	UNITS														
11. RUN NUMBER	UNITS	1-3 (+4)		2-3 (+2)		3-3 (OMC)		4-3 (-2)		5-3 (-4)					
12. WEIGHT OF MOLD + WET SOIL	Grams	11953.0		12043.0		11609.0		11598.0		11834.0					
13. WEIGHT OF MOLD	Grams	7517.0		7496.0		7017.0		7119.0		7591.0					
14. WEIGHT OF WET SOIL (12 - 13)	Grams	4436.0		4547.0		4592.0		4479.0		4243.0					
15. WET UNIT WEIGHT, γwet ([14/453.6]/10)*	Pcf	130.4		133.7		135.0		131.7		124.7					
16. TARE NUMBER		1A	1B	2A	2B	3A	3B	4A	4B	5A	5B				
a. WEIGHT OF TARE + WET SOIL	Grams	308.00	308.00	316.00	313.37	325.21	333.48	249.26	272.67	234.86	258.08				
b. WEIGHT OF TARE + DRY SOIL	Grams	273.00	273.88	286.82	284.87	301.08	309.61	235.30	258.47	225.23	245.95				
c. WEIGHT OF WATER, W_w (a - b)	Grams	35.00	34.12	29.18	28.50	24.13	23.87	13.96	14.20	9.63	12.13				
d. WEIGHT OF TARE	Grams	62.15	61.96	60.70	61.26	62.17	60.96	60.80	61.25	62.01	62.16				
e. WEIGHT OF DRY SOIL, W_s (b - d)	Grams	210.84	211.92	226.12	223.61	238.91	248.65	174.50	197.22	163.22	183.79				
f. WATER CONTENT, $w = \frac{W_w}{W_s} \times 100$ (c / e x 100)	Percent	16.6	16.1	12.9	12.2	10.1	9.6	8.0	7.2	5.9	6.6				
17. AVERAGE WATER CONTENT	Percent	16.4		12.6		9.9		7.6		6.3					
18. DRY UNIT WEIGHT, $\gamma d = \frac{\gamma wet}{1+(w/100)}$	Pcf	112.0		118.7		122.8		122.4		117.3					

* This formula contains the conversion from grams to pounds. Omit the conversion factor if the unit weight used is not grams.

SAMPLE

19. REMARKS: SELECT MATERIAL

20. TECHNICIAN *(Signature)*: SPC Blest
21. COMPUTED BY *(Signature)*: SPC Blest
22. CHECKED BY *(Signature)*: SSG Dobbs WD

DD FORM 1210, DEC 1999 — PREVIOUS EDITION IS OBSOLETE.

Figure 2-55. Sample DD Form 1210

Step 5. Prepare the mold and moisture-determination tares.

a. Lightly oil a mold (4- or 6-inch, depending on the procedure selected).

b. Weigh the mold.

- For the 4-inch mold, weigh the mold with the baseplate to the nearest gram. Record this weight on the form as the weight of the mold (block 13). Do not include the collar.
- For the 6-inch mold, weigh the mold with the baseplate and spacer disk to the nearest gram. Record this weight on the form as the weight of the mold (block 13). Do not include the collar.

c. Attach the collar to the mold. If using the 6-inch mold, place a coarse filter paper on top of the spacer disk.

d. Record the volume of the mold as 0.0333 cubic foot for the 4-inch mold or 0.075 cubic foot for the 6-inch mold with the spacer disk.

e. Mark and weigh 2 moisture-determination tares for each mold prepared. Record as the weight of tare.

Step 6. Place sufficient soil in the mold (about 1 1/2 to 2 inches) to obtain about a 1-inch compacted layer. After compaction of all 5 layers, each layer should be about equal in thickness. The fifth compacted layer will slightly extend into the collar but will not exceed 1/4 inch above the top of the mold.

Step 7. Apply compactive effort.

a. Hold the 10-pound compaction tamper within 5 degrees of vertical, placing its face on top of the soil.

b. Raise the handle until it reaches the top (18 inches) and release it, allowing the weight to fall freely onto the soil.

c. Change the position of the guide and tamper, and repeat the process until the soil layer has received the prescribed 25 blows for procedures A and B or 56 blows for procedure C. Apply the blows at a uniform rate of about 25 blows per minute. The height of fall of the tamper must be controlled carefully and the blows distributed evenly over the specimen's surface (see *Figure 2-56, page 2-108*).

Step 8. Trim the compacted layer. After compacting each layer (except the fifth layer), use a knife to trim any soil adjacent to the mold walls that has not been compacted or that extends above the compacted surface. Include the trimmed soil with the additional soil for the next layer.

Step 9. Repeat steps 6, 7, and 8 until five layers have been compacted in the mold. Each compacted layer should be about equal in thickness (just under 1 inch). Adjust each layer accordingly to ensure that the fifth compacted layer will slightly extend into the collar, but will not exceed 1/4 inch above the top of the mold.

Step 10. Remove the collar from the mold.

a. Cut around the inside edge of the collar to prevent shearing the compacted soil when removing the collar.

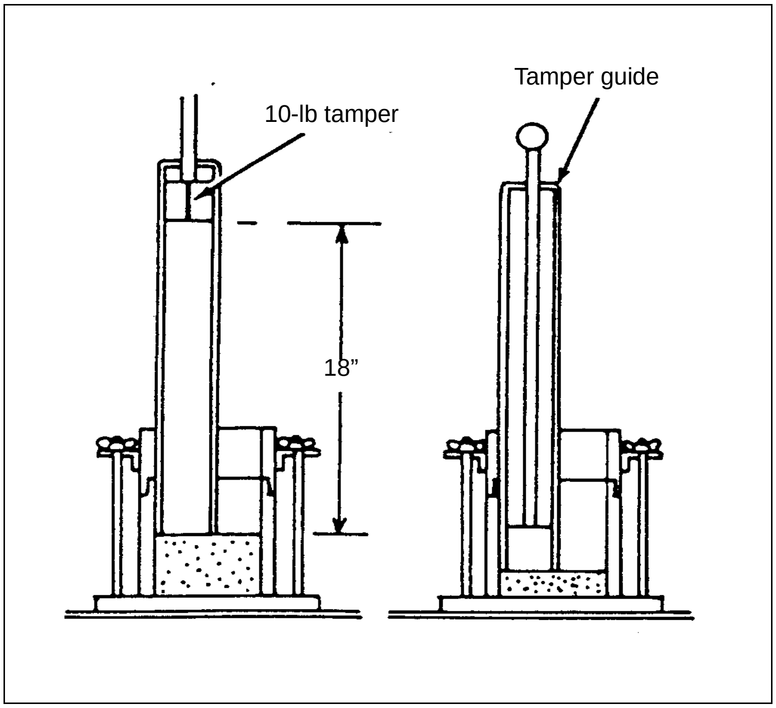


Figure 2-56. Soil compaction in a mold

b. Trim and smooth the compacted soil flush with the top of the mold (see *Figure 2-57*). Use a sawing motion with the straightedge to trim the excess soil. Start at the center of the mold and work outward, first to one side and then to the other. Fill any holes with unused or trimmed soil from the specimen, press in with the fingers, and again scrape the surface with the straightedge.

Step 11. Weigh and record the data. Weigh the complete mold with the baseplate and compacted specimen (including the spacer disk for the 6-inch mold) to the nearest gram. Record the weight on the form as the weight of the mold and wet soil (block 12). Do not include the collar.

Step 12. Prepare the specimen for moisture-content determination.

a. Remove the specimen from the mold.

b. Slice the compacted specimen axially through the center and remove about 250 grams of material from one side of the cut and place it in one of the moisture-determination tares and cover. Remove about 250 grams from the other side of the cut, and place it in the other moisture-determination tare and cover.

Step 13. Repeat steps 5 through 12 for the remaining molds at the different moisture contents described in step 3c.

Step 14. Determine the moisture content of the material in the moisture-determination tares by performing moisture-content testing of the tares as described in Section III.

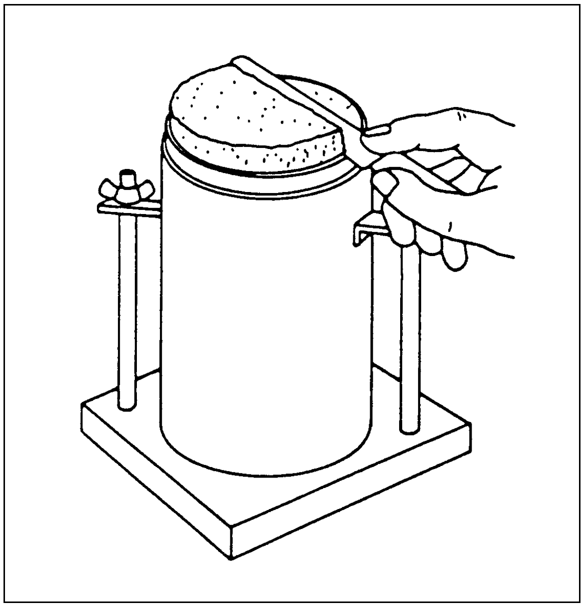


Figure 2-57. Trimming the compacted soil sample

Step 15. Perform calculations. Record the weight of the dry soil and tare on the form. Compute the weight of water, weight of dry soil, and the water content and record it on the form. Compute the average water content from the two tares and record it on the form. Calculate and record the dry unit weight as follows:

$$\textit{dry unit weight} = \frac{\textit{wet unit weight}}{1 + \frac{\textit{percent water content}}{100}}$$

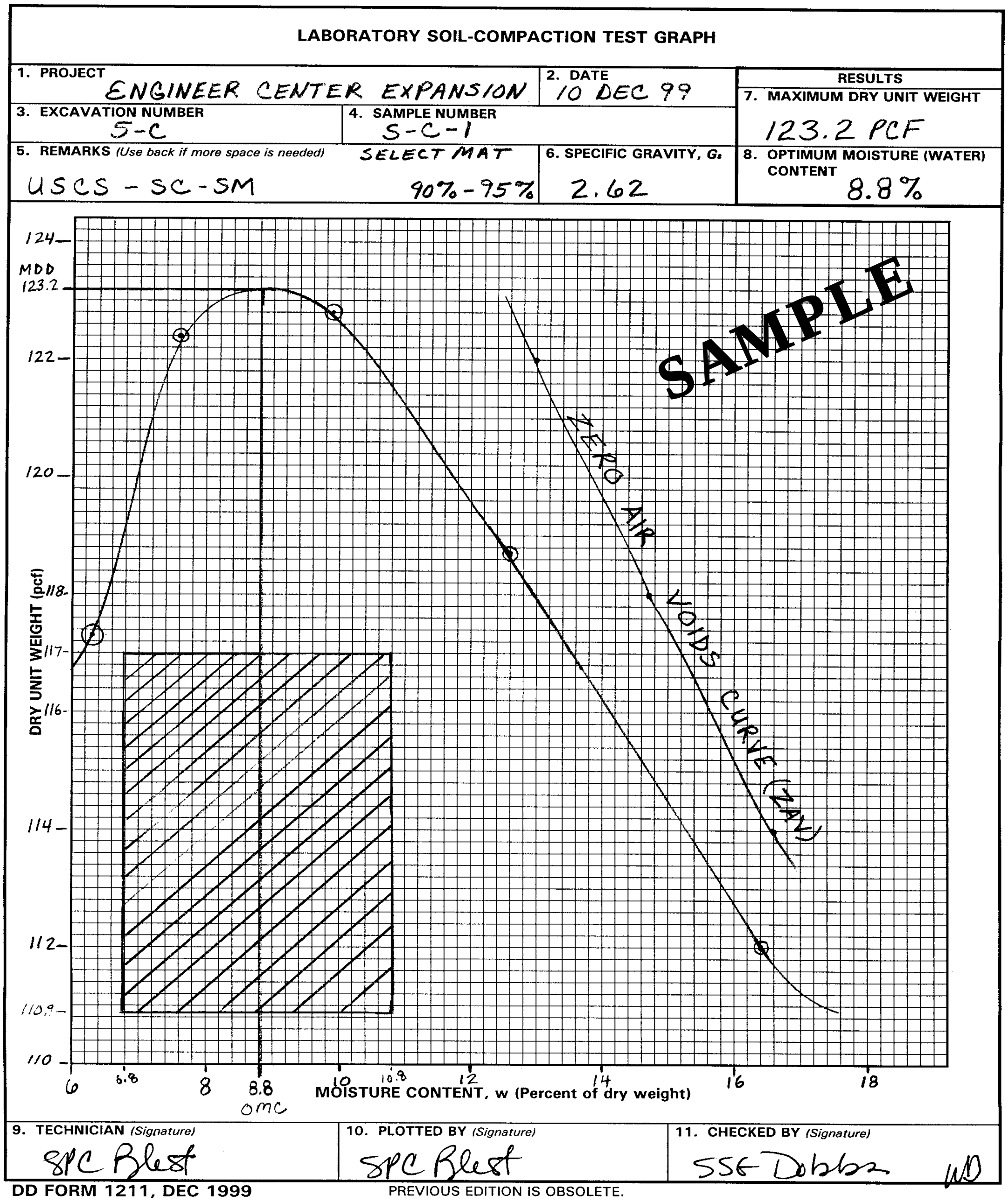
COMPACTION-TEST GRAPH—PRESENTATION OF RESULTS

The soil compaction-test graph (DD Form 1211) is an important part of presenting the data from the compaction test. It is used to plot a compaction curve. This curve is needed to determine the MMD and OMC as part of the compaction-test procedures. It also includes a zero-air-voids curve and a compaction-specification block.

COMPACTION CURVE

The compaction curve is obtained by plotting moisture content versus dry unit weight for each test on the soil-compaction-test graph (see *Figure 2-58, page 2-110*). To construct an acceptable curve, at least two of the plotted points should fall on each side of the OMC. It is important to remember that during the testing period, the only density that can be determined is the wet soil density or wet unit weight. To compute the dry unit weight, the moisture content must be determined. This can take up to 24 hours.

For a typical cohesive soil, dry density increases to a certain point (the OMC) as the moisture in the soil increases. Once the OMC is achieved, the dry density begins to decrease with increasing moisture content. The primary reason for performing the compaction test is to determine the moisture



LABORATORY SOIL-COMPACTION TEST GRAPH

1. PROJECT ENGINEER CENTER EXPANSION
2. DATE 10 DEC 99
3. EXCAVATION NUMBER 5-C
4. SAMPLE NUMBER S-C-1
5. REMARKS (Use back if more space is needed) SELECT MAT USCS - SC-SM 90% - 95%
6. SPECIFIC GRAVITY, G_s 2.62

RESULTS
7. MAXIMUM DRY UNIT WEIGHT 123.2 PCF
8. OPTIMUM MOISTURE (WATER) CONTENT 8.8%

9. TECHNICIAN (Signature) SPC Blest
10. PLOTTED BY (Signature) SPC Blest
11. CHECKED BY (Signature) SSG Dobbs

DD FORM 1211, DEC 1999 PREVIOUS EDITION IS OBSOLETE.

Figure 2-58. Sample DD Form 1211

content at which the MDD can be obtained. After plotting the compaction curve, it is possible to determine the moisture content that will give the MDD for that particular soil directly from the plotted curve.

The compaction curve shows the OMC or the moisture content at which the MDD is obtained for a given compaction effort. By determining the highest point on the compaction curve (apex) and dropping vertically to the horizontal moisture scale or line, the OMC for this particular soil is found to be 8.8 percent, as shown in *Figure 2-58*.

The compaction curve also shows MDD (100 percent compaction). The MDD of 100 percent effort may be obtained by running a tangent from the highest point on the compaction curve for the particular soil to the vertical dry-density scale (see *Figure 2-58*); in this case, 123.2 pounds per cubic foot (pcf).

A compaction curve is not complete without the zero-air-voids curve, which acts as a control to the compaction curve.

ZERO AIR VOIDS AND SATURATION

The zero-air-voids curve represents theoretical values that are practically unattainable—no matter what degree of compactive effort—because it is not possible to remove all the air contained in the voids of a soil by compaction alone. Typically, at moisture contents beyond optimum, the actual compaction curve closely parallels the theoretically-perfect compaction curve. Any values of dry density that plot to the right of the zero-air-voids curve are in error. The error may be in the test measurement, the calculations, or the specific gravity.

At complete saturation, the voids in the solid mass are completely filled with water. That is, no air is present and the degree of saturation (S) is equal to 100 percent. The zero-air-voids curve (100 percent saturation) for the soil tested is shown on the graph in *Figure 2-58*. This curve is obtained by plotting dry densities corresponding to complete saturation at different moisture contents using the following formula:

$$w = S \times \left(\frac{62.43}{g_d} - \frac{1}{G_s} \right)$$

where—

w = water content, in percent

S = degree of saturation, in percent

62.43 = unit weight of water, in pcf

g_d = dry unit weight of soil, in pcf

G_s = specific gravity of solids for this soil (block 6, DD Form 1211)

Use this equation to compute points for plotting the zero-air-voids curve. Plot at least three points for drawing the curve. Use points within the range of the compaction-curve dry unit weights. Select three dry unit weights in this range and calculate as listed above.

Example: The upper plotted point of the zero-air-voids curve for the soil represented in *Figure 2-58* is a whole number just under maximum density (122 pcf). The specific gravity of solids (G_s) was determined to be 2.62. At 100 percent saturation for this density, the corresponding moisture content would be 13 percent. This is determined by the zero-air-voids formula:

$$100 \times \left(\frac{62.43}{122} - \frac{1}{2.62}\right) = 13$$

Any other plotted points are also determined using this formula as follows:

$$100 \times \left(\frac{62.43}{118} - \frac{1}{2.62}\right) = 14.7$$
$$100 \times \left(\frac{62.43}{114} - \frac{1}{2.62}\right) = 16.6$$

PERCENT MOISTURE

To obtain the maximum dry unit weight or density in the field, it is necessary to maintain the construction soil's moisture content as close as possible to the optimum determined from the laboratory compaction test. If the moisture content is not close to the OMC, it will require extra time and equipment effort to obtain the MDD. The limits for moisture contents should be outlined in the specifications for each job. If not specified, the limits should be established as ± 2 percent of the OMC. Using *Figure 2-58*, where the OMC is 8.8 percent, the moisture limits would range from 6.8 to 10.8 percent. This provides the limits for a workable and practical specification block.

PERCENT COMPACTION

Some soils will not or cannot be compacted to 100 percent at a reasonable equipment effort, regardless of the combination. In those cases, it is not mandatory to compact to 100 percent. For each job, the specifications will state the percent of compaction required for the particular loadings. Assume that the specifications require 90 percent of MDD. To find the dry density required, multiply the MDD (100 percent), regardless of its value, by 0.90. This will give the density limit. If the specifications state between 90 and 95 percent, the 90 percent density will constitute the lower limit with 95 percent as the upper limit. A specification block can now be constructed (see *Figure 2-58, page 2-110*).

COMPACTION-SPECIFICATION BLOCK

The compaction-specification block shows a determination range based on the project specifications. If no specifications are given, refer to the minimum compaction specification requirements as listed in FMs 5-410, 5-430-00-1, or 5-430-00-2. Once the range is determined, the specification block is plotted on the compaction curve (see *Figure 2-58*), covering the specified compaction-range requirement in percent for the dry unit weight within a 4 percent range of the OMC (± 2 OMC). The block is then lightly cross-hatched so as to not interfere with the compaction curve. If the field results fall within this block, the job is meeting specifications.

Equipment

Use the following to complete the compaction-specification block:

- DD Form 1211 with compaction curve and zero-air-voids curve.
- A calculator.
- The proposed use of the soil.
- The project's compaction specifications.

Steps

Perform the following steps to complete the soil compaction-specification block (DD Form 1211):

Step 1. Determine the compaction-specification requirements as discussed above.

Step 2. Draw the compaction-specification block. Establish the upper and lower limits of the block as the specification range (in percent) of the dry unit weight. Establish the left and right limits of the block as ± 2 of OMC.

The example in *Figure 2-58, page 2-110,* represents the compaction data from DD Form 1210 (see *Figure 2-55,* p*age 2-106*), the zero-air-voids curve plotted from a specific gravity value of 2.62, and a compaction specification of 90 to 95 percent. Notice the compaction-specification block ranges vertically from 117 to 110.9 pcf and horizontally from 6.8 to 10.8 percent in moisture content. The computation used to achieve the upper and lower limits is based on the MDD (in this case, 123.2 pcf) and the specification range of 90 to 95 percent as follows:

$$123.2 \times 0.95 = 117.0$$

$$123.2 \times 0.90 = 110.9$$

Once the block has been established and drawn, the inside of the block can be lightly cross-hatched to easily identify the range. Do this so as not to interfere with the curve or any other data plotted on the chart.

EFFECT OF WATER ON DENSITY

Figure 2-59, page 2-114, demonstrates that as the moisture content is varied, the dry density also varies. As water is added to an oven-dried soil, the dry density increases until the OMC is reached. The dry density then begins to decrease using a constant compactive effort.

After adding small increments of water to a completely air-dry soil, subsequent compaction with a constant compactive effort causes a small increase in the soil's dry unit weight. During the initial hydration phase, the water being added to the soil is absorbed on the surface of the soil grains. This water does not aid compaction by acting as a lubricant since it is firmly attached to the surface of the soil particles. Adding additional water brings the soil to a point where a slight change in moisture begins to produce a large increase in density. This rapid increase indicates that the lubrication phase of the compaction curve has been reached.

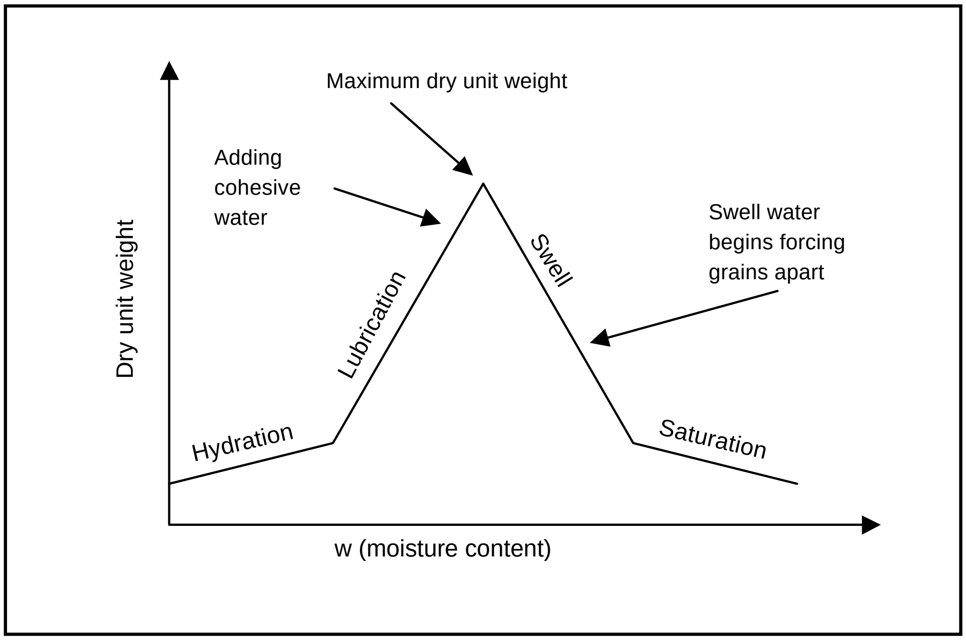


Figure 2-59. Effect of water on density

The first portion of the compaction curve to the right of OMC is known as the swell phase. The addition of water increases the film around the soil particles, forcing the soil particles apart and decreasing the dry density. With further increases in moisture content, free water added to the soil will fill the void spaces. This is known as the saturation phase. In the swell and saturation phases, the water begins to take the place of the solids, thus decreasing the dry density.

EFFECT OF DIFFERENT COMPACTIVE EFFORTS ON DENSITY

The mass-per-unit volume of a soil varies directly with the amount of energy expended to compact that soil. Therefore, the greater the compactive effort, the greater the amount of solids per unit volume. This results in a stronger and more stable soil.

As the compactive effort is increased, the dry density of the soil increases. This means that if more energy is used to compact a soil, the increased energy will cause the particles to be rearranged to a greater extent, thus increasing the mass of soil particles per unit volume. If the compactive effort is decreased, the particles will not be rearranged as much, thus decreasing the dry density. *Figure 2-60* shows how the dry density varies with the compactive effort.

The OMC varies inversely with respect to compactive effort. If the compactive effort is increased, the soil does not have to be as wet to obtain the MDD. In other words, the OMC will be decreased with increasing compactive effort (see *Figure 2-60*).

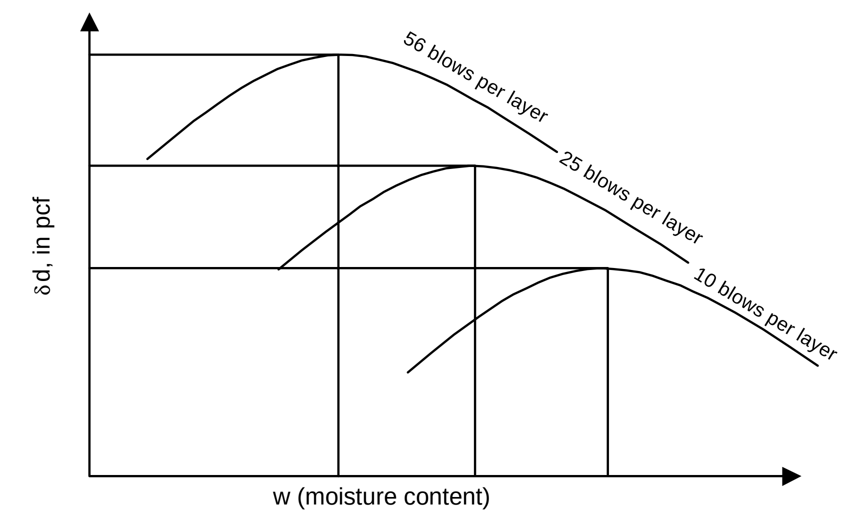


Figure 2-60. Effect of different compactive effort on density

EFFECT OF DIFFERENT TYPES OF SOILS ON DENSITY

Different soils have varying compactive characteristics. Gravelly and sandy soils have a lower OMC and higher densities under the same compactive effort compared with silty and clay soils (see *Figure 2-61, page 2-116*). The sharpness of the curves indicates that moisture content is much more critical in obtaining maximum density for coarse-grained soils than for fine-grained soils.

COMPACTION EQUIPMENT

Equipment normally available to the military engineer for soil compaction includes sheepsfoot, pneumatic-tired, and steel-wheeled rollers. Other construction equipment and load-hauling units may also be used. Crawler-type tractor units are efficient in compacting free-draining sands and gravels that should be kept wet during the compaction process. This equipment is not efficient for compacting cohesive soils. Compaction equipment use is covered in FM 5-434.

For compaction equipment to be used efficiently, the moisture content at which maximum compaction can be obtained (the OMC) and the maximum density to which the soil can be compacted are required. This data is obtained by performing the laboratory compaction test. The stability or strength of the base course in the field can only be obtained if the moisture content allows proper compaction and if compaction is obtained at or above the amount specified.

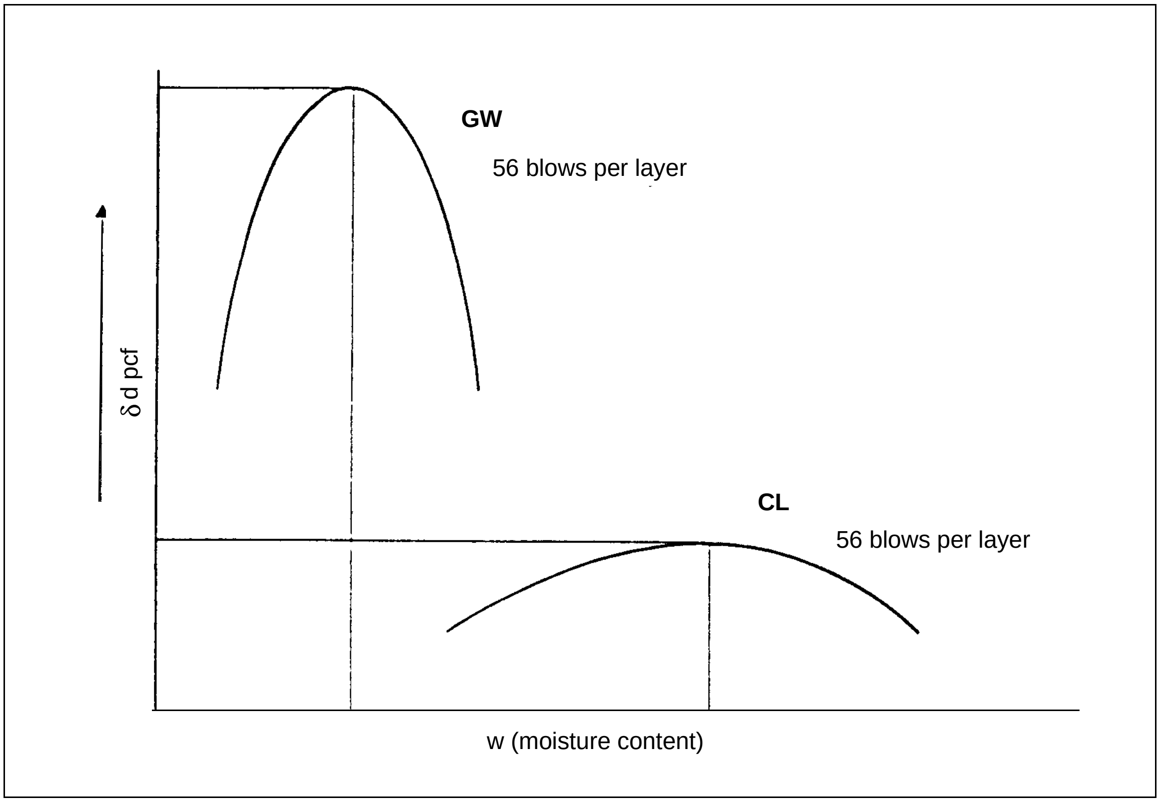


Figure 2-61. Effect of different soil types on density

OTHER COMPACTIVE EFFORTS

Under some circumstances, it may be necessary to use a compactive effort in the laboratory. Usually this is done to study the effect of variation in density on some property of the soil, such as the CBR. In this case, samples are compacted using the procedures previously described, except that the variation in density is achieved by varying the number of blows applied to each layer as described in ASTM D 1883-94. In unusual circumstances, the laboratory compaction procedure may be changed to produce a compactive effort that more closely resembles the energy that can be put into the soil using available rolling equipment. In the CBR test, the compaction procedure calls for 10, 25, or 56 blows per layer. This is explained in Section IX of this chapter.

SECTION VIII. IN-PLACE DENSITY DETERMINATION

Proper field control is essential in earthwork construction. The control tests are conducted on the soil at the jobsite as construction proceeds. If at any time a test indicates that operations are not producing a soil condition specified by the design tests, take immediate action to remedy the situation.

A soil's stress-deformation characteristics are directly related to the soil's moisture content and density, allowing specifications to be set for a given soil as construction proceeds. Densities obtained are compared with minimum density requirements established for the particular job. Water contents are compared with the OMC previously established to see that compaction is taking place within the desired range or to permit its adjustment.

An undisturbed sample of known or measurable dimensions provides information for computing the soil's density and moisture content. If the soil is not in proper condition during construction to remove an undisturbed sample, the density may be determined by measuring the volume of the hole after the sample is removed. The procedure consists of filling the hole with a measured quantity of a known density material (such as sand, oil, or water) and computing the volume of soil removed. The soil's moisture content and density are then determined.

The method for in-place density depends on the type of soil encountered and the equipment available. On moist, cohesive, fine-grained soils, undisturbed samples taken by samplers may be sufficient. Coarse-grained or cohesionless soils make it difficult to obtain an undisturbed sample. In these soils, density determination may require the displacement method. Sand displacement may be used on any type of base course or subgrade material. Oil displacement cannot be used on highly pervious soils, crushed stone, or slag base courses. If the pavement to be used is asphaltic concrete, the residual oil and spillage will tend to soften the asphalt. Displacing water requires the use of a balloon to contain the water and can be used on any type of soil.

If the density determined by the methods described in the following paragraphs is equal to or greater than that required, compaction may be judged to be satisfactory and the placing of another lift may proceed. If the density is lower than that required, additional rolling may be necessary or the moisture content may have to be adjusted. If these methods fail, the weight of the roller may have to be increased, the thickness of lift reduced, or other methods used to obtain adequate compaction. The possibility that the soil being compacted in the field is not the same as the one tested in the laboratory should never be overlooked. Under normal field conditions (the work is proceeding smoothly and uniform soils are being compacted), the number of density and moisture checks required should be limited after the initial period of compacting. If adequate densities are being obtained and the proper moisture content is being maintained, inspections may be performed to determine and verify the number of passes and the combination of rollers to achieve the desired result with minimum effort. Where conditions are more variable, density and moisture checks may be needed more often for a fill of even moderate length. The exact number of checks needed should be determined by the engineer in charge of the job.

SAND-CONE OR SAND-DISPLACEMENT METHOD (ASTM D 1556-90)

The sand-cone or sand-displacement method may be used in either fine- or coarse-grained materials. Calibrated sand is used to determine the volume of the hole from which a sample has been taken.

The sand-cone or sand-displacement test consists of digging out a sample of the material to be tested, determining the volume of the hole, and determining the dry weight of the sample. There are three requirements that must be met for this test.

The volume of the sample should be as close to the same volume at which the sand was calibrated; however, the sample's maximum particle size will determine the volume of sample to be tested. Sample requirements are as follows:

- Material with a maximum aggregate size of 1/2 inch requires a minimum test-hole volume of 0.05 cubic foot.
- Material with a maximum aggregate size of 1 inch requires a minimum test-hole volume of 0.075 cubic foot.
- Material with a maximum aggregate size of 2 inches requires a minimum test-hole volume of 0.10 cubic foot.

A double-cone cylinder must be used. This permits calibrating the sand for each test performed. The sand must be clean, dry, and free-flowing with a constant moisture content during the test. The sand should pass the No. 10 sieve and should have less than 3 percent passing the No. 60 sieve. The ideal solution to ensure that the gradation requirements are met is to obtain Ottawa sand, which generally ranges from the No. 20 to No. 40 sieve sizes.

PURPOSE

Perform this test to determine the in-place density of a soil to within ± 2 pcf.

EQUIPMENT

Use the following items to perform this test in a field environment (see *Figure 2-62*):

- A template with a 6-inch hole.
- A 6-inch soil-density tester.
- A CBR mold.
- A 2 1/2-inch spacer disk.
- Filter paper.
- A knife.
- A hammer.
- Nails, twentypenny (20d).
- A steel straightedge.
- A varnish brush.
- A balance scale sensitive to 1.0 gram with a 20-kilogram capacity.
- A balance scale sensitive to 0.01 gram with a 500-gram capacity.
- A ruler.
- A speedy moisture test set.

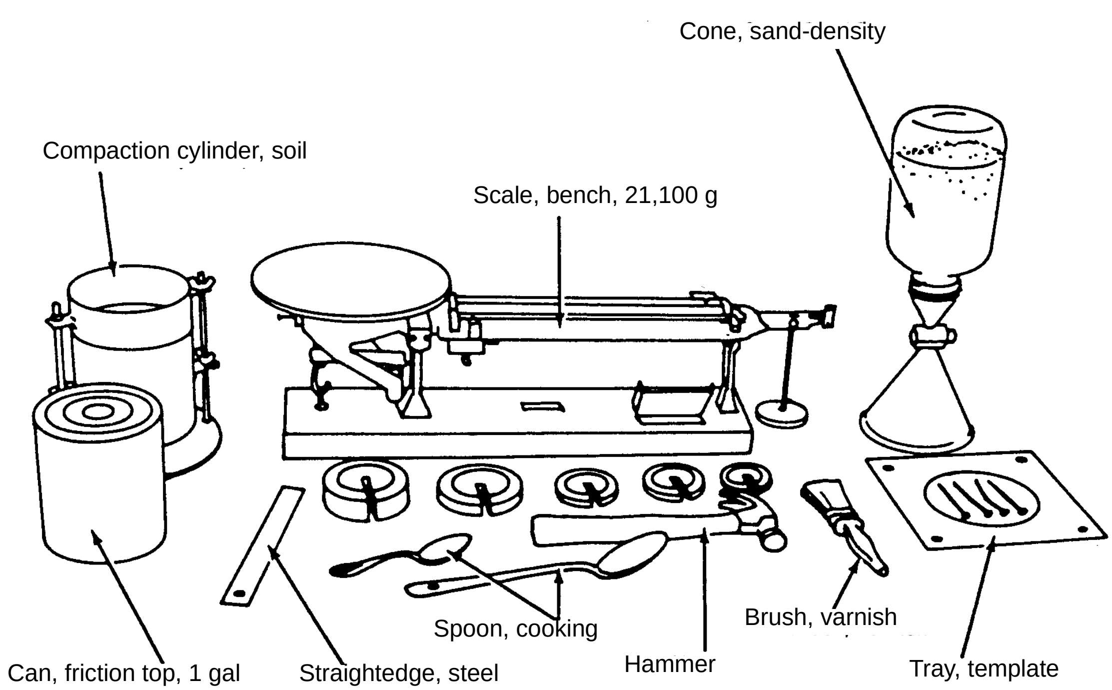


Figure 2-62. Sand-displacement-method apparatus

- A laboratory oven.
- Heat-resistant gloves.
- A spoon.
- A chisel.
- Friction-top cans.
- Sand, well-rounded, passing the No. 10 sieve with less than 3 percent passing the No. 60 sieve.
- DD Form 1215.
- Paper.
- A pencil.
- A calculator.
- A grease pencil.
- Moisture-determination tares.

STEPS

Perform the following steps for the sand-cone or sand-displacement method:

Step 1. Determine the sand's density.

a. Weigh the mold, baseplate, spacer disk, and filter paper. Record this weight (in grams) on line 8 of DD Form 1215 (see *Figure 2-63*).

b. Attach the collar to the mold and place the filled sand-cone apparatus, with the valve closed, on top of the mold.

c. Open the valve and allow sand to fall at its own rate into the mold. Do not jar the apparatus while the sand is falling.

d. Close the valve when the sand stops running into the mold and the collar.

e. Remove the sand cone and collar carefully from the mold.

f. Use a straightedge to strike off the excess sand remaining in the top of the mold.

g. Brush off any sand adhering to the outside of the mold.

h. Weigh the mold full of sand (in grams) and record it on line 7 on the form.

i. Determine the weight (in grams) of the material by subtracting line 8 from line 7 and record the weight on line 9 of the form.

j. Enter the known volume of the mold (in cubic feet) on line 10.

k. Determine the unit weight of the material. Convert the weight of the materials (line 9) from grams to pounds, divide this quotient by the known volume (line 10), and record the weight on line 11.

$$\text{unit weight of material (line 11)} = \frac{\left(\dfrac{\text{weight of sand}}{453.6}\right)}{\text{volume of mold}}$$

l. Repeat steps a through k at least two more times. The unit weight of sand used in the calculations shall be the average of at least three determinations. Record the average unit weight of material on line 12. The maximum variation between any one determination and the average should not exceed 1 percent.

Step 2. Prepare the site for sand-cone testing.

a. Clear the overburden and seat the template tray flush on the surface. Fasten it in place with nails.

b. Seal the spaces on the inside edge under the template using soil from the preparation site.

Step 3. Determine the surface calibration.

a. Weigh the sand-cone apparatus filled with sand. Record the weight (in grams) on line 13 of the form.

b. Turn the sand-cone apparatus over with the valve closed and place it on the template.

IN-PLACE DENSITY DETERMINATION - SAND-CONE METHOD

1. PROJECT ENGINEER CENTER EXPANSION		2. DATE 21 DEC 99
3. JOB NUMBER 16-P-T	4. TEST SITE NORTH CORNER	5. SAMPLE NUMBER 5-C-1
6. ADDITIONAL SPECIFICATIONS SELECT MATERIAL 90-95% MDD=123.2 OMC=8.8%		

CONVERSION FACTORS: 1 in = 2.54 cm 1 cu ft = 1728 cu in Unit weight of water: 1 cc = 1 gram
1 lb = 453.6 gm 1 cu ft = 62.4 lb

CALIBRATION OF SAND (STANDARD MATERIAL)

APPARATUS OR TARE NUMBER		UNITS	1A	1B	1C			
7. WEIGHT OF APPARATUS OR TARE FILLED		Grams	7549	7519	7533			
8. WEIGHT OF APPARATUS OR TARE EMPTY		Grams	4316	4316	4316			
9. WEIGHT OF MATERIAL	(7 - 8)	Grams	3233	3203	3217			
10. VOLUME OF APPARATUS OR TARE		Cu ft	0.0750	0.0750	0.0750			
11. UNIT WEIGHT OF MATERIAL	((9/453.6)/10)*	Pcf	95.0	94.2	94.6			
12. AVERAGE UNIT WEIGHT OF MATERIAL		Pcf	94.58					

CALIBRATION OF APPARATUS			TEMPLATE NUMBER 14	CONE NUMBER 23
13. INITIAL WEIGHT OF APPARATUS + SAND		Grams	6402	5569
14. FINAL WEIGHT OF APPARATUS + SAND		Grams	5846	4986
15. WEIGHT OF SAND IN TEMPLATE AND/OR CONE	(13 - 14)	Grams	556	583

VOLUME OF THE HOLE

16. INITIAL WEIGHT OF APPARATUS + SAND		Grams	5846	4986
17. FINAL WEIGHT OF APPARATUS + SAND		Grams	1006	643
18. WEIGHT OF SAND RELEASED	(16 - 17)	Grams	4840	4343
19. WEIGHT OF SAND IN THE HOLE	(18 - 15)	Grams	4284	3760
20. VOLUME OF THE HOLE	((19/453.6)/12)*	Cu ft	0.0999	0.0876

WATER-CONTENT DETERMINATION

SAMPLE

TARE NUMBER						
21. WEIGHT OF WET SOIL AND TARE		Grams				
22. WEIGHT OF DRY SOIL AND TARE		Grams				
23. WEIGHT OF WATER	(21 - 22)	Grams				
24. WEIGHT OF TARE		Grams				
25. WEIGHT OF DRY SOIL	(22 - 24)	Grams				
26. WATER CONTENT	((23/25) x 100)	Percent	7.7%	7.9%	8.4%	8.2%
27. AVERAGE WATER CONTENT		Percent	7.8%		8.3%	

UNIT-WEIGHT DETERMINATION

TARE NUMBER			1	2
28. WEIGHT OF WET SOIL AND TARE		Grams	5210	5392
29. WEIGHT OF TARE		Grams	388	386
30. WEIGHT OF WET SOIL	(28 - 29)	Grams	4822	5006
31. WET UNIT WEIGHT	((30/453.6)/20)*	Pcf	106.4	126.0
32. DRY UNIT WEIGHT	(31 x [100/(100+27)])	Pcf	98.7	116.3

33. REMARKS * This formula contains the conversion from grams to pounds. Omit the conversion factor if the unit weight used is not grams.

WATER CONTENT DETERMINED BY CALCIUM CARBIDE METHOD (SPEEDY)

34. TECHNICIAN (Signature)	35. COMPUTED BY (Signature)	36. CHECKED BY (Signature)
SPC Carr	SPC Carr	SSG Dobbs WD

DD FORM 1215, DEC 1999 PREVIOUS EDITION IS OBSOLETE.

Figure 2-63. Sample DD form 1215

c. Open the valve and allow the sand to fall at its own rate. Do not jar the apparatus while the sand is falling. Close the valve when the sand stops running.

d. Remove the sand-cone apparatus from the template and weigh it. Record this weight (in grams) on line 14 of the form.

e. Determine the weight of the sand in the cone by subtracting line 14 from line 13. Record the difference on line 15 of the form.

Step 4. Recover as much sand as possible from the template and brush the remaining sand lightly from the hole, being careful not to disturb the soil surface.

Step 5. Dig the sample.

a. Predetermine the weight of a friction-top can. Record this weight on line 29 of the form.

b. Dig a hole through the center of the template. The hole should be 6 inches deep or to the bottom of the lift and about the same diameter as the hole in the template. The sides should be as smooth as possible.

c. Place all soil particles from the hole into the preweighed can, keeping the lid on the can as much as possible to prevent excessive moisture loss.

d. Weigh the wet soil and can. Record the weight on line 28 of the form.

Step 6. Determine the volume of the hole.

a. Refill the jar if it appears there is not enough sand to fill the hole and record the weight of the jar on line 16; otherwise, transfer the weight from line 14 to line 16.

b. Turn the sand-cone apparatus over with the valve closed and place it on the template.

c. Open the valve and allow the sand to fall at its own rate into the prepared hole. Do not jar the apparatus while the sand is falling.

NOTE: If additional sand is needed due to requirements for hole volume, ensure that these jars with sand have been properly weighed and will be on hand during the testing procedures. If used, ensure that the weight of the additional jar plus sand is included on line 16 and that line 17 also includes the final weight of the additional jar.

d. Close the valve when the sand stops running and remove the sand-cone apparatus. Weigh it and record this weight on line 17 of the form.

e. Determine the weight of the material released by subtracting line 17 from line 16. Record this difference on line 18 of the form.

f. Determine the weight of the material in the hole by subtracting line 15 from line 18. Record this difference on line 19 of the form.

g. Recover as much sand as possible from the hole.

h. Compute the volume of the hole. Convert the weight of the material in the hole (line 19) from grams to pounds, divide this quotient by the average unit weight of material (line 12), and record the weight on line 20 of the form using the following formula:

$$\text{volume of the hole (line 20)} = \frac{\left(\frac{\text{weight of sand in hole}}{453.6}\right)}{\text{average unit weight of sand}}$$

Step 7. Determine the average water content of the soil removed from the hole (step 5) using the oven-laboratory method or speedy moisture tester, and record it on line 27 of the form. If using the speedy moisture tester, enter the results on line 27; otherwise, make appropriate entries on lines 21 through 27 using at least two moisture-determination tares according to Section III of Chapter 2.

Step 8. Determine the unit weight (density).

a. Compute the weight of the wet soil by subtracting the weight of the tare (line 29) from the weight of the wet soil and the tare (line 28). Record the difference on line 30 of the form.

b. Compute the wet unit weight (density). Convert the weight of the wet soil (line 30) from grams to pounds, divide this quotient by the volume of the hole (line 20) and record it on line 31 of the form using the following formula:

$$\text{wet density (line 31)} = \frac{\left(\frac{\text{weight of wet soil}}{453.6}\right)}{\text{volume of hole}}$$

c. Compute the dry unit weight (density), and record it on line 32 of the form using the following formula:

$$\text{dry density (line 32)} = \text{wet unit weight} \times \frac{100}{100 + \text{average water content}}$$

NUCLEAR MOISTURE-AND-DENSITY TESTER

Use this method to determine the soil's dry density and moisture content. Individual models of equipment vary in the specific procedures. Radiation protection programs vary as well from service to service. It is for this reason that the procedures are not discussed here. The procedures for this test method must be as prescribed by the individual equipment's manufacturer's manual, the requirements prescribed by the service holding the piece of equipment, and the Nuclear Regulatory Commission licensing agreement with that service.

The testers contain sources of radioactive material, typically cesium and a combination of americium mixed with beryllium powder. The cesium emits gamma radiation that the detector in the tester can count when it is passed through the soil. This count can be translated into density. The americium/ beryllium emits neutrons following collisions with hydrogen which are moderated and detected by the tester. The moisture content can be determined by counting the hydrogen atoms in the soil.

WATER-DISPLACEMENT METHOD

Measure the volume of the hole from which a soil-density sample is taken by placing a rubber balloon in the hole and observing the volume of water required to fill the balloon. A water-balloon device is a watertight container with a float attached to a calibrated scale, graduated directly in cubic feet. A balloon is attached to the bottom of the device to make the test. Fill the cylinder in the device with water and place the apparatus over the area where the sample is to be removed. Allow the balloon to fill with water and take an initial reading. Remove the sample from the ground and replace the device over the hole in the original position. Allow the water to flow by gravity into the balloon in the hole. Blow through the hose attached to the device to increase the air pressure on the water surface and force the water-filled balloon in the hole to conform to all the contours of the hole. Observe the scale attached to the float for a reading of the water volume left in the device. Subtract this value from the original reading. The result is the volume of the hole, in cubic feet.

SECTION IX. CBR TESTS

The CBR test is a relatively simple test used to obtain an indication of the strength of a subgrade soil, subbase, and base-course material for use in road and airfield pavements. The test is used primarily to determine empirically required thicknesses of flexible pavements for highways and airfield pavements. The test was developed by the California Division of Highways in 1929 and adopted by the Corps of Engineers for use in the design of flexible pavements for airfields in locations where frost action is not the controlling factor.

NOTE: The current employed standard for CBR testing is ASTM D 1883-94.

The test procedure determines the CBR of pavement subgrade, subbase, and base-course materials from laboratory-compacted specimens that can be used in the design of a specific airfield. It consists of two steps—

- Preparing the soil test specimens.
- Performing the penetration test on the prepared soil samples.

Although one standardized procedure has been established for the penetration portion of the test, it is not possible to establish one procedure for the preparation of test specimens since soil conditions and construction methods vary widely. The soil test specimens are prepared to duplicate the soil conditions existing (or expected to occur later) in the field.

The method of preparing the test specimens and the number of specimens depend on the type of airfield, the soils encountered at the site, and other factors. Test the soil sample in the laboratory at a density comparable to the density required on the construction site. There are situations where moisture conditions are favorable and the subgrade will not accumulate moisture approaching a saturated condition. Test samples at a moisture content approximating the actual moisture conditions expected during the time the road or airfield is used. In all other conditions, samples are laboratory tested in a saturated condition.

Although penetration tests are most frequently performed on laboratory specimens, they may also be performed on undisturbed soil samples or in the field on the soil in place.

CBR OF LABORATORY-COMPACTED SOILS (ASTM D 1883-94)

The basic operations for conducting the CBR test are the same regardless of variations in soil conditions and types of construction. The test essentially measures the soil's shearing resistance under controlled moisture and density conditions. The CBR for soil is the ratio obtained by dividing the penetration stress required to cause a 3-inch two-area piston to penetrate 0.10 inch into the soil by a standard penetration stress of 1,000 pounds per square inch (psi). This standard penetration stress is roughly what is required to cause the same piston to penetrate 0.10 inch into a mass of crushed rock (limestone). The CBR value may be thought of as the strength of the soil relative to that of crushed rock.

Minor variations in the CBR test will cause wide variations in the results. For this reason, step-by-step procedures are detailed. Difficulties may still arise. Material with gravel or stones does not yield entirely satisfactory results. A number of tests must be conducted to establish a reasonable average value.

The CBR values range from as low as 3 to as high as 80, depending on the type of soils. The fine-grained soils vary from 3 for organic clays to 15 for micaceous or diatomaceous silts and sands. The sand-silt-clay coarse-grained combinations range from 10 for the clayey mixtures to 40 for the gravelly and silty sands. Gravelly soils range from 20 for the clayey group to 80 for the well-graded gravels and gravel-sand mixtures. *Table B-3, pages B-16 and B-17*, lists the typical range for soils classified under the USCS.

PURPOSE

Perform this test is to determine the CBR of a soil to ± 3 percent and determine the best moisture-content range to ± 4.

EQUIPMENT

Use the following items in a laboratory environment to perform this test (see *Figure 2-64, page 2-126*):

- A 225-pound soil sample with known classification, PI, and OMC.
- A CBR laboratory test set consisting of—
  - — 15 CBR molds.
  - — Surcharge weights.
  - — A penetration piston.
  - — Two dial gauges reading to 0.001 inch.
- Pails.
- Plastic bags.

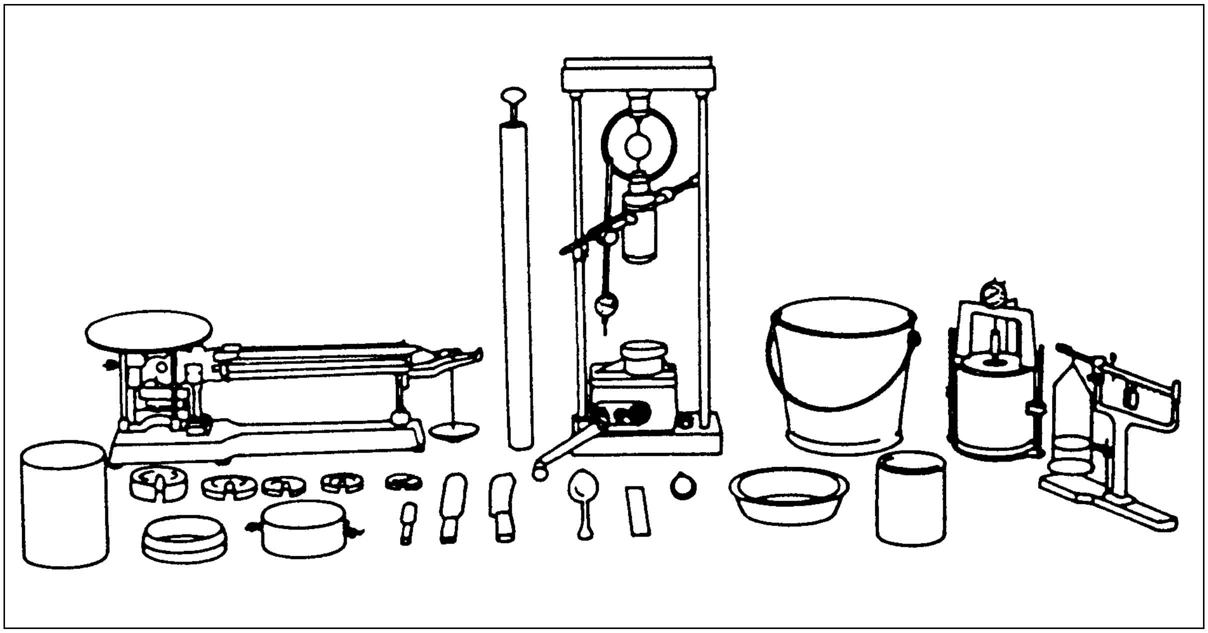


Figure 2-64. Laboratory CBR test-set apparatus

- Shipping tags.
- A compaction tamper.
- Filter paper.
- A recorder.
- Moisture-determination tares.
- Balance scales sensitive to 0.01 gram and 0.1 gram.
- A steel straightedge.
- A mixing pan.
- A spoon.
- A spatula.
- A graduated cylinder (100-milliliter).
- A laboratory oven.
- Heat-resistant gloves. Asbestos gloves should not be used for any materials-testing procedures. If your unit has asbestos gloves, turn them in through your supply system for proper disposal. Order heat-resistant gloves to replace them.
- A pencil.
- Paper.
- A grease pencil.
- A calculator.

- DD Forms 1210, 1211, and 1212.
- A 3/4-inch sieve.
- A No. 4 sieve.
- Pudding pans.
- A stopwatch.
- Plans and specifications.

STEPS

Perform the following steps for the CBR test:

Step 1. Determine the moisture-content range of investigation (± 4 percent of OMC). If the OMC has not yet been definitively established for this soil type, perform the laboratory compaction test as described in Section VIII to obtain the OMC.

Step 2. Prepare the soil sample. The size of the total sample will be about 225 pounds, which should provide enough material for the required 6,800 grams for each of the 15 molds.

a. Dry the soil sample until it can be easily crumbled under a trowel. Drying may be done by air-drying or by using a drying apparatus, provided the temperature of the sample does not exceed 60°C.

b. Break up the sample thoroughly, but not in such a manner as to reduce the size of the individual particles.

c. Sieve the sample over a 3/4-inch sieve. If all material passes the 3/4-inch sieve, use the entire gradation without modification. If there is material retained on the 3/4-inch sieve, remove it and replace it with an equal amount (by weight) of material passing the 3/4-inch sieve but retained on the No. 4 sieve by separation from portions of the sample not otherwise used for testing. (The CBR test is not conducted on any material retained on the 3/4-inch sieve.) This amount will be recorded later on DD Form 1212 (see *Figure 2-65, page 2-128 and 2-129*). .

d. Divide the entire sample into 15 smaller samples of about 6,800 grams each and place them into separate plastic bags. Seal the bags to maintain the current (or floor) moisture content.

e. Determine the moisture content from a 20-gram sample of the remaining material. Record this on a sheet of paper as the moisture content of the floor sample.

Step 3. Prepare and label a 6-inch compaction mold for each water content to be used (-4, -2, OMC, +2, and +4) at the compactive effort of 56 blows per layer as described in step 5 of Section VIII. In addition to the 5 molds required for the compactive effort of 56 blows per layer, prepare a mold for each water content using the other required compactive efforts of 10 and 25 blows per layer. Prepare a minimum of 15 molds. Prepare a DD Form 1212 for each mold and record the weight of the mold with the baseplate (to the nearest gram) on the form before continuing.

Step 4. Prepare the samples at the adjusted water contents.

LABORATORY CALIFORNIA BEARING RATIO (CBR) TEST DATA

1. PROJECT ENGINEER CENTER EXPANSION				2. DATE 30 Aug 99	
3. EXCAVATION NUMBER 5-C		4. SAMPLE NUMBER 5-C-18		5. CONDITION [X] DISTURBED [ ] UNDISTURBED	
COMPACTION DATA	6. MOLD NUMBER 4-3 (omc)		7. NUMBER OF LAYERS 5	8. BLOWS PER LAYER 56	
	9. PERCENT OF 3/4 in MATERIAL REPLACED 5%		10. WEIGHT OF HAMMER (lb) 10 lb	11. HEIGHT OF DROP (in) 18 in	
PROVING-RING DATA	12. NUMBER 891007	13. CONSTANT 97,000 (9.70/0.0001)	14. CAPACITY 10,000 lb	15. SURCHARGE WEIGHT	16. SOAKING (lb) 10 lb / 17. PENETRATING (lb) 10 lb

18. SWELL DATA (Initial / Final)	a. DATE	b. TIME	c. ELAPSED TIME	d. DIAL READING	e. INITIAL HEIGHT	f. SWELL PERCENT (d/e x 100)
Initial	30 Aug 99	0930	0.00 (hr)	0.0	4.6 in	
Final	3 Sep 99	0930	96.00 (hr)	0.025	4.6 in	0.5%

19. PENETRATION DATA

a. PENETRATION (in)	b. STANDARD UNIT LOAD (psi)	c. PROVING RING DIAL READING (in)	d. CORRECTED RING DIAL READING (in)	e. TOTAL LOAD (lb)	f. UNIT LOAD (psi) (e/3.00)	g. CORRECTED UNIT LOAD (psi)	h. CBR (%) (g/b x 100)
0.025	250	0.0013	NO	126.10	42.03		
0.050	500	0.0015	CORRECTION	145.50	48.50		
0.075	750	0.0032	REQUIRED	310.40	103.47		
0.100	1000	0.0038		368.60	122.87	195.6	19.5%
0.125	1125	0.0054	STARTED	523.80	174.60		
0.150	1250	0.0063	WITH	611.10	203.70		
0.175	1375	0.0074	ZERO	717.80	239.27		
0.200	1500	0.0079		766.30	255.43	290.0	19.3%
0.300	1900	0.0100		970.00	323.33		
0.400	2300	0.0119		1154.30	384.77		
0.500	2600	0.0134		1299.80	433.27		

SAMPLE

WATER CONTENT AND UNIT WEIGHT DATA

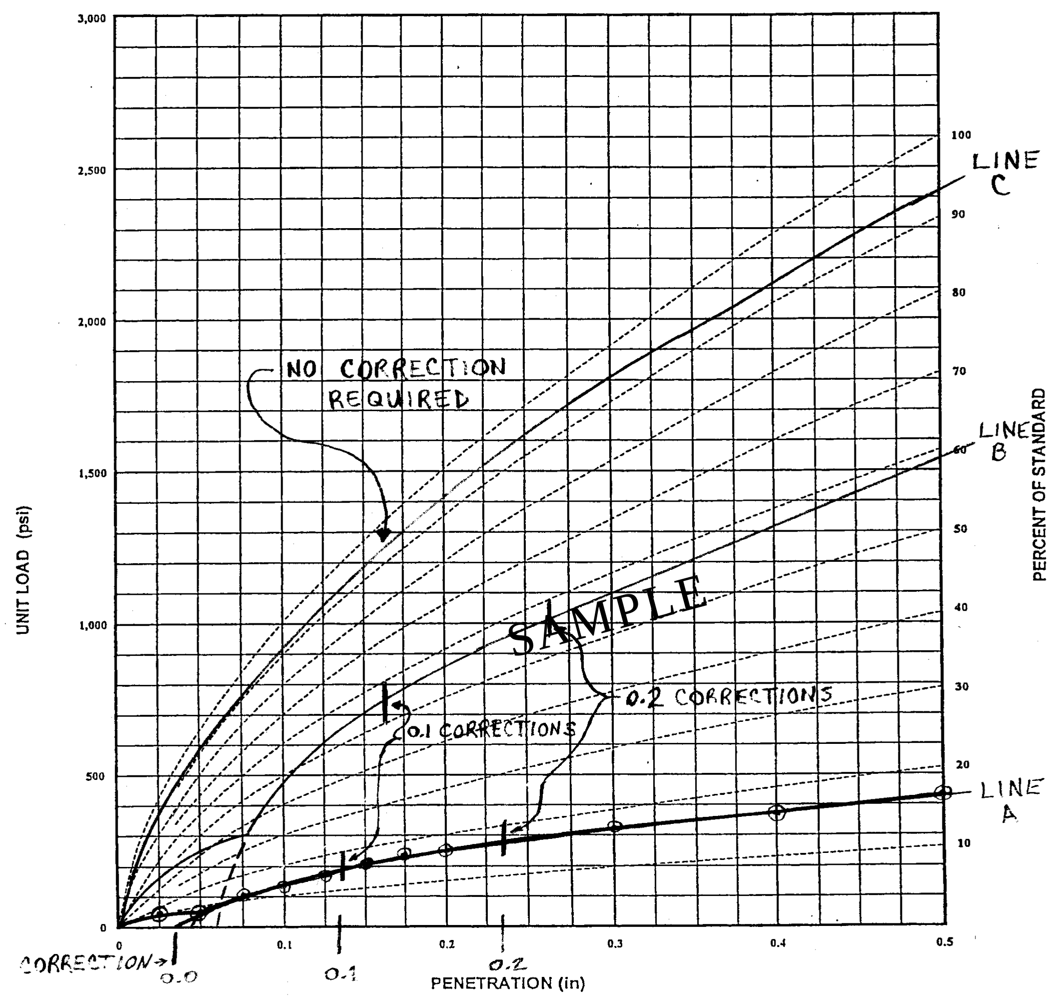
SAMPLES TAKEN	UNITS	BEFORE SOAKING		AFTER SOAKING	
20. WEIGHT OF MOLD + WET SOIL	Grams	11793.0		11878.0	
21. WEIGHT OF MOLD	Grams	7243.0		7243.0	
22. WEIGHT OF WET SOIL (20 - 21)	Grams	4550.0		4635.0	
23. WET UNIT WEIGHT, γ wet ([22/453.6]/0.075)	Pcf	133.7		136.2	
24. TARE NUMBER / SAMPLE TAKEN		BEFORE COMPACTION	AFTER COMPACTION	TOP 1 INCH	FROM MOLD
a. WEIGHT OF TARE + WET SOIL	Grams	24.32	25.54	552.37	523.16
b. WEIGHT OF TARE + DRY SOIL	Grams	23.15	24.41	478.83	454.97
c. WEIGHT OF WATER, W_w (a - b)	Grams	1.17	1.13	73.54	68.19
d. WEIGHT OF TARE	Grams	10.73	11.89	11.36	10.92
e. WEIGHT OF DRY SOIL, W_s (b - d)	Grams	12.42	12.52	467.47	444.05
f. WATER CONTENT, $w = \frac{W_w}{W_s} \times 100$ (c/e x 100)	Percent	9.4	9.0	15.7	15.4
25. AVERAGE WATER CONTENT	Percent	9.2%		15.5%	
26. DRY UNIT WEIGHT, $\gamma d = \frac{\gamma\ wet}{1 + (w/100)}$	Pcf	122.5		117.9	

DD Form 1212, DEC 1999 EDITION OF AUG 57 IS OBSOLETE.

Figure 2-65. Sample DD Form 1212

CBR TEST GRAPH

(Plot test curve below to obtain corrected unit load)



27. REMARKS

- CURVE A (ABOVE) IS PLOTTED FROM PAGE 1 OF DD FORM 1212, FIGURE 2-65.
- CURVE C DOES NOT REQUIRE A CORRECTION.
- CURVES A AND B (SHOWN ABOVE) ILLUSTRATE CURVES WITH CORRECTIONS MADE.

28. TECHNICIAN *(Signature)*	29. COMPUTED BY *(Signature)*	30. CHECKED BY *(Signature)*
PFC Bagonha	PFC Bagonha	SSG Dobbs

DD Form 1212 (BACK), DEC 1999

Figure 2-65. Sample DD Form 1212 (continued)

a. Determine the amount of water to add to each sample using the following procedure:

$$\textit{water to add (in milliliters)} = \textit{weight of sample (in grams)} \times (\textit{desired percent} - \textit{floor moisture content})$$

For example, to determine the amount of water to add to a sample to obtain the determined OMC of 8 percent,

$$6,800 \times (0.08 - 0.02) = 6,800 \times 0.06 = 408.0 \textit{ milliliters}$$

where—

weight of sample = 6,800 grams

OMC = 8 percent (0.08)

floor moisture content = 2 percent (0.02)

To determine the water to add for the remaining samples for the required moisture-content range, perform the same calculation. The example below illustrates this calculation for the remaining samples, taking into consideration that not all of the sample weights will be exactly the same (6,800 grams):

$$\textit{6.0\% moisture for a sample at 6,800 grams: } 6,800 \times (0.06 - 0.02) = \textit{272.2 milliliters}$$

$$\textit{4.0\% moisture for a sample at 6,815 grams: } 6,815 \times (0.04 - 0.02) = \textit{136.3 milliliters}$$

$$\textit{10.0\% moisture for a sample at 6,822 grams: } 6,822 \times (0.10 - 0.02) = \textit{545.8 milliliters}$$

$$\textit{12.0\% moisture for a sample at 6,810 grams: } 6,810 \times (0.12 - 0.02) = \textit{681.0 milliliters}$$

b. Add the water figured from the formulas for each of the 5 desired moisture contents (-4, -2, OMC, +2, and +4), and mix thoroughly to ensure an even distribution of water throughout the sample.

c. Place each sample in an airtight container, and allow to stand for the minimum period of time indicated.

- For GW, GP, SW, and SP soil types, there is no minimum standing period of time.
- For GM and SM soil types, a minimum of 3 hours standing time is required.
- For all other soil types, a minimum of 16 hours standing time is required.

Step 5. Mark and weigh 2 moisture-determination tares for each mold prepared. Record each on DD Form 1212 as the weight of tare.

Step 6. Remove a small quantity of material (20 grams) from each sample and place it in one of the marked tares upon completion of the standing time. Weigh it in preparation for moisture determination and record the results on the form.

Step 7. Place sufficient soil in the mold (about 1 1/2 to 2 inches) to obtain a 1-inch compacted layer. After compaction of all 5 layers, each layer should be about equal in thickness. The fifth compacted layer will slightly extend into the collar but will not exceed 1/4-inch above the top of the mold.

Step 8. Apply compactive effort.

a. Hold the 10-pound compaction tamper within 5 degrees of vertical, placing its face on top of the soil.

b. Raise the handle until it reaches the top (18 inches) and release it, allowing the weight to fall freely onto the soil.

c. Change the position of the guide and tamper and repeat the process until the soil layer has received the prescribed number of blows for the compactive effort required. Apply the blows at a uniform rate of about 25 blows per minute. The height of fall of the tamper must be controlled carefully and the blows distributed evenly over the specimen's surface.

Step 9. Trim the compacted layer. After compacting each layer (except the fifth layer), use a knife to trim any soil adjacent to the mold walls that has not been compacted or that extends above the compacted surface. Include the trimmed soil with the additional soil for the next layer.

Step 10. Repeat steps 7, 8, and 9 until five layers have been compacted in the mold. Each compacted layer should be about equal in thickness (just under 1 inch). Adjust each layer accordingly to ensure that the fifth compacted layer will slightly extend into the collar, but will not exceed 1/4 inch above the top of the mold.

Step 11. Remove the collar from the mold.

a. Cut around the inside edge of the collar to prevent shearing the compacted soil when removing the collar.

b. Trim and smooth the compacted soil flush with the top of the mold. Use a sawing motion with the straightedge to trim the excess soil. Start at the center of the mold and work outward, first to one side and then to the other. Fill any holes with unused or trimmed soil from the specimen, press in with the fingers, and again scrape the surface with the straightedge.

Step 12. Take another small sample from the remaining material after compacting each mold and place it in the other moisture-determination tare and weigh it in preparation for moisture determination. Record the results on the form.

Step 13. Place a disk of coarse filter paper on top of the compacted specimen. Release the mold from the baseplate and while slightly lifting, slide the mold with the spacer disk off the baseplate and onto the edge of the table or countertop. Invert the baseplate and place it on top of the mold against the filter paper and reattach. Raise the mold and baseplate to allow the spacer disk to slide out. Invert the mold with baseplate and place it flat on the table or countertop.

Step 14. Weigh and record the data. Weigh the complete mold with the baseplate and compacted specimen (without the spacer disk) to the nearest gram. Record as the weight of the mold and wet soil (block 12). Do not include the collar.

Step 15. Repeat steps 7 through 14 for each of the compactive efforts required (10, 25, and 56 blows per layer). Compact a minimum of 5 molds for each compactive effort.

Step 16. Soak the samples and measure the swell (see *Figure 2-66*).

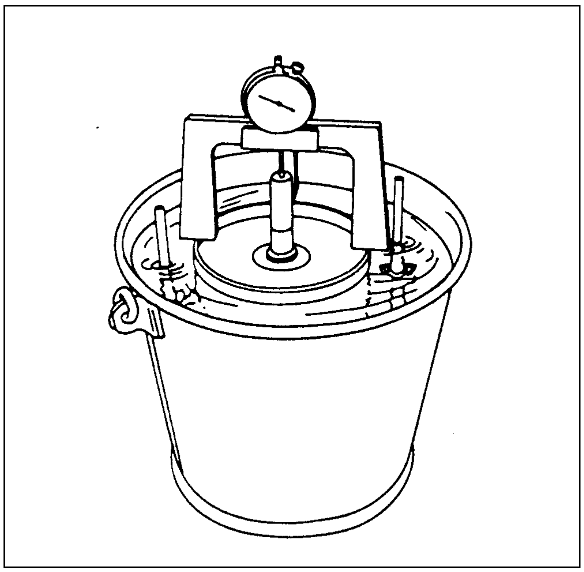


Figure 2-66. Soaking the CBR sample

a. Place surcharge weights on the perforated plate and adjustable stem assembly and carefully lower into the mold onto the filter paper and compacted soil specimen. Ensure that the surcharge applied is equal to the weight of the base material and pavement within 2.27 kilograms, but never use a total weight of less than 4.54 kilograms. If no pavement weight is specified, use 4.54 kilograms. Record the surcharge weight on the form.

b. Immerse the mold in water.

c. Calibrate the adjustable stem so that the tripodal dial reads 100 and can then travel in either direction. Obtain the initial dial reading and record it on the form.

d. Soak the sample for 96 hours.

e. Assemble the penetration apparatus (see *Figure 2-67*).

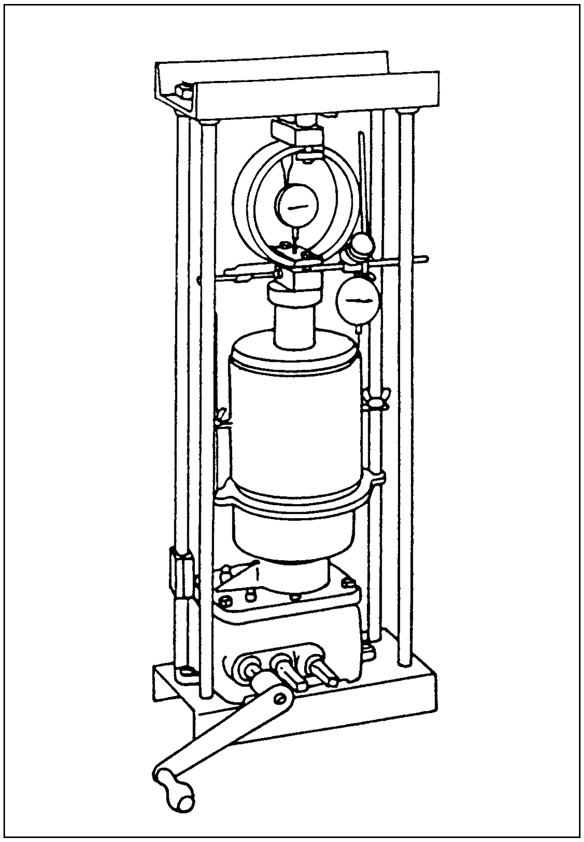


Figure 2-67. Assembled CBR-test penetration apparatus

(1) Attach the jack to the frame.

(2) Attach the proving ring and dial indicator to the frame. Record the proving-ring data on the form.

f. Take the dial reading at 96 hours and record on the the form.

g. Determine the amount of swell, in inches, by subtracting the initial dial reading from the final dial reading. Record the data on the form.

h. Determine the percent of swell and record it on the form using the following formula:

$$\frac{\text{swell in inches (at 96 hours)}}{\text{original sample height}} \times 100$$

Step 17. Drain the CBR mold.

a. Remove the immersed mold from the water and remove the free water. Allow the specimen to drain downward for 15 minutes. Do not disturb the specimen's surface while removing the water. It may be necessary to tilt the specimen to remove surface water.

b. Remove the surcharge weights, the perforated plate, and the filter paper from the mold. Do not disturb the specimen's surface while removing these items.

c. Determine the mass and record it on the form as the weight of the soaked sample.

d. Return a 5-pound surcharge weight to the specimen.

Step 18. Perform the CBR penetration.

a. Prepare the components.

(1) Place the mold on the jack.

(2) Attach and adjust the piston to the jack, then zero the dial indicator.

(3) Lower the penetration piston until it is in contact with the sample with sufficient pressure to cause the load dial to register a load of 1 pound.

(4) Replace the remainder of the surcharge weights required for the mold.

(5) Attach the adjustable arm with the dial indicator to the jack assembly, adjusting the position until the dial-indicator plunger is resting on the mold's projecting rim.

(6) Turn both dial indicators to 0.

b. Apply the load.

(1) Crank the jack to lower the piston at a rate of 0.05 inch per minute.

(2) Read the proving-ring dial indicator when the piston has reached penetration depths of 0.025, 0.050, 0.075, 0.100, 0.125, 0.150, 0.175, 0.200, 0.300, 0.400, and 0.500 inch. Take the first eight readings at 30-second intervals and the remaining three at 2-minute intervals.

(3) Record the proving-ring dial readings on the form.

c. Determine the average moisture of the soaked samples.

(1) Remove the top 1 inch of soil from the mold. For fine-grained soils, place at least 100 grams of soil in a moisture-determination tare. For granular soils, place at least 500 grams of soil in a moisture determination tare.

(2) Weigh the tare and record on the form.

(3) Remove an additional sample from the remaining contents of the mold for moisture determination. For fine-grained soils, place at least 100 grams of soil in a moisture-determination tare. For granular soils, place at least 500 grams of soil in a moisture-determination tare.

(4) Weigh the tare and record on the form.

(5) Perform the moisture-content determination of the tares. Record the results and average on the form.

Step 19. Solve the computations for each reading, and record the results on the form.

a. Determine the total load, in pounds, by multiplying the proving-ring dial reading (block 19c) by the proving-ring constant (block 13). Enter this number in block 19e of the form. The corrected ring dial readings need not be determined as long as the dial indicators have been zeroed before penetration. If the dials were not adjusted to 0 before penetration, determine the corrected ring dial readings and enter them in block 19d. Calculate the total load from the corrected reading instead of the observed reading.

b. Determine the unit load (in psi) by dividing the total load by 3. Enter this number in block 19f of the form. The value of 3 is determined by the area of the penetrating piston in square inches.

c. Determine the corrected unit load (in psi) by plotting (on the reverse side of the form) the unit load (in psi) against the depth of penetration (in inches). If the curve has an initial concave upward shape between 0 and 0.1, then the zero point must be adjusted. This occasionally happens with some soil types under certain conditions and it is necessary to obtain true penetration loads. Adjust the zero point of the curve as indicated in the example in *Figure 2-65, page 2-128*. Once the zero-point correction has been made, the 0.100- and 0.200-inch points are moved to the right on the curve the same distance as the zero point. Obtain corrected unit-load values from the corrected graphs at 0.100- and 0.200-inch penetrations and enter in block 19g of the form. If no corrections were made, the numbers entered into block 19g will be the same as block 19f.

d. Calculate the CBR (in percent) for penetration at 0.100 and 0.200 inches using the following formula:

$$\frac{\textit{corrected unit load}}{\textit{standard unit load}} \times 100$$

Since the standard unit load for each penetration is given (block 19b of the form), perform the following computations for each penetration:

$$\textit{CBR for 0.100} = \frac{\textit{corrected unit load}}{1,000} \times 100$$

$$\textit{CBR for 0.200} = \frac{\textit{corrected unit load}}{1,500} \times 100$$

NOTE: The CBR value of the mold is computed at 0.100- and 0.200-inch penetrations. The bearing ratio normally reported is that of the 0.100-inch penetration. When the ratio at 0.200-inch penetration is greater, the test must be verified by another test. If the test is verified with similar results, use the bearing ratio at the 0.200-inch penetration.

Step 20. Complete DD Form 1212. Ensure that any other information concerning the soil sample is indicated in the remarks block.

UNDISTURBED SAMPLE TESTING

Tests on undisturbed samples are used when the base design calls for uncompacted soil, such as highly compressible clay that loses strength upon remolding, or when correlating field in-place tests to the design-moisture condition. For this latter condition, duplicate samples should be tested to determine the correction necessary for the in-place tests. The reduction that occurs from four days of soaking is applied as a correction to the field in-place test.

Care and patience are necessary to maintain the relatively undisturbed samples in this condition. If proper lateral support is not given on the sides of the samples, erroneous CBR values will result. In fine-grained materials, molds or metal jackets are satisfactory. With samples cut or trimmed from a pedestal, use a mixture of 10 percent resin and 90 percent paraffin to fill the annular space and offer support. For gravelly soils, the box method is desirable. Use wax paper or paraffin to cover the sample and prevent moisture loss while transporting it to the laboratory.

Perform soaking and penetration tests after removing the paper or paraffin from the end of the specimen and after leveling the surface (use a thin layer of sand, if necessary).

IN-PLACE FIELD CBR TESTING

To overcome some of the shortfalls associated with older in-place field CBR test methods, the Corps of Engineers Waterway Experimentation Station has developed the dual-mass dynamic cone penetrometer (DCP) (see *Figure 2-68*) for evaluating the load-carrying capability of military roads and airfields. The results from using the DCP are reported in terms of index values which can be converted to CBR values. Three correlations currently exist for this conversion, each dependent on the soil type being tested.

The procedures for testing with the DCP and the correlation of CBR values can be found in the user's manual for the equipment or in FM 5-430-00-2, Annex J.

PRESENTATION AND ANALYSIS OF CBR DATA

The CBR value, molding water content, and dry density for each specimen can be presented in several ways that facilitate analysis. The individual test programs used to present this data are relative to the type of soil encountered and are discussed in the following paragraphs.

TEST PROGRAM FOR NONSWELLING SOILS

The test program for nonswelling soils applies to the majority of soils used in construction. As *Table 2-14* indicates, soils that fall into this group might be used as compacted subgrade, select, or subbase materials depending on their strengths and location regarding the construction site. The compaction requirements can then be determined as listed in *Table 2-15, page 2-138*.

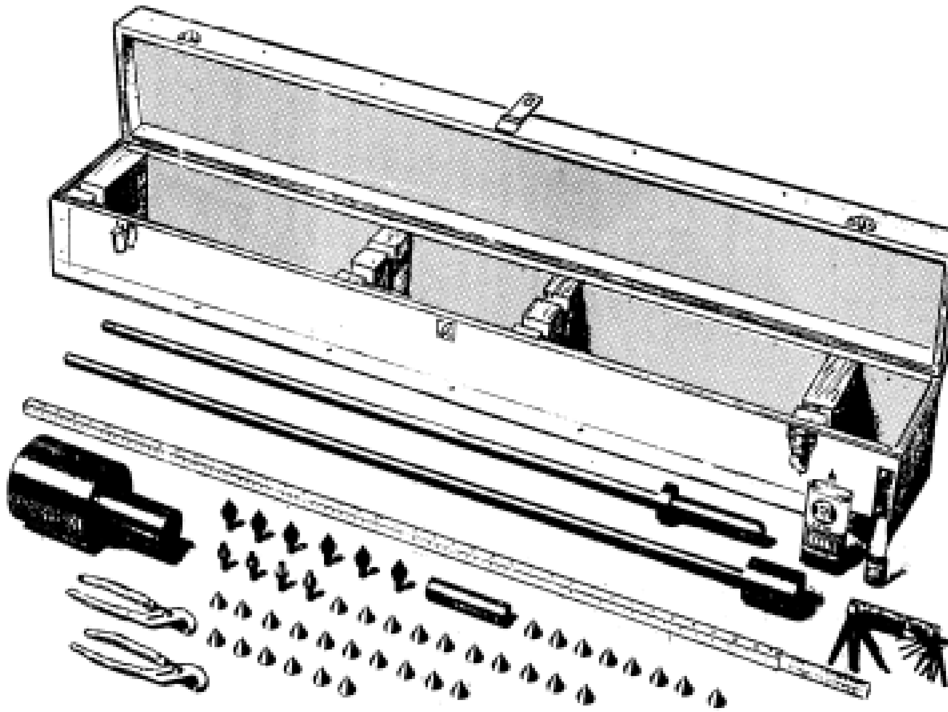


Figure 2-68. DCP test kit

Table 2-14. Summary of remolded CBR laboratory test programs

Test Program	Type of Soil Normally Tested*	Compaction Blows Per Layer	Probable Use of Test Results
Swelling soils	CH, MH, and OH	10, 25, and 56	Low-quality compacted subgrades
Free-draining soils	GW, GP, SW, and SP	25, 56, and 72	Compacted subgrade, select, and subbase materials
Other soils	All except CH, MH, OH, GW, GP, SW, and SP	For CBR >20: 25, 56, and 72 For CBR <20: 10, 25, and 56	Compacted subgrade, select, and subbase materials

***This categorization is intended to serve as a guide for planning laboratory activities. Deviations may be noted in the initial stages of a test program which will dictate adjustments.**

Table 2-15. Summary of compaction requirements

Material	Percentage of Compaction of Materials With Design CBR Values of 20 and Above
Base course	No less than 100% of CE 56 maximum density
Subbase and subgrade	No less than 100% of CE 56 maximum density
Material	**Percentage of Compaction of Materials With Design CBR Values Below 20**
Select material and subgrade in fills	Cohesionless fill will not be placed at less than 95% of CE 56 maximum density. Cohesive fill will not be placed at less than 90% of CE 56 maximum density

Example

To illustrate the methods of evaluating the design CBR, the data given on the DD Form 2463 for the Engineer Center expansion road (see *Figure 2-69, pages 2-139 through 2-143*) will be used. The data was taken from the subgrade along a proposed road alignment. The object of the following analysis is to determine a soil-placement moisture-content range for a specified level of compactive effort which gives the greatest assured design CBR. This technique for determining a design CBR provides for a strength measure of at least 15.0 when the associated density and moisture-content ranges are followed. Greater strengths will be realized within the specified limits, but the value obtained allows the engineer to size the structure for the worst condition. Notice that for this soil and the limits used, the greatest assured strength occurs for the 4 percent moisture-content range centered on the OMC. This may not always be the case. Also note that the analysis is based on an initial selection of density limits. You may find it better to evaluate other density limits that meet the minimum requirements to see if an adjustment to these limits yields greater strengths.

Steps

Perform the following steps for CBR testing of a nonswelling soil:

Step 1. Establish the OMC of the soil at 56 blows per layer by using the data collected from the compaction test as outlined in Section VII (see *Figure 2-58, page 2-110*). For this example, OMC equals 8.8 percent.

Step 2. Establish a moisture range for CBR investigation. The moisture range generally used for nonswelling soils is OMC ± 4 percent. This is a time-saving guide, as experience shows that the maximum CBR normally occurs at compaction moisture contents within this range and that testing soils beyond these limits is wasted effort. For this example, the moisture-content investigation range is 5 to 13 percent.

Step 3. Compact the samples within the moisture-content investigation range at different levels of compactive effort as described earlier in this section. This allows for evaluation of soil strength when field placement is other than 100 percent of the compaction test's maximum density.

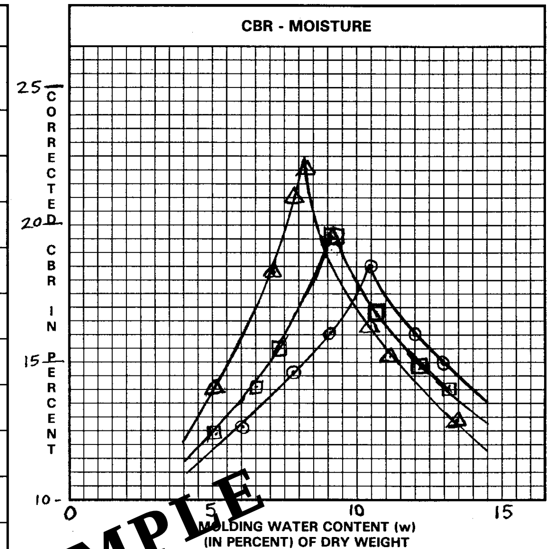
CALIFORNIA BEARING RATIO (CBR) ANALYSIS

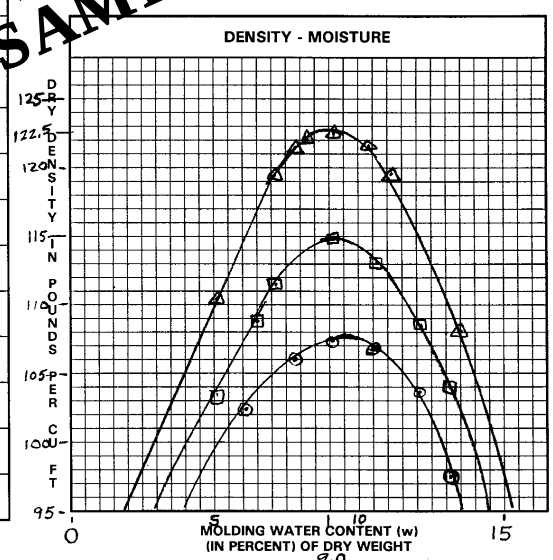
1. PROJECT	2. DATE
ENGINEER CENTER EXPANSION	4 SEP 97

3. SOIL CLASSIFICATION	4. LOCATION OF SOIL	5. GROUP NUMBER
SC	NORTH CORNER	5-C

DATA SUMMARY

MOLD NUMBER	BLOWS PER LAYER	MOISTURE CONTENT, *W (percent)*	DRY DENSITY	CORRECTED CBR *(percent)*	SWELL *(percent)*
M-Ø1	1Ø ○	6.2	1Ø2.5	12.7	Ø.62
Ø2		7.8	1Ø6.Ø	14.6	Ø.58
Ø3		9.1	1Ø7.5	16.2	Ø.56
Ø4		1Ø.5	1Ø7.4	18.5	Ø.54
Ø5		12.2	1Ø3.8	16.2	Ø.53
Ø6		13.3	97.5	15.Ø	Ø.53
Ø7	25 □	5.2	1Ø3.6	12.4	Ø.6Ø
Ø8		6.5	1Ø8.9	14.2	Ø.56
Ø9		7.3	111.6	15.5	Ø.55
1Ø		9.2	114.8	19.5	Ø.54
11		1Ø.7	113.1	16.9	Ø.53
12		12.3	1Ø8.5	14.8	Ø.52
13		13.2	1Ø4.Ø	14.3	Ø.52
14	56 Δ	5.1	11Ø.4	14.1	Ø.55
15		7.2	119.6	18.4	Ø.51
16		7.8	121.4	21.Ø	Ø.5Ø
17		8.3	122.Ø	22.Ø	Ø.51
18		9.2	122.5	19.5	Ø.5Ø
19		10.4	121.3	16.4	Ø.49
2Ø		11.2	119.5	15.3	Ø.48
21		13.5	1Ø8.1	12.9	Ø.48





6. TECHNICIAN *(Signature)*	7. COMPUTED BY *(Signature)*	8. CHECKED BY *(Signature)*
SSG DOBBS	SFC McKimmey SFC McK	SFC MORTIMER

DD FORM 2463, DEC 1999 PREVIOUS EDITION IS OBSOLETE. Page 1 of 5 Pages

Figure 2-69. Sample DD Form 2463, page 1

CBR FAMILY OF CURVES				5-C
W (Percent)		BLOWS/LAYER 10	BLOWS/LAYER 25	BLOWS/LAYER 56
5	DRY DENSITY, in pcf	99.0	103.0	110.5
	CORRECTED CBR, in percent	11.7	12.3	13.9
6	DRY DENSITY, in pcf	102.4	107.2	115.5
	CORRECTED CBR, in percent	12.5	13.5	15.6
7	DRY DENSITY, in pcf	104.9	110.5	119.0
	CORRECTED CBR, in percent	13.6	15.0	18.0
8	DRY DENSITY, in pcf	106.5	113.0	121.6
	CORRECTED CBR, in percent	14.8	17.0	21.5
9	DRY DENSITY, in pcf	107.5	114.7	122.5
	CORRECTED CBR, in percent	16.1	19.5	19.7
10	DRY DENSITY, in pcf	107.9	114.2	121.7
	CORRECTED CBR, in percent	17.5	18.2	17.1
11	DRY DENSITY, in pcf	106.8	112.2	119.7
	CORRECTED CBR, in percent	17.8	16.5	15.5
12	DRY DENSITY, in pcf	104.1	109.3	116.4
	CORRECTED CBR, in percent	16.5	15.3	14.3
13	DRY DENSITY, in pcf	100.0	105.0	111.9
	CORRECTED CBR, in percent	15.4	14.4	13.2
	DRY DENSITY, in pcf			
	CORRECTED CBR, in percent			
	DRY DENSITY, in pcf			
	CORRECTED CBR, in percent			
	DRY DENSITY, in pcf			
	CORRECTED CBR, in percent			
	DRY DENSITY, in pcf			
	CORRECTED CBR, in percent			
	DRY DENSITY, in pcf			
	CORRECTED CBR, in percent			

SAMPLE

DD FORM 2463, DEC 1999 — Page 2 of 5 Pages

Figure 2-70. Figure 2-69. Sample DD Form 2463, page 2 (continued)

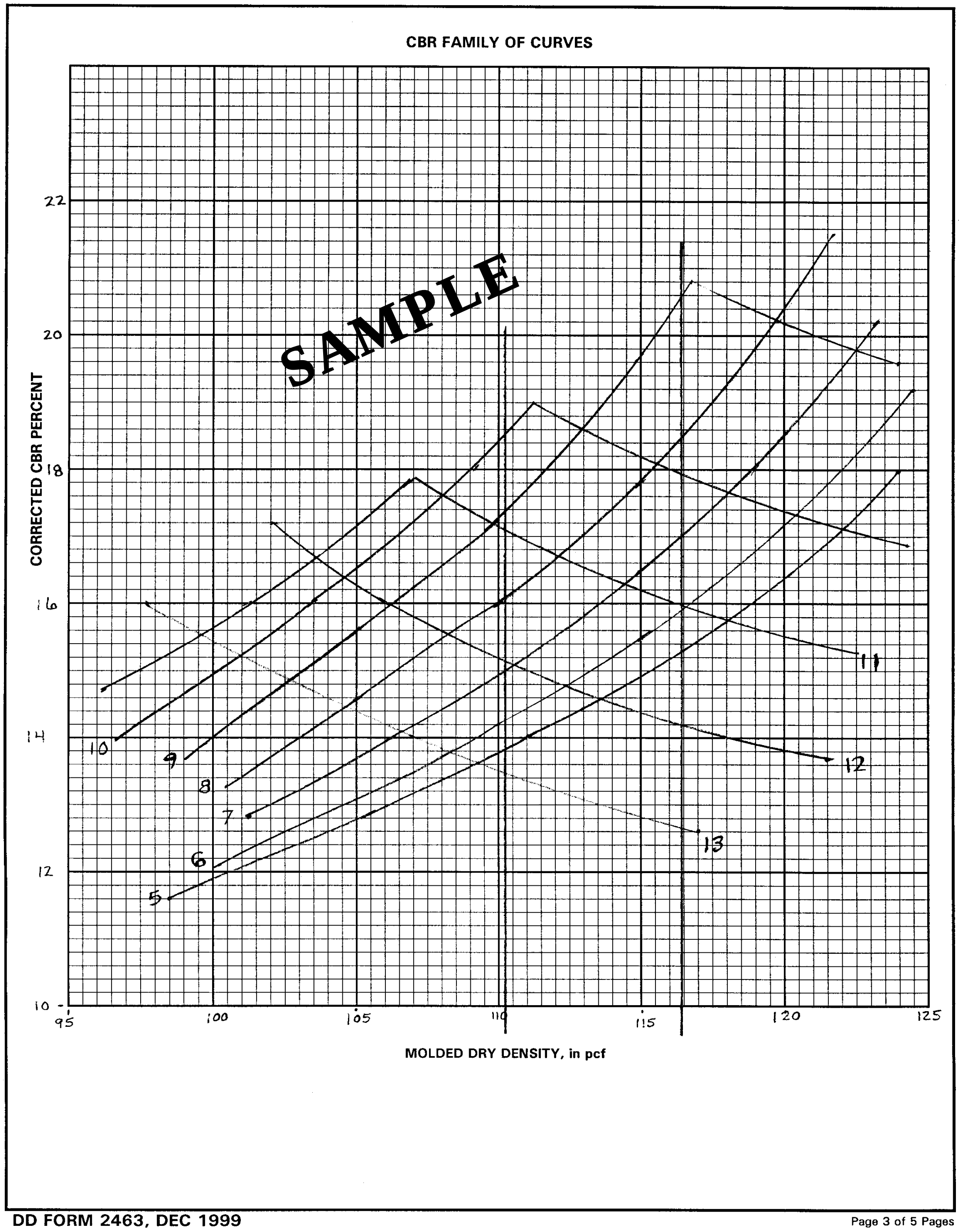


Figure 2-70. Figure 2-69. Sample DD Form 2463, page 3 (continued)

DESIGN CBR 5-C

W (Percent)	LOWEST CBR	W PERCENT RANGE 4 %	ASSURED CBR
5	13.8	5 % TO 9 %	13.8
6	14.3	6 % TO 10 %	14.3
7	15.0	7 % TO 11 %	15.0
8	16.1	8 % TO 12 %	14.3
9	17.4	9 % TO 13 %	12.7
10	17.8	% TO %	
11	15.8	% TO %	
12	14.3	% TO %	
13	12.7	% TO %	
		% TO %	
		% TO %	
		% TO %	
		% TO %	
		% TO %	

SAMPLE

COMPACTION DATA

MAXIMUM DRY DENSITY (MDD) AT CE 56 122.5

RANGE 90 % TO 95 %

DENSITY 110.3 PCF TO 116.4 PCF

DESIGN CBR

(HIGHEST ASSURED) 15.0

DESIGN MOISTURE

RANGE 7 % TO 11 %

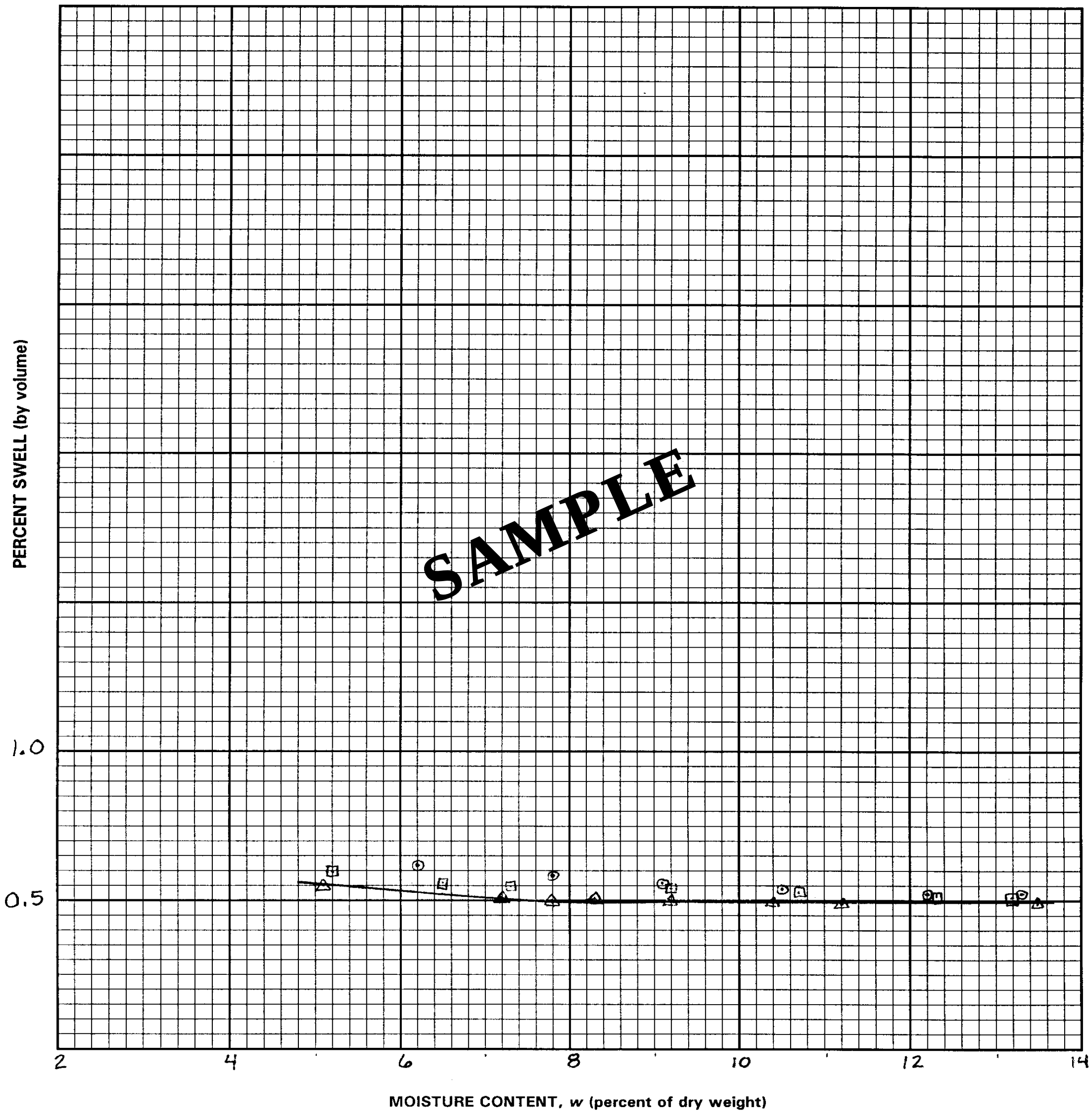
DD FORM 2463, DEC 1999

Page 4 of 5 Pages

Figure 2-71. Figure 2-69. Sample DD Form 2463, page 4 (continued)

CBR SWELL DATA

5-C



NOTE: Maximum acceptable swell is 3 percent.

○ - 10 blows/layer
□ - 25 blows/layer
△ - 56 blows/layer

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Page 5 of 5 Pages

Figure 2-72. Figure 2-69. Sample DD Form 2463, page 5 (continued)

The levels of compactive effort selected in the laboratory are based on the compaction requirements. If the soil is to be used as select material or subgrade in fills (CBR < 20), it may be placed at less than 100 percent of the compaction test's maximum density for CE 56, as indicated in *Table 2-15, page 2-138*. Additionally, laboratory compactive efforts of 10, 25, and 56 blows per layer are usually selected for this soil. If the soil is a very high-quality subgrade or a subbase (CBR ≥ 20), the laboratory tests should include samples compacted in excess of 56 blows per layer. Normally 25, 56, and 72 blows per layer are adequate. The only stipulations placed on the levels of compactive effort are that a 56-blow-per-layer compaction curve be obtained and that data be developed at two other levels of compactive effort encompassing the specified placement densities.

In this example, the soil type is SC and the DD Form 1211 from the compaction test displays a bell-shaped compaction curve. This is indicative of a either a swelling or a nonswelling soil. A U-shaped compaction curve indicates a free-draining soil. An assumption is made then that this is a nonswelling soil. This information is based on typical soil characteristics for soils of type SC as found in *Table B-3, pages B-16 and B-17*, and *Table 2-14, page 2-137*. Using *Table 2-14* and column 15 of *Table B-3* as a guide, the samples were compacted at 10, 25, and 56 blows per layer. The DD Form 1212 for this sample compacted at 56 blows per layer at approximate OMC can be found in *Figure 2-65, page 2-128*.

Step 4. Soak the samples and measure the swell as outlined in the previous section.

Step 5. Perform CBR penetration tests and determine the corrected CBR for each sample according to the technique discussed in the previous section. Note that accumulating the required data involves a considerable amount of work. At a minimum, 15 molds (5 per level of compactive effort) must be made. In this example, 21 molds were compacted, soaked, and then penetrated.

Step 6. Transfer the results of the 21 tests from each DD Form 1212 onto the data summary section of DD Form 2463, page 1 (see *Figure 2-69, page 2-139*).

Step 7. Plot the data on the graphs of dry density versus molding moisture content and corrected CBR versus molding moisture content on DD Form 2463, page 1 (see *Figure 2-69*).

Step 8. Determine the moisture range for the CBR family of curves. For a nonswelling soil, the moisture content that corresponds to the MDD is the OMC. The moisture range is OMC ± 4 percent. In this example, the OMC discovered from DD Form 2463 is 9 percent; therefore, the range for the family of curves is 5 to 13 percent.

Step 9. Transcribe the data points from the graphs onto page 2 of the DD Form 2463 (see *Figure 2-69, page 2-140*) for each whole moisture percentage in the range determined from step 8. This step is performed to identify values of dry density and CBR for whole-integer moisture contents within the range of investigation at each level of compactive effort. Some of the data may be transferred directly from the data-summary table. The remainder must be interpolated from the CBR/dry-density versus molding moisture-content graphs.

Step 10. Plot the CBR family of curves on page 3 of DD Form 2463 (see *Figure 2-69, page 2-141*). This step places the laboratory data in a form that lends itself to analysis. The trends of strength variation are determined as the moisture content and dry density change. Drawing a CBR family of curves involves considerable practice, numerous attempts, and subsequent adjustments. The example (*Figure 2-69*) shows that the available data has been plotted on a graph of corrected CBR versus molded dry density for whole moisture contents. For low molding water contents (from 5 to 8 percent), there was an increase in strength with dry density. At high moisture contents (12 and 13 percent) the reverse was true. For the intermediate moisture contents, there was an increase in strength to some point and then a decrease as the dry density increased.

Step 11. Proceed with an engineering analysis. After all the testing has been completed, it is the engineer's responsibility to ensure that the CBR data is properly obtained and presented. The engineer must analyze the data and understand how the results affect the design and economic factors. Before considering the details of the analysis, it is possible to observe two points of interest about the soil being used for the example. First, the maximum strength of this soil does not occur at OMC but at 1 percent drier (see corrected CBR versus molding water content). Second, the CBR family of curves shows that for some moisture contents the soil loses strength as the dry density or level of compactive effort increases. The impact of these two factors is important. If maximum strength from this soil is desired, that strength may in some soils be achieved at a moisture content less than OMC and at some level of compactive effort less than CE 56. The reasons for these two phenomena are highly speculative. Soil placement at OMC and the most compactive effort possible are not always the answers to good construction.

Step 12. Establish a density range at which soil will be placed in the field. The TO standard compaction range is 5 percent, unless otherwise stated. The flow chart in *Figure 2-70, page 2-146,* provides the information necessary for determining the density and moisture ranges for nonswelling, swelling, and free-draining soils. For nonswelling soils, the following information is normally used to assist in determining a density range.

To facilitate construction, it is common to specify a reasonable range of densities that can be economically obtained and then examine the strength values that would occur without that range. Establishing the density range depends greatly on economics. The more latitude given to the builder, the better the chances of placing the soil within established limits. However, if an extreme range is stipulated, the CBR value allowed for design might be reduced and thicker pavement structure could be required. Another factor is the actual field compaction experience obtained from either a test strip or prior construction. Such data can be accumulated by measuring the in-place dry densities for different numbers of passes with the available compaction equipment and determining the point where additional passes give little increase in density. For this example, the soil type was determined to be SC with a PI of 10, as shown on DD Form 1209 (see *Figure 2-47, page 2-95*). With this information following the flow chart, the soil must be placed to at least 90 percent of MDD.

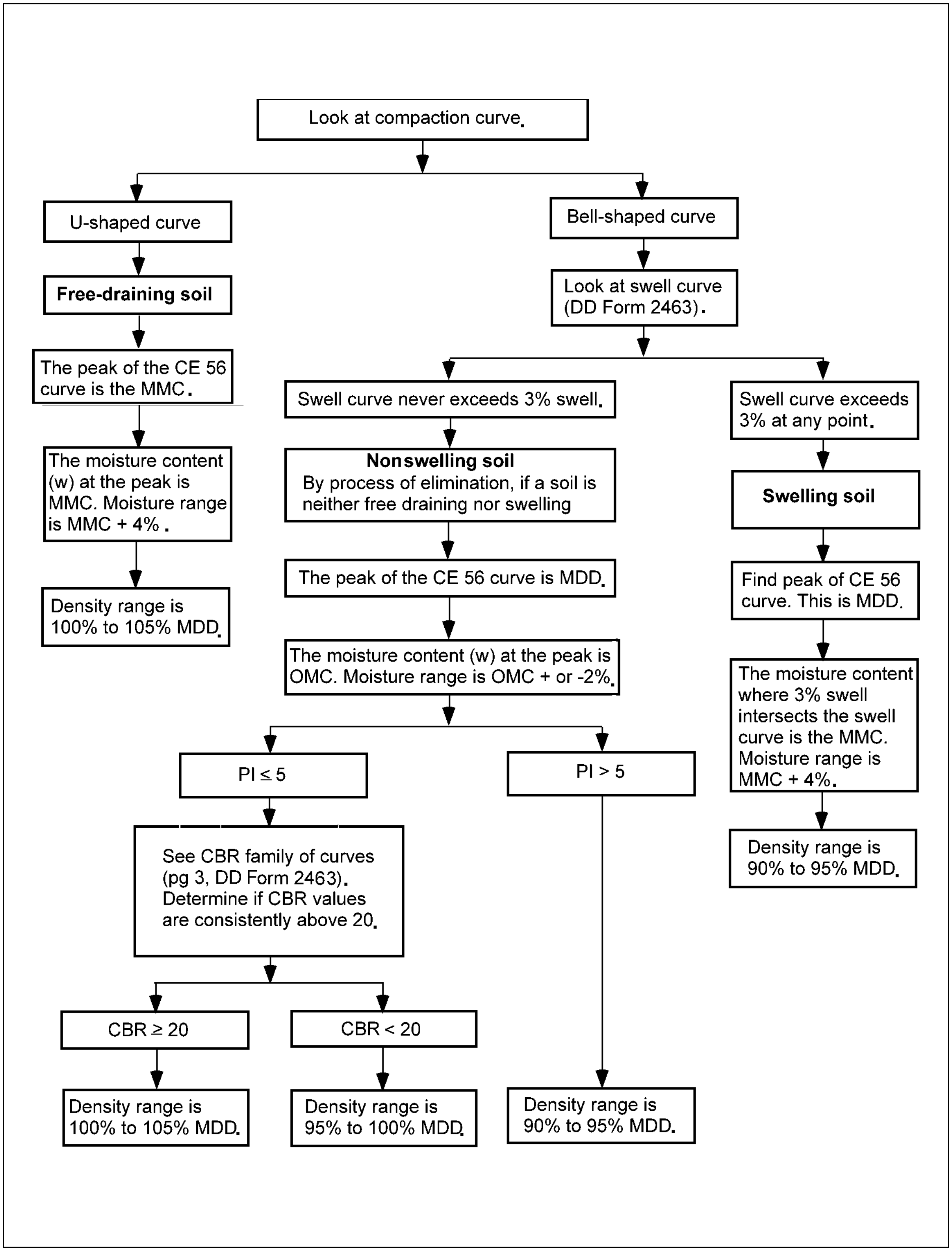

Figure 2-70. Density and moisture requirements using the CBR design method

This would provide a density range, in pcf, from 110.3 to 116.4. This is calculated in the following manner:

$$0.90 \times 122.5 = 110.3\ pcf$$

$$0.90 \times 122.5 = 116.4\ pcf$$

Using the range between 90 and 95 percent, these limits can be imposed on the CBR family of curves by drawing two vertical lines, one at 110.3 and the other at 116.4 pcf.

Step 13. Determine the assured CBR values between the specified density limits. If the builder is allowed to place the soil between 110.3 and 116.4 pcf, this step involves determining the CBR values obtained for each moisture content. The change in CBR for any specific moisture-content line between the two density limits shows that a range of strengths is possible. Since the builder will be allowed to place the soil anywhere between the established density limits, the CBR value selected as a potential design strength should represent the worst case. Using 8 percent moisture as an example, the CBR at 110.3 pcf is 15.6. At 116.4 pcf, the CBR is a maximum of 18.0. Of the two, 15.6 is the minimum strength for the specified density range. This procedure was followed for the remaining moisture contents in the example, and the results are recorded on page 4 of DD Form 2463 (see *Figure 2-69, page 2-142*).

Step 14. Determine the CBR values for potential moisture-content specification ranges. Like the density range, a moisture-content range that can be economically achieved in the field is desired. Within the overall range of investigation (OMC ± 4 percent), a smaller specification range giving the greatest assured CBR will be determined. Experience shows that a 4 percent range (± 2 percent) is a reasonable requirement; however, this span is not intended to represent an absolute rule. A smaller range may be specified to achieve a larger design CBR and a reduction in pavement thickness requirements. This savings in pavement materials may be offset by increased costs associated with the difficulties in meeting the more stringent requirements. Conversely, for some soils an expanded moisture-content specification may have little effect on the design CBR. The sample problem uses a 4 percent specification range. One possible range is 6 to 10 percent. If the engineer specified that the soil be placed within these limits, the worst possible strength would be a CBR of 14.4. A continued analysis can be done for the other possible 4 percent ranges, as shown on page 4 of DD Form 2463 (see *Figure 2-69*).

Step 15. Select the moisture-content range that gives the greatest assured CBR. In steps 13 and 14, CBR values were selected assuming that the builder will be allowed to place the soil anywhere between potential moisture content and density specification limits. Now the desired set of limits is selected. The tabulation in step 14 shows that the soil, if placed between 7 and 11 percent moisture, will give the largest of the possible CBR values. Thus, 15.0 becomes the design CBR. To ensure that a CBR of 15.0 is achieved, compaction must be 90 to 95 percent MDD or 110.3 to 116.4 pcf.

TEST PROGRAM FOR SWELLING OR EXPANSIVE SOILS

There is a small group of soils which expand objectionably after being compacted and saturated. This presents a problem in pavement design as this expansion or swell can damage the structure through reverse settlement. The measure of swell is expressed as a percentage of the initial sample height. Objectionable swell is defined as that in excess of 3 percent of the initial sample height. A soil's expansive nature is mainly due to the type of clay minerals present. For example, montmorillonitic clay consists of the smallest and most highly charged particles found in nature. The combination of large surface-area-per-unit volume and high surface charge causes a tremendous affinity for water and the ability to expand or shrink as water is taken in or removed from the soil.

Experience shows that the PI is an excellent indicator of expansive soils. Although a high PI does not guarantee that the soil is expansive, critical soils should be checked more closely for swell tendencies. See *Table 2-16* for suggested guidelines. *Table 2-14, page 2-137*, indicates that the potentially expansive soils—by USCS classification—are CH, MH, and OH. The test procedure to determine a design CBR for an expansive soil is similar to that discussed for nonswelling soils, but the objective is different. For nonswelling soils, the object is to find the greatest assured CBR value for some range of densities and moisture contents. The object of the test program for expansive soils is to find the moisture-content ranges that will prevent objectionable swell and provide the highest-soaked CBR. Generally, the minimum swell and the highest-soaked CBR occur at a molding moisture content higher than the OMC.

Table 2-15. Swell potential

PI	Expansiveness
0 to 14	Not expansive
14 to 25	Marginal
25 to 40	Critical
40	Highly critical

Example

The following is an example of such a test for a CH soil. As most of the steps are similar to those developed for the case of nonswelling soils, only differences will be discussed.

Steps

Step 1. Establish the soil's OMC. Determine a moisture range for CBR investigation. The OMC ± 4 percent range of investigations as used for the nonswelling soils may not apply. It will be necessary to prepare samples over a wider range of moistures with most of the work being done on samples higher than the OMC. Prepare samples over a range of the OMC ± 8 percent. As illustrated later, much of the laboratory work done on samples dry of the OMC is not essential.

Step 2. Compact the samples within the moisture-content range of investigation at different levels of compactive effort. As the type of soil being tested will generally be cohesive and will have a CBR less than 20, *Table 2-15, page 2-138,* indicates that compaction must be at least 90 percent MDD. An upper limit can be established as expansive soils are very difficult to compact at levels greater than 100 percent of MDD. Laboratory compactive efforts of 10, 25, and 56 blows per layer are adequate for nearly all cases.

Step 3. Soak the samples and measure the swell. This step deviates from the same step for the nonswelling soil. For each sample, measure the expansion, compute the percent of swell, and plot against the molding water content. As an example, the triangular data point at 10 percent moisture on the swell data curve (see *Figure 2-69, page 2-139*) was obtained as follows:

- Initial sample height = 4.60 inches.
- Final dial reading = 0.025 inches.
- Molding water content = 10.0 percent.
- Level of compactive effort = blows per layer.
- Free-swell index or percentage of swell = (0.025/4.60) x 100 = 0.5 percent.

Step 4. Plot the points on page 5 of the DD Form 2463 (see *Figure 2-69, page 2-143*).

NOTE: The example of page 5, DD Form 2463 provided in *Figure 2-69* is based on data from the nonswelling soil type as explained in the nonswelling program section. A plot of data for a swelling soil may look slightly different than this example, as indicated in *Figure 2-71*.

Once the points are plotted, a curve is then usually fit to only the CE 56 data points. The curve for a swelling soil (see *Figure 2-71, page 2-150*) shows that this soil, if placed and compacted at molding moisture contents of 14 percent or greater, will swell 3 percent or less.

Step 5. Perform CBR penetration tests and determine the corrected CBR for each sample.

Step 6. Plot the data on graphs of dry density versus molding moisture content and corrected CBR versus molding moisture content.

Step 7. Reformat the data on DD Form 2463, page 2 (*Figure 2-69, page 2-140*).

Step 8. Plot the CBR family of curves (DD Form 2463, page 3 (*Figure 2-69, page 2-141)*.

Step 9. Establish a density range at which soils will be placed in the field. If no prior experience or benefit of a test strip is available, then the flow chart in *Figure 2-70, page 2-146,* may be used. In this case, the minimum level of compaction is 90 percent of MDD. Assuming a reasonable specification range of 5 percent, the upper limit will be set at 95 percent MDD.

The actual density range is calculated as discussed in the previous example for nonswelling soils. These calculated limits are then placed on page 3 of DD Form 2463 by drawing two vertical lines on the CBR family of curves.

For example, if the MDD was determined to be 110, then the following calculation would be performed to establish the actual density limits:

$$110 \times 0.90 = 99 \text{ pcf}$$

$$110 \times 0.95 = 104.5 \text{ pcf}$$

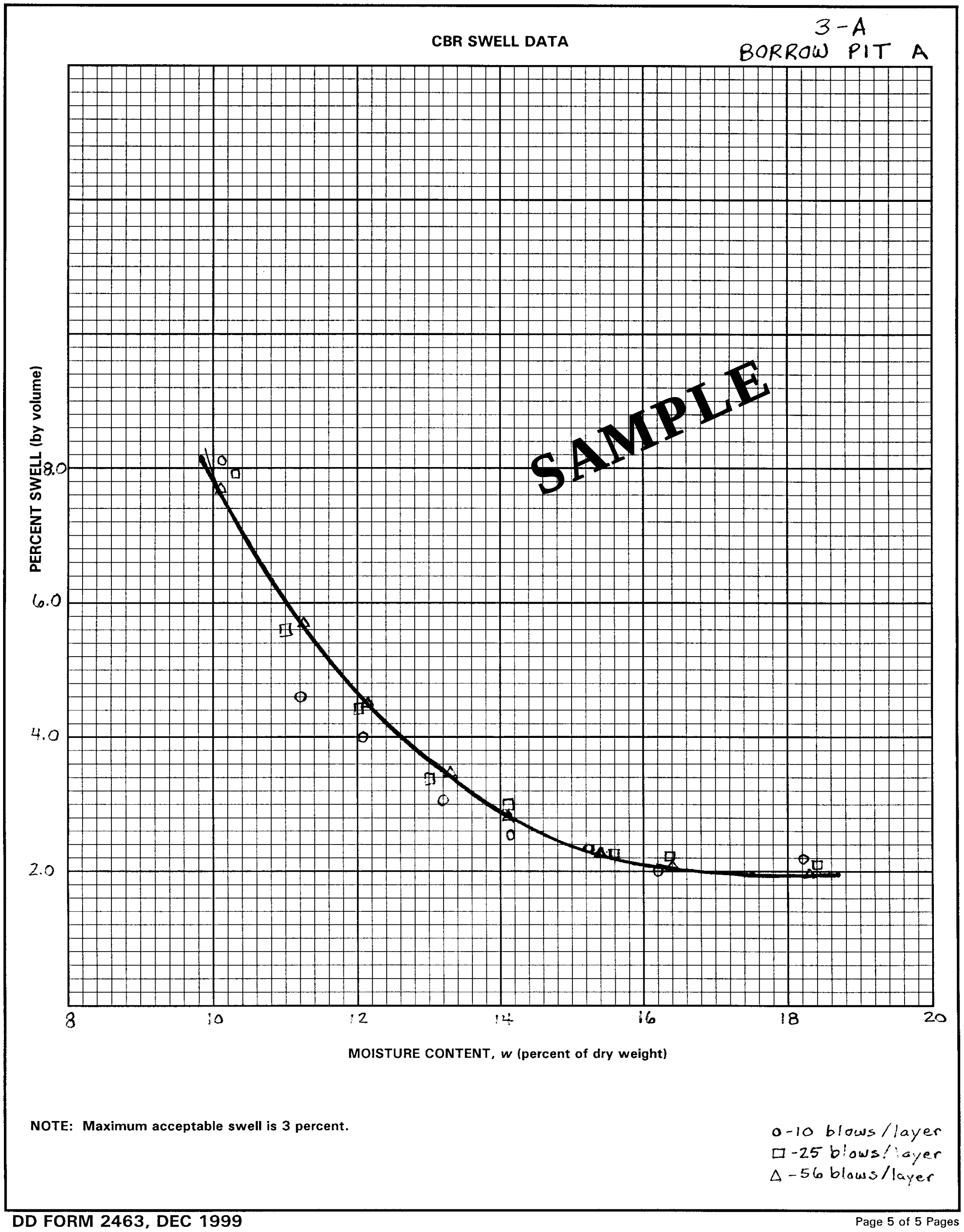

Figure 2-71. Sample DD Form 2463, page 5

Step 10. Determine the assured CBR values between the specified density limits. As more than 3 percent swell is not acceptable, evaluation of the CBR values at moisture contents less than 14 percent is needless. The CBR values of the applicable moisture contents should range from 14 through 20. The CBR values of the applicable moisture contents were determined to be the amounts shown in *Table 2-17*.

Table 2-16. Determining CBR values for moisture-content percentages for swelling soils

w	CBR
14	3.4
15	4.2
16	3.2
17	2.2
18	1.3
19	0.9
20	0.4

Step 11. Determine the CBR values for potential moisture-content specification ranges. For this example the values shown in *Table 2-18* were derived.

Step 12. Select the moisture-content range that gives the greatest design CBR. Step 11 shows that the 14 to 18 percent range provides the greatest CBR value. Thus, the design CBR value is 1.3. This value is obtained when the soil is placed at a moisture content between 14 and 18 percent and a density of between 99.0 and 104.5 pcf.

Table 2-17. Determining CBR values for potential moisture-content ranges for swelling soils

w (range, in percent)	CBR
14 to 18	1.3
15 to 19	0.9
16 to 20	0.4

Step 13. Analyze the results. Note that this design value was obtained at the expense of strength. This technique does not provide for drying the soil to a moisture content less than the amount of placement. Should such extreme drying take place, excessive shrinkage and pavement failure might be expected. However, it takes considerable effort to remove water from expansive soils and such soils are normally protected from drying by the overlying pavement. The first thing to consider when encountering an expansive soil is testing another location. However, this is not always feasible, and this technique does not allow for determination of a design CBR at which swell is not excessive.

Expansive soils can be chemically stabilized to allow building. Adding small amounts of lime considerably reduces the potential for shrinkage and swell. Soils stabilization is further discussed in Chapter 5 of this manual as well as TM 5-822-14 and FMs 5-430-00-1 and 5-430-00-2.

TEST PROGRAM FOR FREE-DRAINING SOILS

Determining a design CBR for free-draining soils requires the least testing of the three remolded laboratory test programs. *Table 2-14, page 2-137*, gives the USCS classification and the uses of the soils in this group.

The ease in testing is due to the free-draining characteristics or lack of fines in the soil. The CBR analysis sheet for borrow pit A shows that the density-versus-moisture-content curves have a concave, upward shape and show maximum densities between 7 and 9 percent moisture, depending on the level of compactive effort (see *Figure 2-72*). For each curve, there is a limiting or minimum moisture content (MMC) at which moisture above that required to fill the voids after compaction is squeezed or drained from the soil (shown by the triangle, square, or circle in *Figure 2-72*). The dashed lines to the right of the MMC represent attempts to compact the soil in a saturated condition, but the results after compaction are densities and moisture contents at the limiting condition. This means that field placement is relatively easy for such soils. To ensure the MDD for any level of compactive effort, the only control measure necessary is to have more water available than that required for the MDD at the appropriate level of compactive effort. The corrected CBR-versus-molding-water-content curves show the same pattern in relation to moisture content as the dry density. Soils placed with a moisture content above the minimum moisture content achieve the maximum CBR possible for that level of compactive effort. In other words, moisture contents of loose soils above the limiting values have little bearing on the strength of a soil after compaction. This makes laboratory testing, field placement, and field control relatively easy matters.

Example

To arrive at a design CBR, the steps outlined in the previous examples will again be followed.

Steps

Step 1. Establish the soil's MMC at 56 blows per layer. It is obtained by locating the moisture content at which the MDD is achieved on the compaction curve. For this example, the MMC is 8 percent with a MDD of 120 pcf. To ensure that a free-draining soil is being tested, this curve should display a MDD at a limiting or minimum moisture content.

Step 2. Compact the samples at different levels of compactive effort. Compaction curves must be made for three levels of compactive effort up to the MMC. As free-draining soils are frequently represented by well- and poorly graded sands and gravels with CBR values above 20, *Table 2-15, page 2-138*, indicates a compactive effort in excess of 100 percent of maximum CE 56 dry density. Therefore, 25, 56, and 72 blows per layer are usually used.

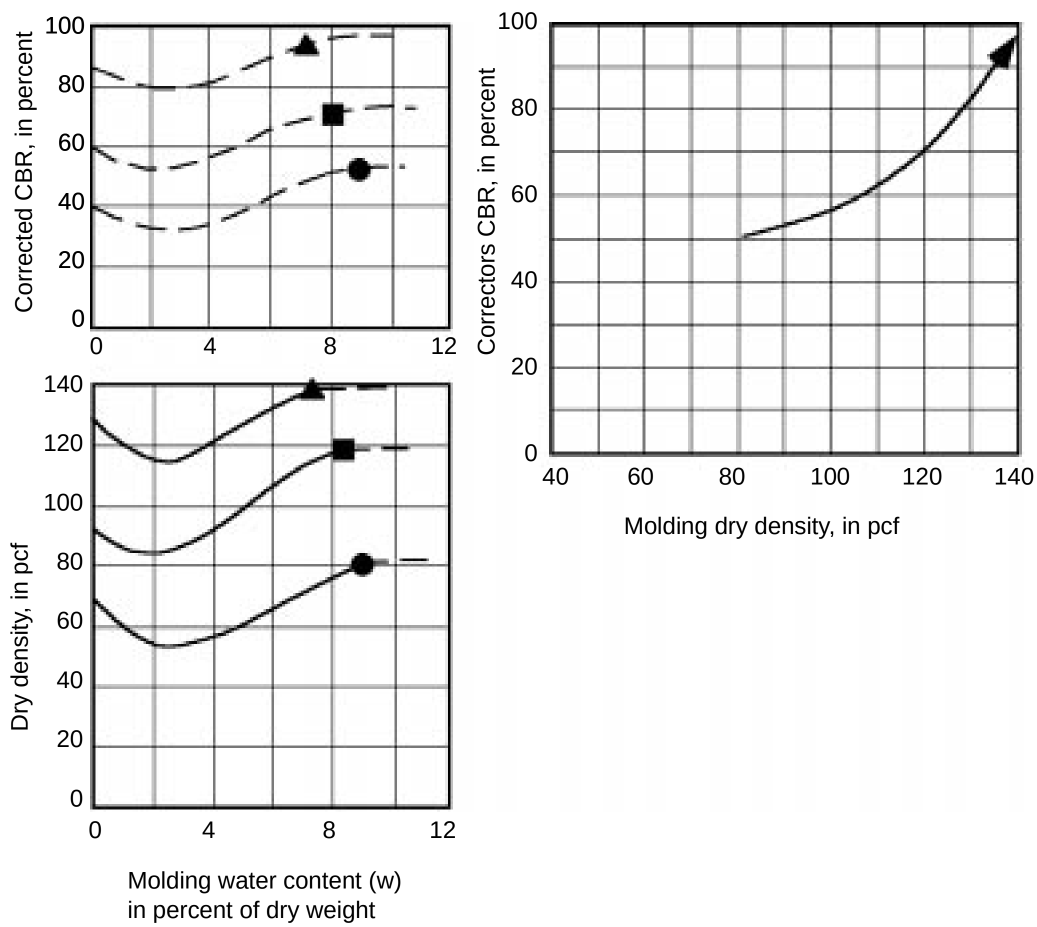

Figure 2-72. Plotted results for a free-draining soil, borrow pit "A"

Step 3. Soak the samples and measure the swell. Swell measurements are not required, and soaking can be eliminated when it is determined that saturation does not affect the strength.

Step 4. Perform CBR penetration tests. Only the samples at the limiting moisture contents for each level of compactive effort need to be tested. Normally, more than one sample at the limiting conditions will be made for each level of compactive effort, and all should be tested.

Step 5. Plot the data on graphs of dry density versus molding moisture content and corrected CBR versus molding moisture content. Only the plot of dry density versus molding moisture content is required. The corrected CBR-versus-molding-moisture-content graph is presented only for discussion.

Step 6. Plot the CBR family of curves. This graph can be condensed into a single line. The three data points are obtained by plotting the corrected CBR against the associated dry density at the limiting moisture content.

Step 7. Establish a density range at which the soil will be placed in the field. Using the criteria from *Table 2-15, page 2-138,* and noting that the CBR value for this soil is usually always greater than 20, the minimum level of compaction allowed is 100 percent of maximum CE 56 dry density. Because no additional information is provided, specify 100 to 105 percent of maximum CE 56 dry density. The actual density range is as follows:

$$1.00 \times 120.0 = 120.0 \text{ pcf}$$

$$1.05 \times 120.0 = 126.0 \text{ pcf}$$

Step 8. Determine the design CBR and placement moisture content. The CBR family of curves shows that the minimum CBR value achieved between the density range is 70, which is achieved at 120 pcf. The placement moisture content necessary to ensure that this strength is obtained is 8 percent or greater.

Considerably greater CBR values can be achieved if more field compaction is applied to the soil. If this is not too costly, it may be advantageous to specify greater densities.

SECTION X. TECHNICAL SOILS REPORT

A good program for soils testing not only requires that careful and complete tests be performed, but also that the tests be completed as quickly as possible and that the data be presented in a clear, logical consistent manner. Therefore, you must be familiar with the tests, the sequence of testing, and the presentation of results.

SOILS TESTS REQUIRED

The tests required by any program depend on the type of construction being planned. However, there are a number of tests run consistently on road and airfield construction programs. A complete testing program should include the following tests:

- Soils exploration (see Sections I and II).
- Compaction (see Section VII).
- Plasticity index (see Section VI).
- Particle-size analysis (see Section V).
- CBR (see Section IX).
- Trafficability (see FMs 5-430-00-1 and 5-430-00-2).

PURPOSE OF THE REPORT

The soil tests listed above are specific tests used to gain knowledge about the control of soils during construction, including the—

- Suitability of subgrade and borrow materials.
- Degree to which soil can be compacted.

- Bearing value of the subgrade and borrow material under projected future conditions.
- Location of ledge rock and groundwater table.
- Susceptibility to detrimental frost action.

Each test supplies the necessary data to answer questions based on engineering evaluation of scientific data rather than a meaningless guess.

ORGANIZATION AND SCOPE OF THE TESTS

Because of the number of tests to be performed for a particular project, careful planning may avert considerable delays in the presentation of the results. List the tests required and their sequence in a manner that will permit running the tests continuously, without delays due to time needed for soaking or drying samples.

An example of the daily activities in a complete soil-testing program are listed in *Figure 2-73*. Some testing programs may not include all the tests listed in the example and soil types or test results may change the activity list. An activity schedule for each unit may be different due to equipment and mission priority.

The following paragraphs cite some considerations that may be helpful in setting up a continuous soil testing program.

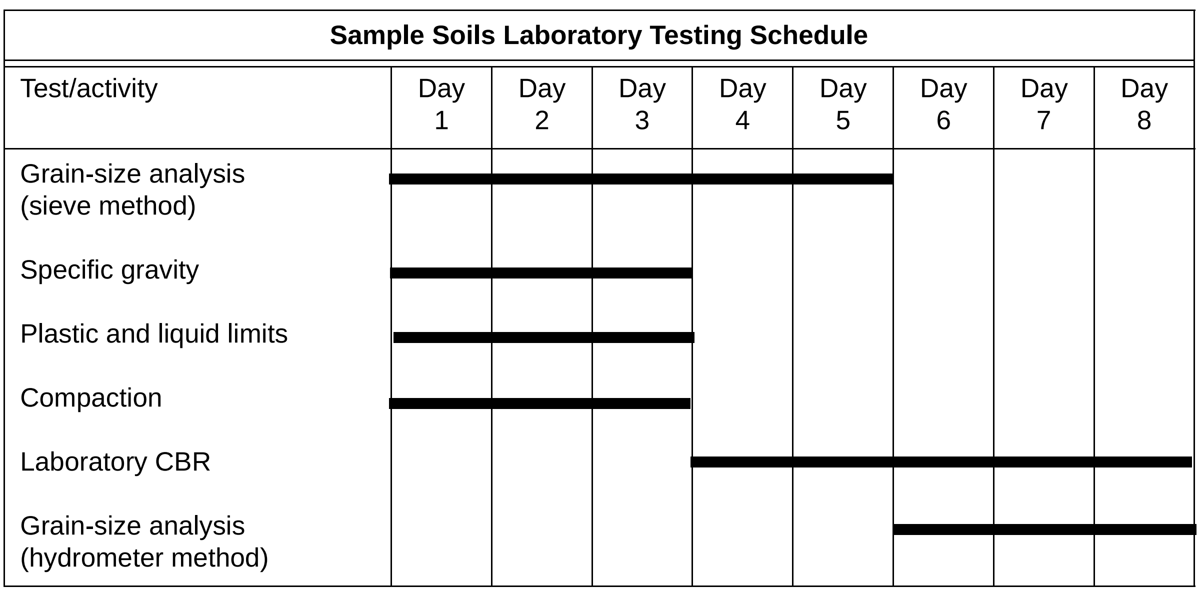

Figure 2-73. Sample schedule for soils laboratory testing

Exploration

Before any tests can be performed, representative samples of the soil involved in a given project must be obtained. This, however, is only one objective of soil exploration. Other considerations include plotting a profile of boring results, locating ledge rock, determining the depth to the groundwater table, determining field moisture content, and field-identifying the soils sampled.

Particle/Grain-Size Analysis

The mechanical analysis is another test that should be used to occupy periods between other tests. The test is an evaluation of the grain-size distribution used to establish the gradation of the soil sample. The sieve analysis and hydrometer analysis may be used in obtaining the required information.

LL and PL Tests

One use of LL and PL test results is to predict how the fine-grained portion (No. 200 fraction) will affect the engineering value of a particular soil sample. This evaluation, obtained through soil classification, is to ensure that the sample being tested meets specifications set on the LL and PL for the particular project for which it will be used. These tests should be performed while waiting for compaction-test moisture-content samples to dry and CBR samples to soak or any time between other tests.

Compaction Test

The compaction test indicates the MDD that can be obtained practically in the field. It also indicates the OMC at which this dry density can be obtained. Since this will be a test used for control purposes, it should be run as soon as possible. While moisture-content samples from this test are drying, tests for plasticity and particle-size analysis can be started.

Laboratory CBR Test

The CBR test is determined by an arbitrary penetration procedure to obtain a modulus of shearing resistance of a subgrade or base-course soil. This value is used to determine the required thicknesses of the various base courses through its application to empirically derived design curves. Because the procedure for this test may involve a four-day soaking requirement, CBR samples should be prepared as soon as the necessary information from the results of the compaction test is available. This information may be obtained from approximated values of the OMC.

Field In-Place CBR Test

The latest addition to equipment used for determining the CBR value of a soil is the dual-mass DCP. The procedures for testing with the DCP and the correlation of CBR values can be found in the user's manual for the equipment or in Annex J of FM 5-430-00-2.

SOILS TECHNICAL REPORT

In writing technical reports, one of the most important aids is a clear, logical outline of the subject. Outlines will vary according to the program conducted and the data required, but the suggested format that follows should help organize a report.

Frequently, portions of the information shown in the outline will be required at different times. For this reason, a preliminary report and several supplementary reports may actually be made before the project is completed. However, if all of the information provided follows the same basic outline, filing the data and assembling the final report will be simplified.

PURPOSE

Use the following information to write a soils technical report that includes all pertinent data given in the conditions and follow the recommended outline.

EQUIPMENT

Use the following items and information to write a soils technical report:

- Soil boring logs.
- The soil's profile.
- The soil's field identification.
- In-place moisture data.
- Particle/grain-size analysis data.
- LL and PL data.
- The USCS laboratory soils classification.
- CBR test data.
- In-place density data (as required locally).
- In-place CBR data.
- A topographic map of the site.
- Aerial photographs (if available).
- Pencils.
- Pens.
- Paper.
- The project directive.
- FM 5-430-00-1.

OUTLINE

Use the following recommended outline to organize a technical soils report:

1. Project.

A. Description. What type of construction is being performed (for example, Class D road, base camp, and airstrip)?

B. Purpose and scope. Who is requesting construction? What is the extent and why is it being performed?

2. Site description.

A. Location. All map references and directions including county or province (if available).

B. Existing facilities. This could include many things such as old logging roads, dirt paths, patrol roads, buildings, overhead power lines, and so forth (see sketches).

C. Topography, cultivation, and drainage. Description of terrain features. (forest, farmland, well drained, swampy, hills, and so forth).

D. Climate. Temperature extremes, seasonal precipitation, average wind speed, and so forth.

3. Geology.

A. Overburden. Main depositing force (river, glacial, and so forth), rock classes (sedimentary, igneous, metamorphic), and depth of overburden.

B. Bedrock. Average depth to bedrock and state of bedrock, such as faulted, fractured, or folded.

4. Site conditions.

A. Field explorations. Details of performed tests, location of test sites, and explanation of sample tags.

B. Field tests. Type of field tests performed and field sample results (enclose copies in Annex G).

C. Laboratory tests. Type of laboratory tests performed. Do not include MDD or laboratory CBR results.

D. Test results. Synopsis of test results and classifications. Refer to forms in Annex F.

5. Fill and borrow materials.

A. Field explorations. Details of performed tests, location of test sites, and explanation of sample tags.

B. Field tests. Type of field tests performed and field sample results (enclose copies in Annex G).

C. Laboratory tests. Type of laboratory tests performed. Do not include MDD or laboratory CBR results.

D. Test results. Synopsis of test results and classifications. Refer to forms in Annex F.

6. Conclusions and recommendations.

A. Final site selection (if applicable). Exact location of finished project. Refer to plans enclosed in Annex C.

B. Economical design. Low-cost or resource alternatives to current suggestions (soil-cement, asphalt binder, chemical stabilization methods, mats or fabrics, and so forth).

C. Minimum specifications. Design CBR, MDD, and OMC specifications. Refer to laboratory forms in Annex F.

7. Annexes.

A. Project directive and all directives involving this project.

B. General plan drawings (geology should be indicated).

C. Location plan drawings (existing and proposed features).

D. Profiles and cross sections.

E. Boring logs.

F. Laboratory testing data.

G. Field testing data.

NOTE: Not every subject will apply to every report. In many reports, some of the items may be covered in several sentences, while others may require a page of discussion. Some items (for example 5, 6, and 7) may have to be repeated for each runway in a major airfield. All laboratory test forms will be included in Annex C. If a specific test form is not necessary or not conducted, write the words "Not Applicable" across the form.

RETURN TO TOC