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In-situ and Lab Testing Procedures for Soil, Concrete, and Asphalt

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"Materials Testing"

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Chapter 10

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Chapter 10

Materials Testing

Topics

1.0.0 Soils Testing

2.0.0 Concrete and Concrete Testing

3.0.0 Bitumens and Bituminous-Materials Testing

4.0.0 Hazardous-Material Precautions

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Overview

As an Engineering Aid, especially if you are an EA doing a tour in a construction battalion, materials testing is a major part of your responsibilities.

EA Basic introduced you to materials testing and presented many of the basic soils and concrete tests that you must perform. This chapter will expand on that subject area and introduce you to several additional soils tests expected from a proficient EA.

It will present information on the ingredients necessary to produce concrete, and provide different procedures for testing those ingredients. In addition, it will present information on tests used to identify a concrete mixture design, and tests used to determine a concrete design‘s strength.

Furthermore, it will offer information on bituminous materials, methods used to test those materials, and introduce you to various tests used in the design of bituminous pavement mixtures.

Some of the tests discussed in this chapter may appear to be in detail; however, they are only the fundamental procedures. The objective of this chapter is not for you to know how to perform the actual tests, but rather for you to learn the purpose and principles of the tests. If/when you actually perform any of the materials tests discussed, refer to the current detailed procedural guidance that is provided by the referenced authoritative sources.

Finally, this chapter will present a short discussion on hazardous material precautions.

Objectives

When you have completed this chapter, you will be able to do the following:

1. Describe the different types of soil testing.
2. Describe the different types of concrete and concrete testing.
3. Describe the different types of bitumen and bituminous materials testing.
4. Describe the importance of hazardous material precautions.

1.0.0 SOILS TESTING

An EA must know how to perform soil compaction and soil density testing, two of the most common and important soils tests. This section will discuss those tests, along with the California bearing ratio test (CBR) and hydrometer analysis.

1.1.0 Compaction Test

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.

Equipment Operators accomplish compaction in the field by rolling or tamping the soil with special construction equipment. EAs accomplish compaction in the laboratory by the impact of hammer blows, vibration, static loading, or other methods that do not alter the water content of the soil.

Typically, to accomplish laboratory compaction:

1. Place a soil sample into a cylinder of known volume.
2. Drop a tamper onto the soil, of known weight, from a known height, for a given number of blows.

The amount of work done to the soil per unit volume of soil is called *compactive effort*.

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 optimum moisture content (OMC), and the associated dry density is called the maximum dry density (MDD).

Each compactive effort for a given soil has its own OMC, for as the compactive effort increases, the MDD generally increases and the OMC decreases.

The following briefly describes the equipment and procedures of the compaction test that determines the MDD obtainable and the OMC under a given compactive effort. Refer to *Materials Testing,* FM 5-472/NAVFAC MO-330 for more information and direction.

1.1.1 Equipment

Figure 10-1 shows the principal equipment used for a compaction test, the compaction cylinders, and the compaction tamper.

There are two compaction cylinders. The smaller cylinder is called the Proctor mold, named for engineer Ralph R Proctor who published (*Engineering News Record,* Sept. 7, 1933) proposed equipment and procedures that established the testing criteria.

The original Proctor test has evolved until today the American Society for Testing and Materials (ASTM) publishes two standards for testing compaction characteristics:

1. ASTM D698 - 07e1 *Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort* (12 400 ft-lbf/ft^3 [600 kN-m/m^3])

   - Sometimes referred to as the Standard Proctor Test

2. ASTM D1557 - 07 *Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort* (56,000 ft-lbf/ft^3 [2,700 kN-m/m^3])
   - Sometimes referred to as the Modified Proctor Test

Figure 10-1 — Typical soil compaction testing apparatus.

Both efforts have three designated methods (A, B, and C) with the 4-inch diameter Procter mold used for A & B, while a 6-inch diameter mold is used for method C. This 6-inch diameter mold is sometimes referred to as the CBR mold since it can also be used for preparing samples for the California Bearing Ratio (CBR) test.

Both efforts accommodate similar materials with the designated methods:

- A — For material passing the No. 4 sieve — 4-inch mold
- B — For material passing the 3/8 sieve — 4-inch mold
- C — For material passing the 3/4 sieve — 6-inch mold

Both efforts identify similar compaction blows:

- A — For material passing the No. 4 sieve — 4-inch mold — 25 blows
- B — For material passing the 3/8 sieve — 4-inch mold — 25 blows
- C — For material passing the 3/4 sieve — 6-inch mold — 56 blows

The real differences are in the number of layers, the drop tamper weight, and the drop tamper height.

- ASTM D698 - 07e1 (Standard Procter Test) — 3 layers — 5.5 pound tamper — 12-inch height
- ASTM D1557 – 07 (Modified Procter Test) — 5 layers — 10 pound tamper — 18-inch height

Obviously, with fewer layers, less weight, and lower height, the Standard Procter Test will impart a great deal less energy to a sample material than the Modified Procter Test.

As a result, the laboratory MDD is lower and the OMC is higher for the standard test compared to the modified test on the same soil.

The modern use of heavier compaction equipment and the desirability of having a higher load-bearing fill combine to necessitate the use of the modified test (ASTM D1557 – 07) much more frequently than the standard test (ASTM D698 - 07e1).

Both cylinders have detachable base plates and 2-inch extensions. The 4-inch diameter cylinder is 4.584 inches high, with a volume of 0.0333 cubic feet (1/30). The 6-inch diameter cylinder is 7 inches high, with a volume of .0750 cubic feet.

The compaction tamper is simply a tamper in a cylindrical guide. The tamper is a drop weight of 5.5 or 10 pounds with a 2-inch diameter striking face. The cylindrical guide regulates the drop height at 12 or 18 inches. To use the compaction tamper, place the guide on top of the specimen, draw the tamper to the top of the guide, and allow it to drop naturally.

Additional items you need to perform compaction testing:

- Balance or scale for weighing the material in grams
- 3/4-inch, 3/8-inch, and a No. 4 sieve
- Moisture canisters
- Miscellaneous lab tools, such as a mixing pan, spoon, trowel, spatula
- Steel straightedge for striking excess material from the top of the mold after compaction and collar removal

1.1.2 Sample Preparation and Compaction Procedures

To determine the OMC at which the MDD occurs for a given compactive effort, you need about five specimens, each with successively increasing moisture content. For the Proctor mold, you need about 6 pounds per specimen (about 30 pounds total); for the CBR mold, you need about 12 to 14 pounds per specimen (about 60 to 70 pounds total).

Before you begin compacting, air-dry the sample by spreading the material in the sun or in front of an electric fan and then determine the moisture content. This water content determination will be the basis for estimating the amount of water you need to add to each trial specimen.

The driest specimen should contain just enough water to produce a damp mixture that crumbles readily. Increase the water content by about 2 percent for each succeeding specimen until the wettest specimen is quite wet and plastic.

Compaction procedures for both gravelly and non-gravelly soils are the same with two exceptions. (Note: Remember that the No. 4 sieve is the dividing sieve between sandy and gravelly soil particles.)

1. The 4-inch Proctor mold is used for fine-grained soil (method A) and slightly gravely soil (method B) — the 6-inch CBR mold is used for more gravelly soil.
2. The Proctor mold uses 25 tamper blows per layer — the CBR mold uses 56 blows per layer.

This provides equal compactive efforts for the two mold sizes and soil volumes.

To compact the soil:

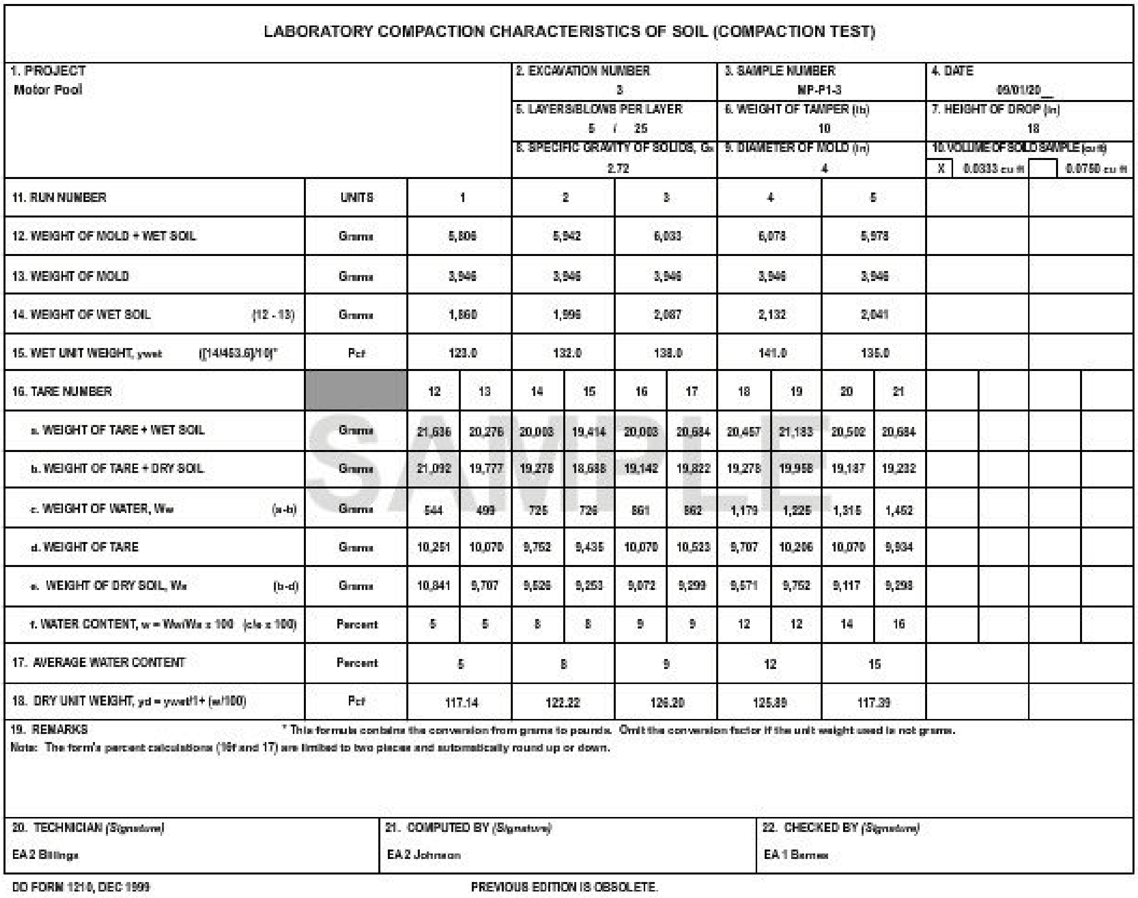
- Attach the base plate and collar to the mold.

- In equal layers, fill the mold to the top of the collar.
- Compact each layer with the appropriate 25 or 56 equally distributed blows.
- Remove the collar.
- Weigh the mold and compacted material.
- Take moisture content samples from the top and bottom of the specimen.
- Determine the moisture content for each; if they differ, use the average.

1.1.3 Data and Calculations

Refer to *Figure 10-2* for entries on DD Form 1210. It provides an example of the test results and calculations for a compaction test. Since this test used a 10-pound tamper from an 18-inch height and a Proctor mold, you can identify it as using ASTM D1557.

Five compaction runs were made. For each run the recorder entered the weight of the compacted soil plus the mold, and by subtracting the weight of the mold, arrived at the weight of the wet soil. The wet unit weight was then computed by converting grams to pounds, and increasing the volume to 1 cubic yard using the formula provided. In this case, $Block14 \div 453.6 \div Block10$. (Note: Conversion rates are 1 g = .0022 lb. and 1 lb. = 453.6 g.)



LABORATORY COMPACTION CHARACTERISTICS OF SOIL (COMPACTION TEST)

1. PROJECT Motor Pool
2. EXCAVATION NUMBER 3
3. SAMPLE NUMBER MP-P1-3
4. DATE 09/01/20__
5. LAYERS/BLOWS PER LAYER 5 / 25
6. WEIGHT OF TAMPER (lb) 10
7. HEIGHT OF DROP (in) 18
8. SPECIFIC GRAVITY OF SOLIDS, Gs 2.72
9. DIAMETER OF MOLD (in) 4
10. VOLUME OF SOLID SAMPLE (cu ft) ☒ 0.0333 cu ft ☐ 0.0750 cu ft

11. RUN NUMBER	UNITS	1		2		3		4		5					
12. WEIGHT OF MOLD + WET SOIL	Grams	5,806		5,942		6,033		6,078		5,978					
13. WEIGHT OF MOLD	Grams	3,946		3,946		3,946		3,946		3,946					
14. WEIGHT OF WET SOIL (12 - 13)	Grams	1,860		1,996		2,087		2,132		2,041					
15. WET UNIT WEIGHT, ywet ([14/453.6]/10)*	Pcf	123.0		132.0		138.0		141.0		135.0					
16. TARE NUMBER		12	13	14	15	16	17	18	19	20	21				
a. WEIGHT OF TARE + WET SOIL	Grams	21,636	20,276	20,003	19,414	20,003	20,684	20,457	21,183	20,502	20,684				
b. WEIGHT OF TARE + DRY SOIL	Grams	21,092	19,777	19,278	18,688	19,142	19,822	19,278	19,958	19,187	19,232				
c. WEIGHT OF WATER, Ww (a-b)	Grams	544	499	725	726	861	862	1,179	1,225	1,315	1,452				
d. WEIGHT OF TARE	Grams	10,251	10,070	9,752	9,435	10,070	10,523	9,707	10,206	10,070	9,934				
e. WEIGHT OF DRY SOIL, Ws (b-d)	Grams	10,841	9,707	9,526	9,253	9,072	9,299	9,571	9,752	9,117	9,298				
f. WATER CONTENT, w = Ww/Ws x 100 (c/e x 100)	Percent	5	5	8	8	9	9	12	12	14	16				
17. AVERAGE WATER CONTENT	Percent	5		8		9		12		15					
18. DRY UNIT WEIGHT, yd = ywet/1+ (w/100)	Pcf	117.14		122.22		126.20		125.89		117.39					

19. REMARKS * This formula contains the conversion from grams to pounds. Omit the conversion factor if the unit weight used is not grams.
Note: The form's percent calculations (16f and 17) are limited to two places and automatically round up or down.

20. TECHNICIAN (Signature)	21. COMPUTED BY (Signature)	22. CHECKED BY (Signature)
EA 2 Billings	EA 2 Johnson	EA 1 Barnes

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Figure 10-2 — Typical data sheet for a Modified Procter Test. DD Form 1210.

Blocks 16a through 16f contain the raw and calculated data for the moisture-content tests for each run. (Note: there are two tests for each run, one from the soil on the top of the mold and one from the bottom. The averages are set down as average moisture content, Block 17.)

Finally, the dry unit weight (density) in pounds per cubic foot (pcf) for each run was calculated by the formula shown in Block 18, and for the same compactive effort of ASTM D1557, the data shows that the density varies with the average moisture content.

However, determining the dry unit weight (density) is just a step in the process. The ultimate objective of the compaction test is to determine the moisture content that yields MDD for a given compactive effort, the OMC.

Refer to *Figure 10-3* for entries on DD Form 1211. This example shows how you determine the OMC by applying the test results to plot a curve.

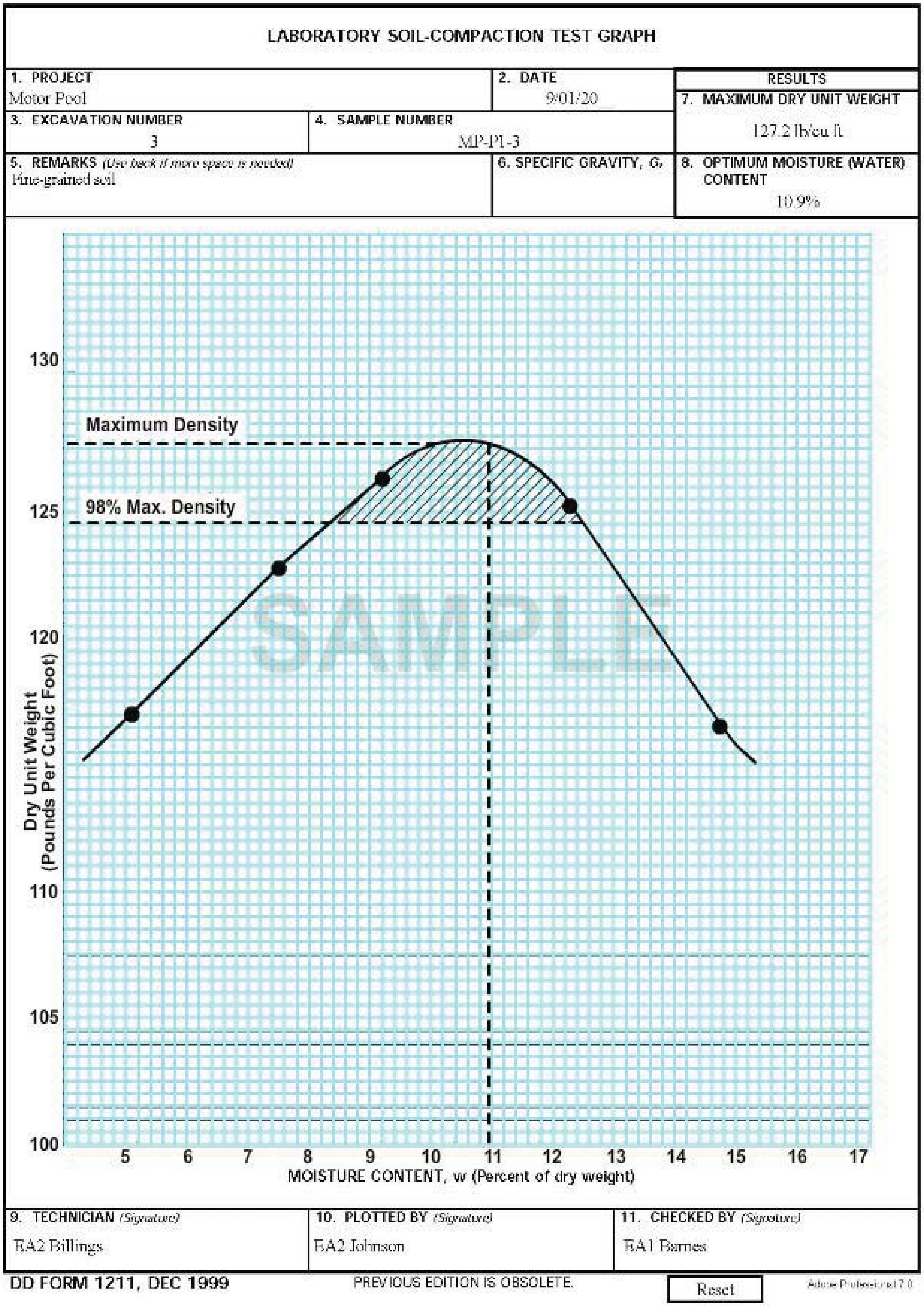
On Form 1211, plot the average moisture contents (w) on the horizontal coordinates (Block 17 Form 1210) and plot the dry unit weight (pcf) on the vertical coordinates (Block 18 Form 1210). Note that none of the dry unit weight data is at the peak of the curve, but rather the average of the two highest is used to peak the curve in a smooth parabolic transition.

For the test results plotted in this example, the curve indicates that the maximum attainable density for the given compactive effort was 127.2 pcf at which the OMC was 10.9 percent.

The dotted line marked “98% maximum density” would indicate for this example only, that project specifications required the constructors to obtain a maximum density of 98 percent through compaction. Since the maximum attainable was 127.2 pcf., 98 percent of this is 124.7 pcf., and the dotted line is drawn at the 124.7 pcf level.

Therefore, any moisture content lying within the crosshatched area (above the 98% line and under the curve) would produce the specified density for a given compactive effort. By looking at the extreme ends of the cross hatched areas, you can then conclude that the range of permissible moisture content is from 9 to 13 percent.

Refer to ASTM D698 - 07e1 *Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort* and ASTM D1557 - 07 *Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort* for additional information.



LABORATORY SOIL-COMPACTION TEST GRAPH

1. PROJECT Motor Pool	2. DATE 9/01/20	RESULTS 7. MAXIMUM DRY UNIT WEIGHT 127.2 lb/cu ft
3. EXCAVATION NUMBER 3	4. SAMPLE NUMBER MP-P1-3	
5. REMARKS *(Use back if more space is needed)* Fine-grained soil	6. SPECIFIC GRAVITY, G_s	8. OPTIMUM MOISTURE (WATER) CONTENT 10.9%

9. TECHNICIAN *(Signature)* EA2 Billings	10. PLOTTED BY *(Signature)* EA2 Johnson	11. CHECKED BY *(Signature)* EA1 Barnes

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Figure 10-3 — Example of plotting/determining OMC. DD Form 1211.

1.2.0 Density Tests

Once you have 1) determined the maximum density obtainable for a given soil at a given compactive effort, and from those results 2) plotted the range of densities and moisture contents that will satisfy the project's compaction requirements, you need to 3) have a control in place to measure whether or not the compaction requirements are being met on site, or "in situ."

Density testing is that control. If density tests produce results within the range specified, then the compaction is complete; if test results reflect densities outside the specified range, then either additional rolling may be necessary or the moisture content may need to be adjusted, or a combination of both. 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.

Under normal field conditions where the work is proceeding smoothly and uniform soils are being compacted, after the initial period of compacting the number of required density and moisture checks should be limited. If adequate densities are being obtained and proper moisture content is being maintained, inspection and oversight may transition with minimum effort to determining and verifying the combination of rollers and number of passes to achieve the desired result.

Where conditions are more variable, density and moisture checks may be needed more often for a fill of even moderate length. The engineer in charge of the job needs to determine the exact number of checks required to meet the project's requirements.

Several different methods are used to determine the in-place density of a soil, but EAs are most likely to use the sand-cone/sand-displacement method or the nuclear moisture-density meter method.

1.2.1 Sand-Cone or Sand-Displacement Method

You may use the sand-cone or sand-displacement method 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 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.

Refer to ASTM D1556 - 07 *Standard Test Method for Density and Unit Weight of Soil in Place by the Sand-Cone Method* and FM 5-472/MO-330 (Ch.2) *Materials Testing* for a full discussion of the procedures.

1.2.1.1 Equipment and Tools

Figure 10-4 shows the essential equipment and tools you need to perform the test. You will also need a baking pan, moisture content canisters, a paintbrush with moderately long bristles, and some modeling clay.

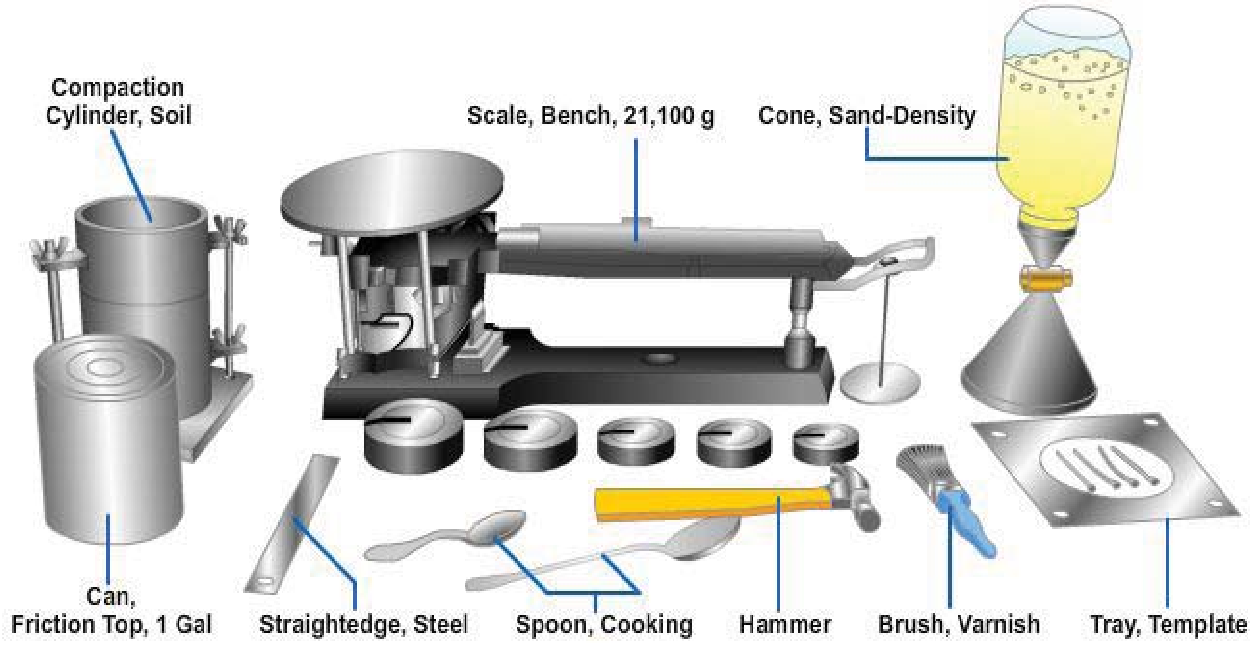


Figure 10-4 — Sand-cone (sand-displacement) apparatus with diagram.

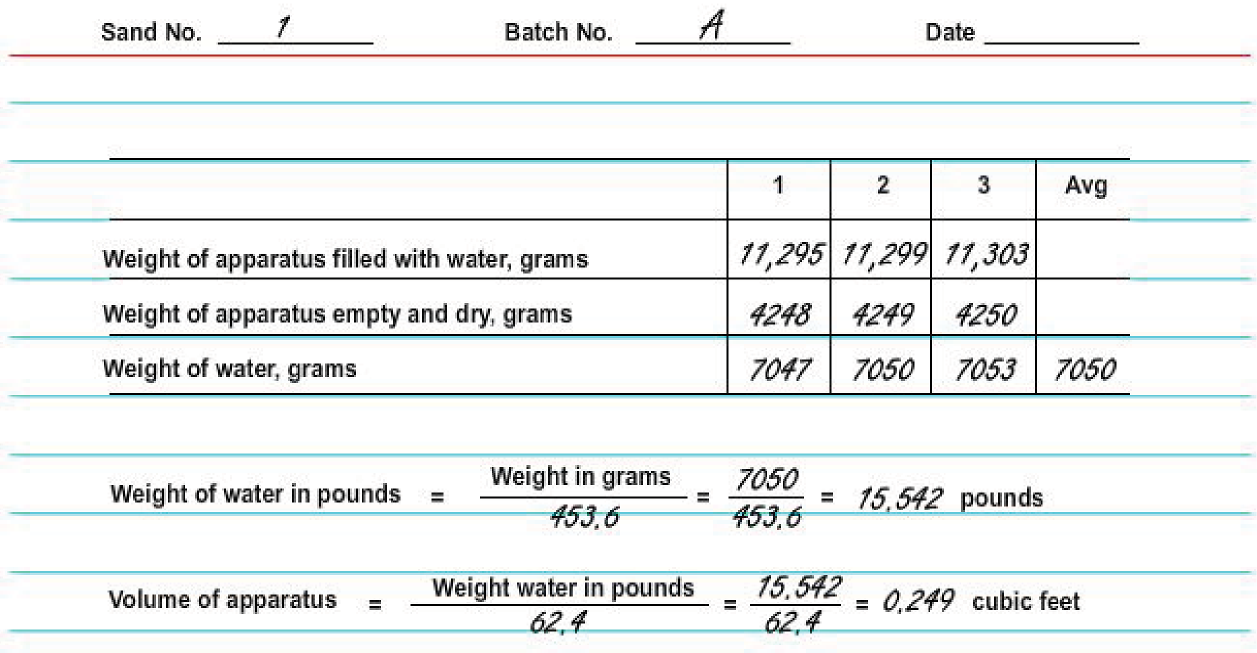
1.2.1.2 Calibration

The sand-cone/sand-displacement method includes three calibration procedures you must complete before you conduct the test: apparatus, sand, and surface.

The first (apparatus calibration**)** determines the volume of the jar and connecting cone (up through the cone valve). Refer to *Figure 10-5* for a calibration example.

To perform the calibration:

- Weigh assembled apparatus (jar and cone) when empty, clean, and dry.
- Record weight on data sheet.
- Weigh apparatus when jar and smaller end of cone is filled with water.
    - Ensure no air is trapped in water.
- Record weight on data sheet.
- Empty water from apparatus.
- Repeat steps at least three times.
- Determine average weight of water.
- Compute the volume of apparatus using the formulas shown in *Figure 10-5*.



Sand No. 1 Batch No. A Date

	1	2	3	Avg
Weight of apparatus filled with water, grams	11,295	11,299	11,303	
Weight of apparatus empty and dry, grams	4248	4249	4250	
Weight of water, grams	7047	7050	7053	7050

$$\text{Weight of water in pounds} = \frac{\text{Weight in grams}}{453.6} = \frac{7050}{453.6} = 15.542 \text{ pounds}$$

$$\text{Volume of apparatus} = \frac{\text{Weight water in pounds}}{62.4} = \frac{15.542}{62.4} = 0.249 \text{ cubic feet}$$

Figure 10-5 — Sample data sheet for calibrating sand-cone (sand-displacement) apparatus.

The second (sand calibration**)** determines the density of the sand. The sand for the sand-cone test must be clean, dry, free-flowing, and, while the test is performed, have a constant moisture content. Most suitable is a uniformly graded, well-rounded sand that passes the No. 20 sieve but is retained on the No. 40 sieve. It should contain almost no material finer than the No. 200 sieve.

You can purchase this sand in bulk quantities and extensively reuse it to perform many sand-cone tests; you may opt to determine the density of the sand upon receipt, but since changes in temperature and humidity affect the sand's bulk density, you must still recalibrate the sand before each test.

Refer to *Figure 10-6* DD Form 1215*.* To calibrate (or recalibrate) the sand:

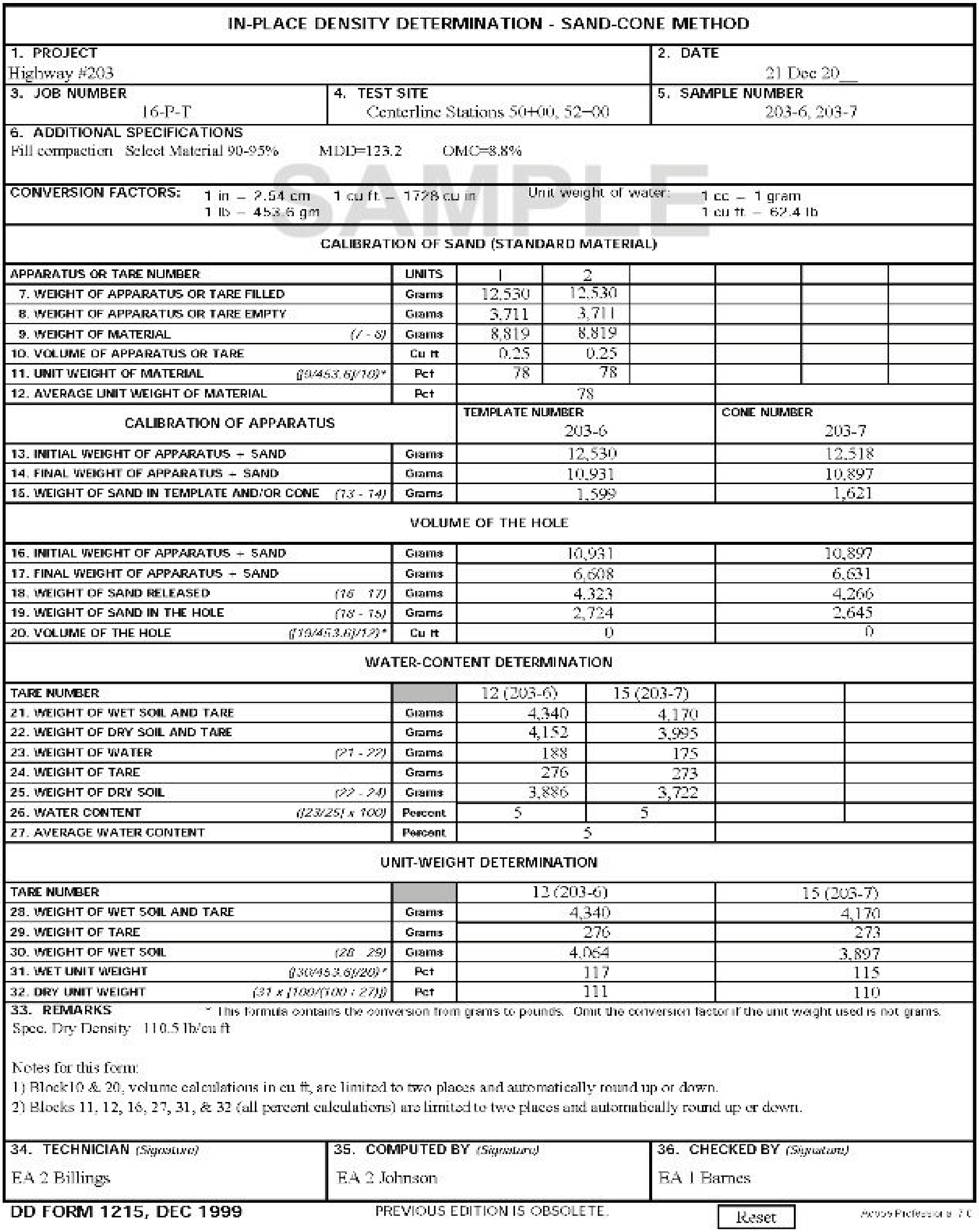
- Record volume from first calibration in Block 10.
- Weigh assembled apparatus when empty, clean, and dry.
- Record weight in Block 8.
- Fill apparatus with air-dried sand by pouring in through large end of cone.
- When jar and lower end of cone are filled, remove all excess sand.
- Weigh sand-filled apparatus.
- Record weight in Block.
- Subtract weights to determine weight of sand.
- Record in Block 9.
- Determine calibrated density of sand (unit weight of material) using formula provided.
- Record in Block 11.

As an alternative method of sand calibration, you can use a container of known volume such as a Proctor mold. In this method:

- Weigh mold and attached base plate.
- Attach mold collar.
- Pour sand through sand cone into mold.
- Remove collar.
- Strike off excess sand.
- Brush off outside of mold and base plate.
- Weigh sand-filled mold and base plate.

The difference in weights (filled and empty) divided by the known volume of the mold (0.333 for Procter mold, 0.0750 for CBR mold) is the density of the sand.

The third (surface calibration) is part of site preparation and must be performed at the test site.



IN-PLACE DENSITY DETERMINATION - SAND-CONE METHOD

1. PROJECT Highway #203		**2. DATE** 21 Dec 20__
3. JOB NUMBER 16-P-T	**4. TEST SITE** Centerline Stations 50+00, 52+00	**5. SAMPLE NUMBER** 203-6, 203-7

6. ADDITIONAL SPECIFICATIONS
Fill compaction Select Material 90-95% MDD=123.2 OMC=8.8%

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

CALIBRATION OF SAND (STANDARD MATERIAL)

APPARATUS OR TARE NUMBER	UNITS	1	2				
7. WEIGHT OF APPARATUS OR TARE FILLED	Grams	12,530	12,530				
8. WEIGHT OF APPARATUS OR TARE EMPTY	Grams	3,711	3,711				
9. WEIGHT OF MATERIAL (7 - 8)	Grams	8,819	8,819				
10. VOLUME OF APPARATUS OR TARE	Cu ft	0.25	0.25				
11. UNIT WEIGHT OF MATERIAL ([9/453.6]/10)*	Pcf	78	78				
12. AVERAGE UNIT WEIGHT OF MATERIAL	Pcf	78					

CALIBRATION OF APPARATUS		TEMPLATE NUMBER 203-6	CONE NUMBER 203-7
13. INITIAL WEIGHT OF APPARATUS + SAND	Grams	12,530	12,518
14. FINAL WEIGHT OF APPARATUS + SAND	Grams	10,931	10,897
15. WEIGHT OF SAND IN TEMPLATE AND/OR CONE (13 - 14)	Grams	1,599	1,621

VOLUME OF THE HOLE

16. INITIAL WEIGHT OF APPARATUS + SAND	Grams	10,931	10,897
17. FINAL WEIGHT OF APPARATUS + SAND	Grams	6,608	6,631
18. WEIGHT OF SAND RELEASED (16 - 17)	Grams	4,323	4,266
19. WEIGHT OF SAND IN THE HOLE (18 - 15)	Grams	2,724	2,645
20. VOLUME OF THE HOLE ([19/453.6]/12)*	Cu ft	0	0

WATER-CONTENT DETERMINATION

TARE NUMBER		12 (203-6)	15 (203-7)		
21. WEIGHT OF WET SOIL AND TARE	Grams	4,340	4,170		
22. WEIGHT OF DRY SOIL AND TARE	Grams	4,152	3,995		
23. WEIGHT OF WATER (21 - 22)	Grams	188	175		
24. WEIGHT OF TARE	Grams	276	273		
25. WEIGHT OF DRY SOIL (22 - 24)	Grams	3,886	3,722		
26. WATER CONTENT ([23/25] x 100)	Percent	5	5		
27. AVERAGE WATER CONTENT	Percent	5			

UNIT-WEIGHT DETERMINATION

TARE NUMBER		12 (203-6)	15 (203-7)
28. WEIGHT OF WET SOIL AND TARE	Grams	4,340	4,170
29. WEIGHT OF TARE	Grams	276	273
30. WEIGHT OF WET SOIL (28 - 29)	Grams	4,064	3,897
31. WET UNIT WEIGHT ([30/453.6]/20)*	Pcf	117	115
32. DRY UNIT WEIGHT (31 x [100/(100 + 27)])	Pcf	111	110

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

Spec. Dry Density 110.5 lb/cu ft

Notes for this form:
1) Block10 & 20, volume calculations in cu ft, are limited to two places and automatically round up or down.
2) Blocks 11, 12, 16, 27, 31, & 32 (all percent calculations) are limited to two places and automatically round up or down.

34. TECHNICIAN *(Signature)* EA 2 Billings	**35. COMPUTED BY** *(Signature)* EA 2 Johnson	**36. CHECKED BY** *(Signature)* EA 1 Barnes

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Figure 10-6 — In-place density determination, sand-cone (sand-displacement) method. DD Form 1215.

1.2.1.3 Site Preparation

Site preparation requires the following actions:

1. Preparing the test surface
    - Select an area of the compacted surface that appears most level.
    - Remove loose debris but do not pack or smooth the surface.
2. Seating the template tray
    - Seat template tray flush on the surface, especially around center hole.
    - Seal any spaces around center hole with modeling clay.
    - Force nails through corner holes in tray to hold it firmly in place.
3. Surface calibration of the tray (Surface calibration accounts for surface irregularities of the area to be tested.)
    - Record weight of sand filled apparatus in Block 13 (see Block 7).
    - Close valve.
    - Turn sand-filled apparatus over; place large cone over center hole.
    - Open valve; allow sand to pass through until large cone is completely filled.
    - Do NOT shake or vibrate the apparatus.
    - Close valve.
    - Weigh apparatus with remaining sand.
    - Record in Blocks 14 and 16.
    - Subtract weights to determine weight of sand that passed through cone valve into lower cone and center hole.
    - Record in Block 15.

After performing the surface calibration, recover as much of the sand from the tray as possible without disturbing the template tray or the soil in the hole.

Brush the remaining sand particles lightly from within the tray. Leave the template in place for the volume-of-hole determination.

1.2.1.4 Volume-of-Hole Determination

The volume-of-hole determination consists of digging out a soil sample through the center of the template and computing the volume of the resulting hole.

- Record known tare weight of container in Blocks 24 and 29.
- Dig through center hole of template tray about 6 inches deep and approximately same diameter as hole in tray.
    - Keep inside of hole as free from pockets and sharp protuberances as possible.
- Remove material from hole ensuring **ALL** material is placed in container.
    - Keep lid on container as much as possible to prevent excessive moisture loss until it is weighed.
- When all removed material is in container, immediately weigh.

- Record in Blocks 21 & 28.
- Mark container for later identification when soil moisture content is determined.
- Place sand-cone apparatus over hole in tray.
- Open valve to allow sand to flow into hole just dug.
- Close valve when sand stops flowing.
- Weigh apparatus with remaining sand.
- Record in Block 17.
- Determine weight of sand required to fill hole, and volume of hole using the formulas provided.
- Record in Blocks 18, 19, and 20.

1.2.1.5 Density Determination

Now that you have determined the volume of the hole, the only remaining requirements are to determine the moisture content and the dry density of the sample removed from the hole.

- Determine moisture content by using the oven-dried method you studied in EA Basic.
- Record in Blocks 22-27.
- Compute wet density (wet unit weight) using the formula provided.
- Record in Blocks 30 and 31.
- Compute dry density (dry unit weight) using the formula provided.
- Record in Block 32.

1.2.2 Nuclear Moisture-Density Meter Method

ASTM D 6938 REV A 2008-JUN-01,*Standard Test Method for In-Place Density and Water Content of Soil and Soil- Aggregate by Nuclear Methods (Shallow Depth)*

Another method available to determine moisture content and density of in-place soil uses a nuclear moisture-density meter (*Figure 10-7*).

A nuclear moisture-density meter contains sealed radioactive materials, typically cesium (Cs) (*SEE-zee-əm*) and a combination of americium (Am) (*AM-ə-RIS-ee-əm*) mixed with beryllium (Be) (*bə-RIL-ee-əm*) powder.

The cesium emits gamma radiation that the detector in the meter can count when it is passed through the soil. This count can be translated to density.

The americium, interacting with the beryllium, emits neutrons following collision with hydrogen that are moderated and detected by the meter. The moisture content can be determined by measuring the hydrogen concentration in the soil.

When you use the moisture-density meter, you obtain and use counts or readings with a calibration chart to determine the wet density and moisture content. Then, dry density is computed from the wet density.

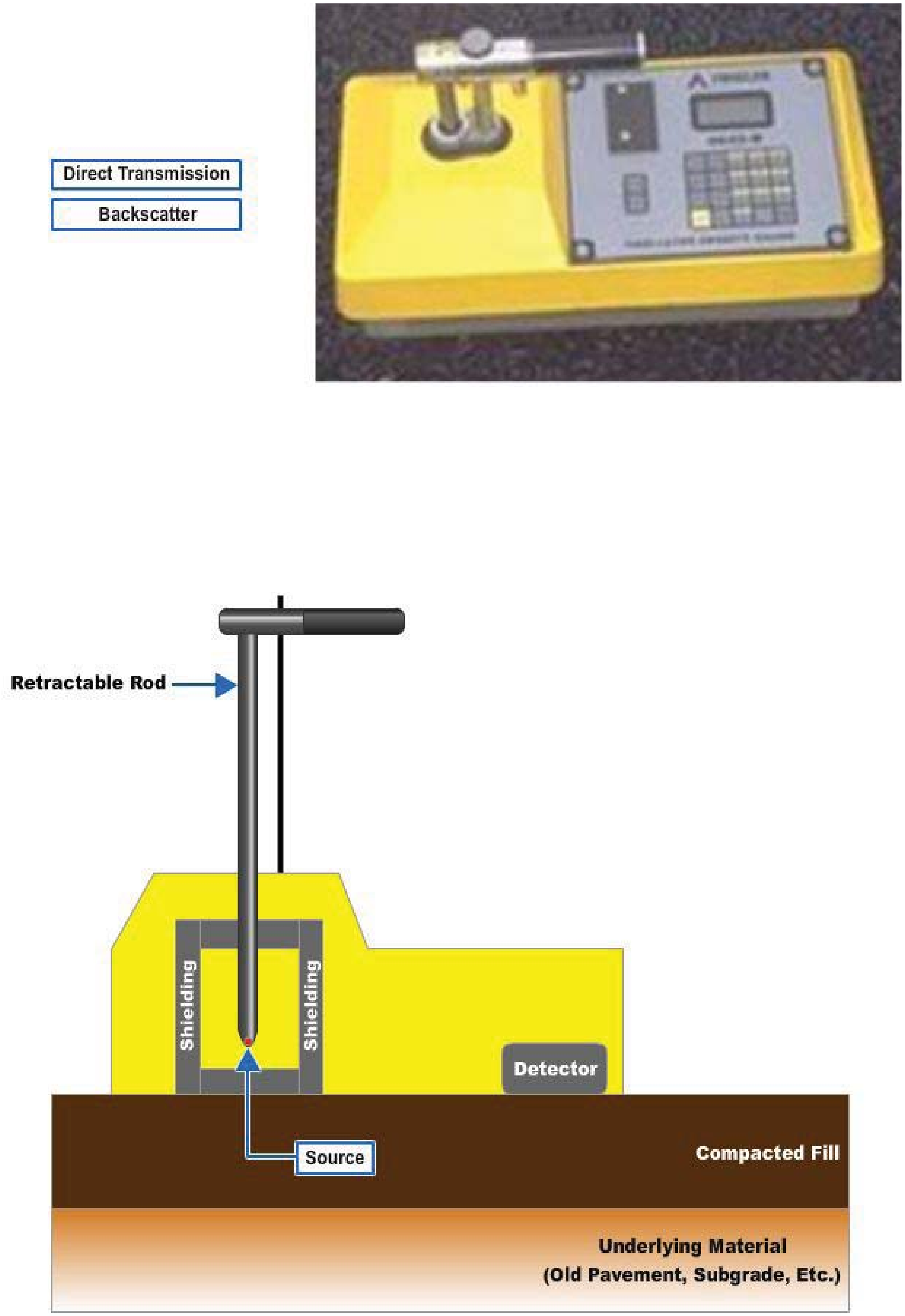


Figure 10-7 — Example of a nuclear moisture-density meter.

⚠ CAUTION ⚠

You must complete specialized training and be certified through the Naval Construction Training Center at Gulfport, Mississippi, or Port Hueneme, California, before using the nuclear moisture-density meter.

1.3.0 Bearing Tests

ASTM D1883 - 07e2 *Standard Test Method for CBR (California Bearing Ratio) of Laboratory-Compacted Soils*

A soil's bearing capacity is expressed in terms of shear resistance, in other words, the capacity of the load-bearing portion of a material to resist displacement in the direction of the force exerted on it by a load. There are various types of load-bearing tests, but this chapter will present only the California bearing ratio (CBR) test.

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). Therefore, the CBR value may be thought of as the strength of the soil relative to that of crushed rock.

⚠ CAUTION ⚠

Minor variations in the CBR test will cause wide variations in the results. Consequently, when you are tasked with performing this test, follow in detail the step-by-step procedures in FM 5-472/NAVFAC MO 330. Difficulties may still arise.

⚠ CAUTION ⚠

The CBR is a measure of the shearing resistance of a soil under carefully controlled conditions of density and moisture. It is determined by a penetration shear test and is used with ***empirical*** (em-**pir**-i-kuh l) curves for designing flexible pavements.

The test procedure used to determine the CBR consists of two principal steps:

1. Prepare soil test specimens.
2. Perform penetration test on prepared samples.

A single standardized procedure for the penetration portion of the test has been established, but because soil conditions and construction methods vary too widely, it is not possible to establish a single procedure for preparing test specimens, and the soil test specimens need to be prepared to duplicate the soil conditions existing (or expected to occur later) in the field.

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

1.3.1 CBR Test Equipment and Tools

Figure 10-8 shows the equipment and tools needed to perform the CBR test. Most obvious could be the CBR mold previously described by name, but the principal piece of equipment is the CBR loading press used to force the penetration piston into the compacted soil specimen.

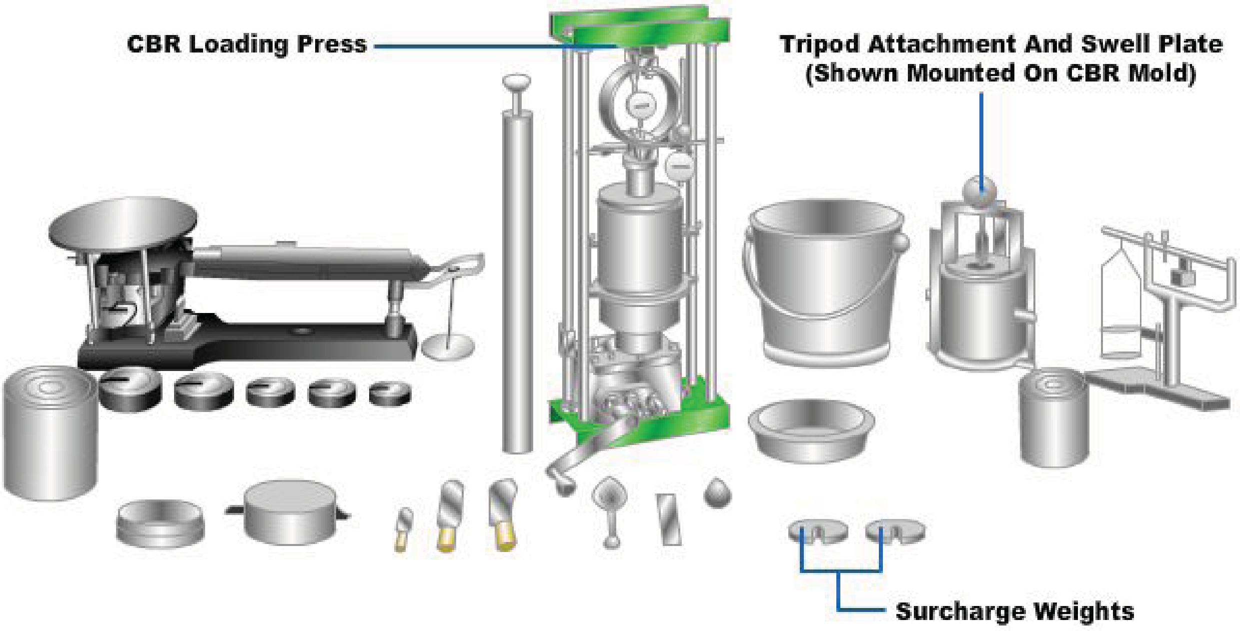


Figure 10-8 — Example of laboratory CBR test equipment and tools.

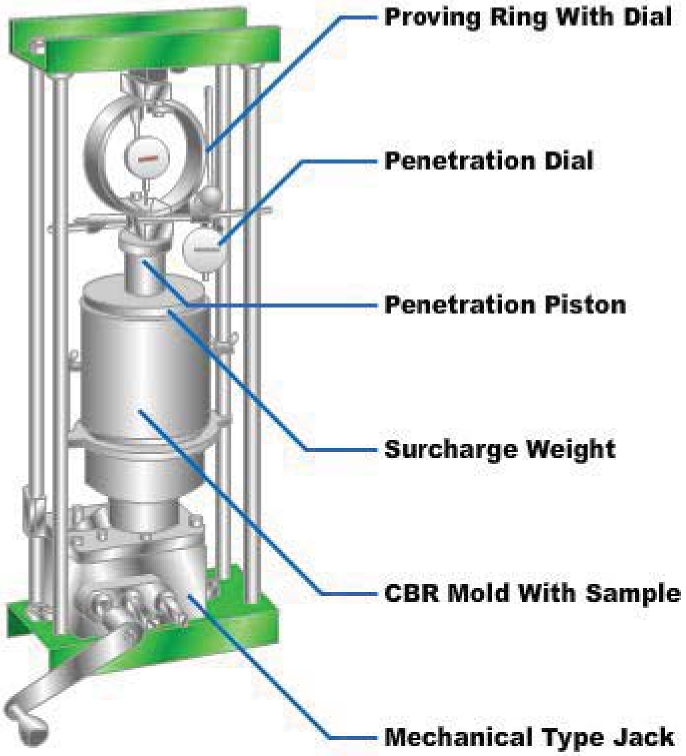


Figure 10-9 — Typical assembled CBR loading press.

The complete CBR loading-press assembly includes a penetration piston, proving ring and proving-ring dial, penetration dial, and a mechanical (or motorized) jack (*Figure 10-9*).

Three proving rings have capacities of 2,000, 5,000, and 7,000 pounds, respectively.

Surcharge weights are used to approximate (within 5 pounds) the expected weight of the project's pavement and base.

When fitted with a dial indicator, the tripod attachment and swell plate are used to measure expansion (swell) of the sample material in the CBR mold.

Other sundry laboratory equipment and tools needed to perform the test include a balance or scale, 10-pound tamper, mixing bowls, spoons, spatulas, soaking tank or bucket, and moisture canisters.

1.3.2 Preparation of Test Samples

When you perform a CBR test on a compacted sample, use the 6-inch-diameter CBR mold, and insert a 2½-inch spacer disk in the bottom of the mold before adding soil material, thus reducing the depth of the final prepared sample to 4½-inches. Using any other size spacer will result in volume and compactive effort data changes that may not meet ASTM D1883 or other recognized standards for the CBR test.

The number of specimens you prepare and the method you use to prepare them will depend upon such factors as the type of airfield or road, and the soils encountered at the site. You need to test the soil sample in the laboratory at a density comparable to the density required at the construction site.

However, there are situations where moisture conditions are favorable and the subgrade will not accumulate moisture approaching a saturated condition. In these cases, you should test samples at a moisture content approximating the actual moisture conditions anticipated during the time the road or airfield will be used. In all other conditions, test the laboratory samples in a saturated condition.

You attain a saturated condition by soaking the sample. First, place the sample in the mold and compact it. The compactive effort used and the number of compacted samples required depend upon the soil type, weight and type of field compaction equipment, and other job conditions. (Refer to FM 5-472/NAVFAC MO-330 for specific guidance.)

Normally, compactive efforts are 10, 25, and 56 blows per layer (for five layers). Compact a minimum of 5 molds for each compactive effort. The 10-pound tamper is used from the 18-inch height for compacting the samples.

After compacting the sample, remove the collar, trim the top, and remove the base plate and spacer disk. Place a piece of filter paper over the trimmed top, then place the base plate over the top, turn the mold over, and set it in a bucket on its base plate. Now the bottom of the sample next to the spacer disk during compaction is uppermost.

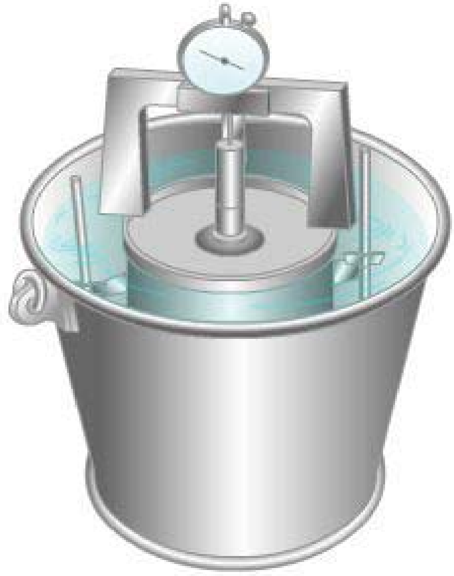


Figure 10-10 — Example of apparatus soaking a CBR sample testing for swell.

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 (5 lbs), but never use a total weight of less than 4.54 kilograms (10 lbs).

If no pavement weight is specified, use 4.54 kilograms.

Then set the CBR mold, tripod attachment, dial, and swell plate, into a bucket, as shown in *Figure 10-10*.

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. Soak the sample for 96 hours.

Then, at the end of the soaking period, read the dial again to determine the amount of swell. A swell exceeding 3 percent of the initial height of the specimen is considered excessive.

Make a final reading of the dial, remove the sample and mold from the water, and allow them to drain for about 15 minutes before conducting the penetration test. It may be necessary to tilt the specimen to remove surface water, but do not disturb the specimen's surface while removing the water.

1.3.3 Penetration Test

To perform the actual CBR penetration test, execute the following steps according to FM 5-472/NAVFAC MO 330/AFJMAN 32-1221(I), entering all information on DD Form 1212 as illustrated in *Figures 10-11 and 10-12*.

1. Prepare the components.
    - Place the mold on the jack.
    - Attach and adjust the piston to the jack; then zero the dial indicator.
    - 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.
    - Replace the remainder of the surcharge weights required for the mold.
    - 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.
    - Turn both dial indicators to 0.
2. Apply the load.
    - Crank the jack to lower the piston at a rate of 0.05 inch per minute.
    - 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.
    - Record the proving-ring dial readings on the form.
3. Determine the average moisture of the soaked samples.
    - 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.
    - Weigh the tare and record on the form.
    - 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.
    - Weigh the tare and record on the form.

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

4. Solve the computations for each reading, and record the results on the form.
    - 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.
    - 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.
    - 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 10-12*. 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.
    - Calculate the CBR (in percent) for penetration at 0.100 and 0.200 inches using the formula:

$$\frac{corrected\ unit\,load}{s\tan dard\,unit\,load}\times 100$$

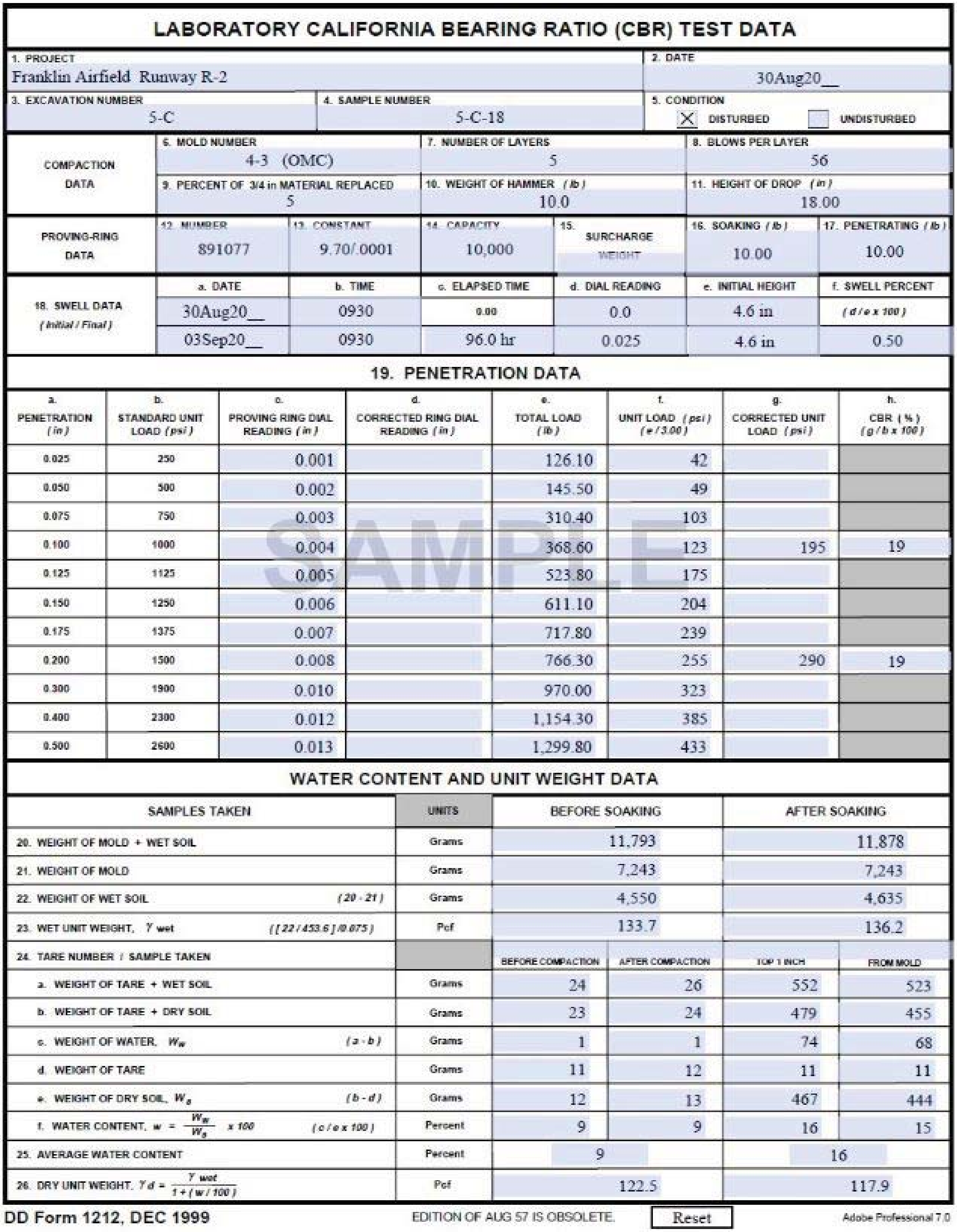
Since the standard unit load for each penetration is given (Block 19b of the form), perform the following computations for each penetration:

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

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

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.

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



LABORATORY CALIFORNIA BEARING RATIO (CBR) TEST DATA

1. PROJECT Franklin Airfield Runway R-2		2. DATE 30Aug20__
3. EXCAVATION NUMBER 5-C	4. SAMPLE NUMBER 5-C-18	5. CONDITION ☒ 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)* 10.0	11. HEIGHT OF DROP *(in)* 18.00

PROVING-RING DATA	12. NUMBER 891077	13. CONSTANT 9.70/.0001	14. CAPACITY 10,000	15. SURCHARGE WEIGHT	16. SOAKING *(lb)* 10.00	17. PENETRATING *(lb)* 10.00

18. SWELL DATA *(Initial / Final)*	a. DATE	b. TIME	c. ELAPSED TIME	d. DIAL READING	e. INITIAL HEIGHT	f. SWELL PERCENT
	30Aug20__	0930	0.00	0.0	4.6 in	*(d / e x 100)*
	03Sep20__	0930	96.0 hr	0.025	4.6 in	0.50

19. PENETRATION DATA

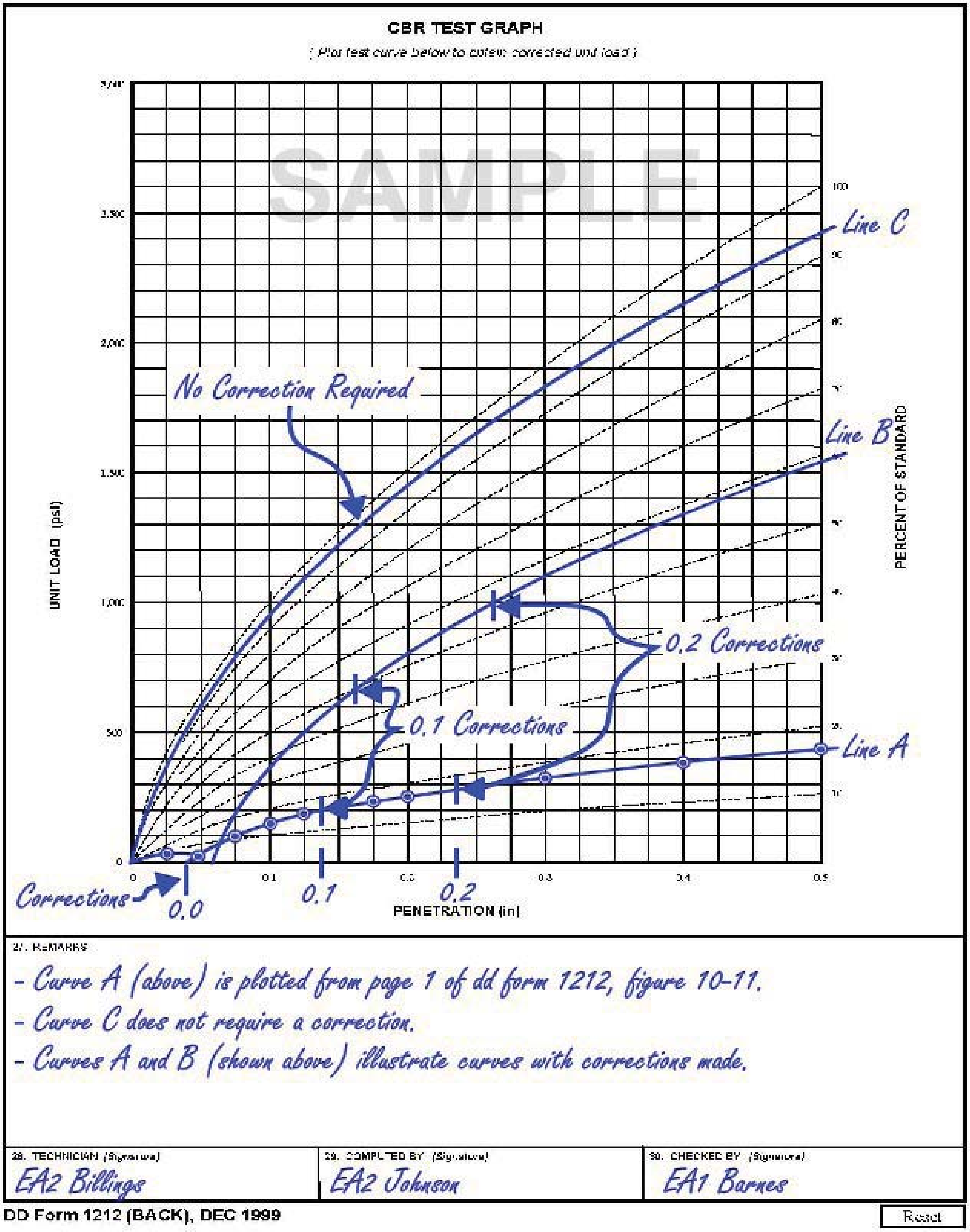
a. PENETRATION *(in)*	b. STANDARD UNIT LOAD *(psi)*	c. PROVING RING DIAL READING *(in)*	d. CORRECTED RING DIAL READING *(in)*	e. TOTAL LOAD *(lb)*	f. UNIT LOAD *(psi)* *(e / 3.00)*	g. CORRECTED UNIT LOAD *(psi)*	h. CBR (%) *(g / b x 100)*
0.025	250	0.001		126.10	42		
0.050	500	0.002		145.50	49		
0.075	750	0.003		310.40	103		
0.100	1000	0.004		368.60	123	195	19
0.125	1125	0.005		523.80	175		
0.150	1250	0.006		611.10	204		
0.175	1375	0.007		717.80	239		
0.200	1500	0.008		766.30	255	290	19
0.300	1900	0.010		970.00	323		
0.400	2300	0.012		1,154.30	385		
0.500	2600	0.013		1,299.80	433		

WATER CONTENT AND UNIT WEIGHT DATA

SAMPLES TAKEN	UNITS	BEFORE SOAKING		AFTER SOAKING	
20. WEIGHT OF MOLD + WET SOIL	Grams	11,793		11,878	
21. WEIGHT OF MOLD	Grams	7,243		7,243	
22. WEIGHT OF WET SOIL *(20 - 21)*	Grams	4,550		4,635	
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	26	552	523
b. WEIGHT OF TARE + DRY SOIL	Grams	23	24	479	455
c. WEIGHT OF WATER, W_w *(a - b)*	Grams	1	1	74	68
d. WEIGHT OF TARE	Grams	11	12	11	11
e. WEIGHT OF DRY SOIL, W_s *(b - d)*	Grams	12	13	467	444
f. WATER CONTENT, $w = \frac{W_w}{W_s} \times 100$ *(c / e x 100)*	Percent	9	9	16	15
25. AVERAGE WATER CONTENT	Percent	9		16	
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. Reset Adobe Professional 7.0

Figure 10-11 — Example of California bearing ratio test data. DD Form 1212 (front).



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 10-11.
- Curve C does not require a correction.
- Curves A and B (shown above) illustrate curves with corrections made.

28. TECHNICIAN *(Signature)* EA2 Billings	29. COMPUTED BY *(Signature)* EA2 Johnson	30. CHECKED BY *(Signature)* EA1 Barnes

DD Form 1212 (BACK), DEC 1999

Reset

Figure 10-12 — Example of California bearing ratio test data. DD Form 1212 (back).

1.4.0 Hydrometer Analysis

ASTM D422 - 63(2007) *Standard Test Method for Particle-Size Analysis of Soils*

In EA Basic you learned that a soil containing 3% or more by weight of particles smaller than 0.020 mm in diameter is considered susceptible to frost. To determine if a soil reaches the 3% threshold of that size particle, you need to perform a particle-size analysis of the materials passing the No. 200 (0.074-mm) sieve.

You do this by hydrometer analysis. This section identifies the items you use for a hydrometer analysis and briefly summarizes the procedures. For a full presentation of the procedures, you refer again to FM 5-472/NAVFAC MO-330 or to ASTM D422.

1.4.1 Apparatus

Figure 10-13 shows some of the items you need to perform a particle-size analysis by hydrometer analysis.

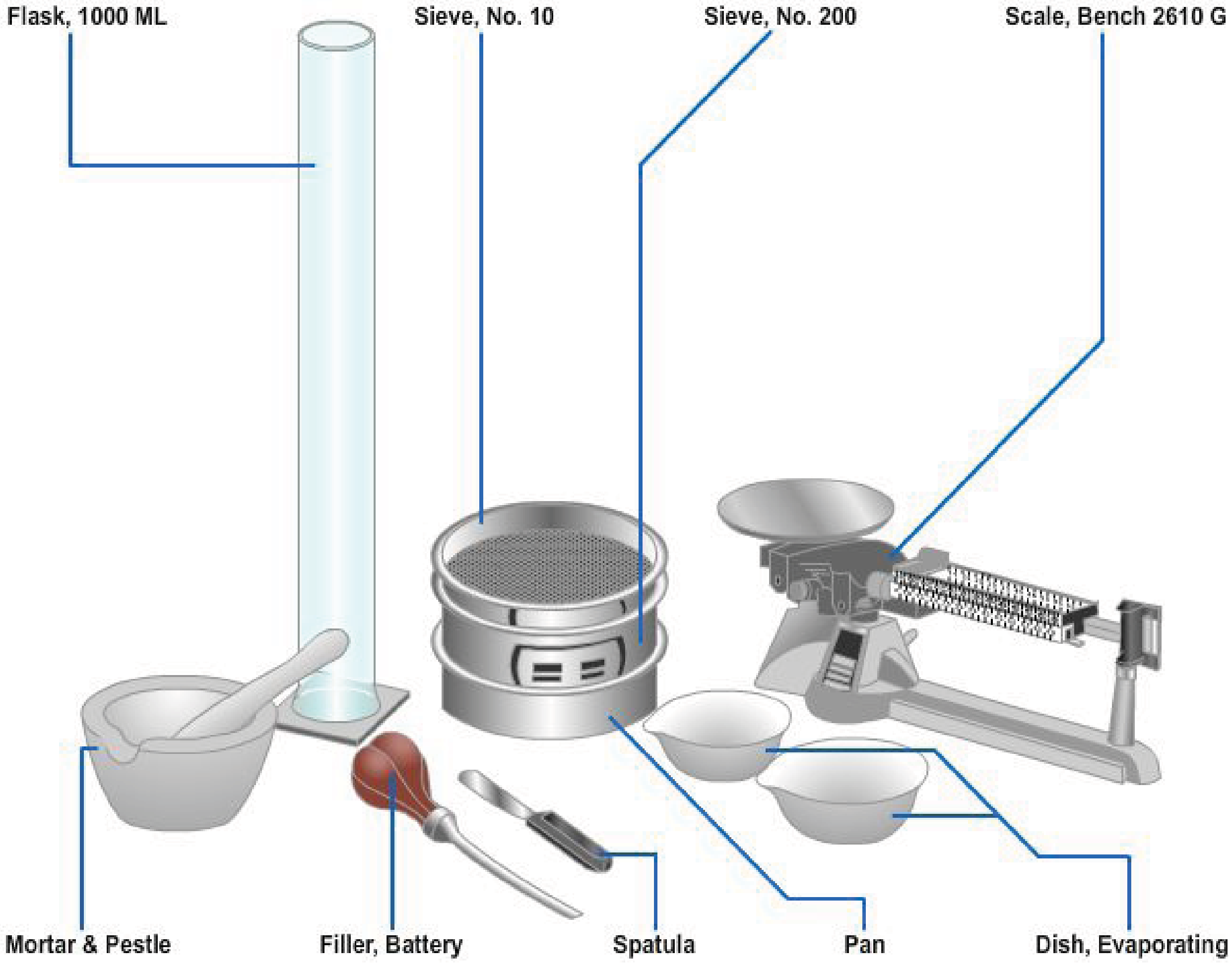


Figure 10-13 — Example of equipment for grain size distribution by hydrometer analysis.

You will also need an ASTM hydrometer, and a dispersion cup and stirrer as shown in *Figures 10-14 A* & *B* respectively, a thermometer accurate to 1°F (0.5°C), and a clock or watch with a second hand.

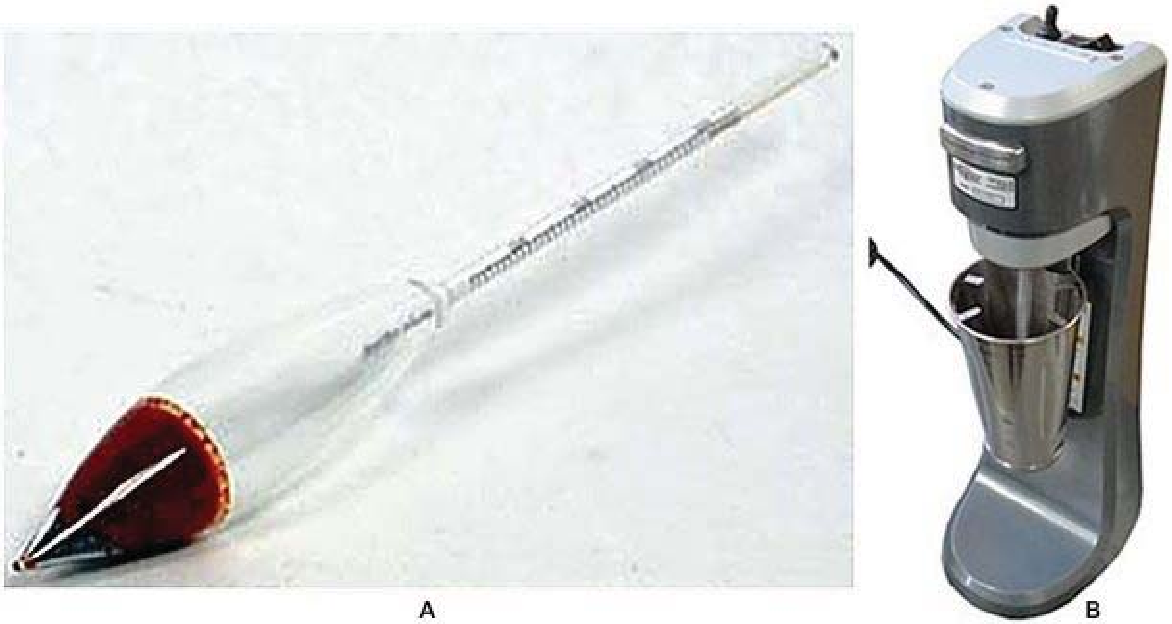


Figure 10-14 — Example of additional equipment for hydrometer analysis.

ASTM hydrometers are graduated to read in either specific gravity or in grams per liter, and are calibrated at a standard temperature of 68°F (20°C).

1.4.2 Sample Preparation and Test Procedure

The following steps provide guidance to perform the hydrometer test, but refer to FM 5-472/NAVFAC MO-330 for more specific details.

1. Prepare sample.
    - Obtain –200 sample as prepared in sieve analysis.
        - Sandy soils — approximately 100 grams
        - Silty or clayey soils — approximately 50 grams
    - Place in dish.
    - Add distilled water until submerged.
    - Determine amount and type of dispersing agent.
    - Record in Blocks 9 and 10 DD Form 1794.
        - Typically 15 milliliters
    - Add dispersing agent.
    - Soak for 16 hours (minimum).
2. Determine hydrometer type.
    - Type 151H — range 1.000 to 1.038 — measures specific gravity.
    - Type 152H — range 0 to 60 — measures grams per liter.
3. Determine composite correction for meniscus and dispersing agent.
    - Place about 500 milliliters of distilled water in graduated cylinder.
    - Place amount of dispersing agent used in step one in cylinder and mix well.

- Add additional distilled water to reach 1,000 milliliter.
- Place hydrometer in cylinder and allow to settle for 20-25 seconds.
- Read hydrometer at top of meniscus formed on stem.
  - Type 151H — composite correction is difference between reading and 1.
  - Type 152H — composite correction is difference between reading and 0.
- Record in Block 11 DD Form 1794.
- Remove hydrometer from dispersing fluid cylinder.
- Place in cylinder of distilled water.

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

4. Perform hydrometer test.

- Record all identifying information for sample, dispersing agent, quantity used, and composite correction on DD Form 1794 (*Figure 10-15*).
- Obtain decimal fines from original soil sample from DD Form 1206.
- Record in Block 12 DD Form 1794.
- Obtain specific gravity of solids (G_s) of soil sample from DD Form 1208.
- Record G_s in Block 13 DD Form 1794.
- Empty and thoroughly rinse graduated cylinder containing dispersing solution.
- Transfer soaked sample to a dispersion cup, using distilled water to wash any residue from dish into cup.
- Add distilled water to cup until water surface is 3 inches below top of cup.
- Place cup in dispersing machine and mix.
  - Silts and sands — 5 minutes
  - Low-plasticity clay — 7 minutes
  - High-plasticity clay — 9 minutes
- Transfer mixed solution to clean 1,000-milliliter graduated cylinder.
  - Use distilled water to wash any residue from cup into cylinder.
- Add distilled water until reaching 1,000-milliliter volume mark.
- Place rubber cap over open end of the cylinder.
- Turn cylinder upside down and back for a period of 1 minute to complete agitation of 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.
- After shaking for 1 minute, place cylinder on a level and sturdy surface where it will not be disturbed.

- Remove cap and start timer.
- Remove any foam that formed during agitation by lightly touching it with a bar of soap.
- Immerse hydrometer slowly into liquid for 20 to 25 seconds before each reading. Take hydrometer reading (R^1) at 1 and 2 minutes elapsed time.
    - As soon as the 1- and 2-minute readings are taken, carefully remove hydrometer and place it in second cylinder of pure distilled water using a spinning motion.
- Record R^1 in Block 16.
- Place a thermometer in solution.
- Record the temperature reading, in centigrade, to nearest whole degree.
- Record ^0C in 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.
- Repeat hydrometer immersions for remainder of required readings at following intervals: 5, 15, and 30 minutes; 1, 2, 4, and 24 hours.
    - After each reading, remove hydrometer and place in cylinder of distilled water.
- Obtain corresponding temperature readings.
- Record timed R^1 & ^0C readings in Blocks 16 & 18.

5. Determine dry weight of sample.
    - Weigh pudding pan or dish.
    - Record in Block 24.
    - Carefully wash all of sample and place into dish.
    - Oven-dry sample, allow it to cool, and determine and record weight of sample and pan or dish.
    - Record in Block 23.
6. Determine weight of the dry soil by subtracting the weight of the pan from the weight of the pan and dry soil.
    - Record as weight of oven-dried soil (W_s) Block 25.
7. Compute the results on DD Form 1794.

Formulas are provided below data entry blocks on DD Form 1794, but further explanation of calculations (with tables) are available in FM 5-472/NAVFAC MO-330.

1.4.3 Calculations

Hydrometer readings require correction due to the following factors:

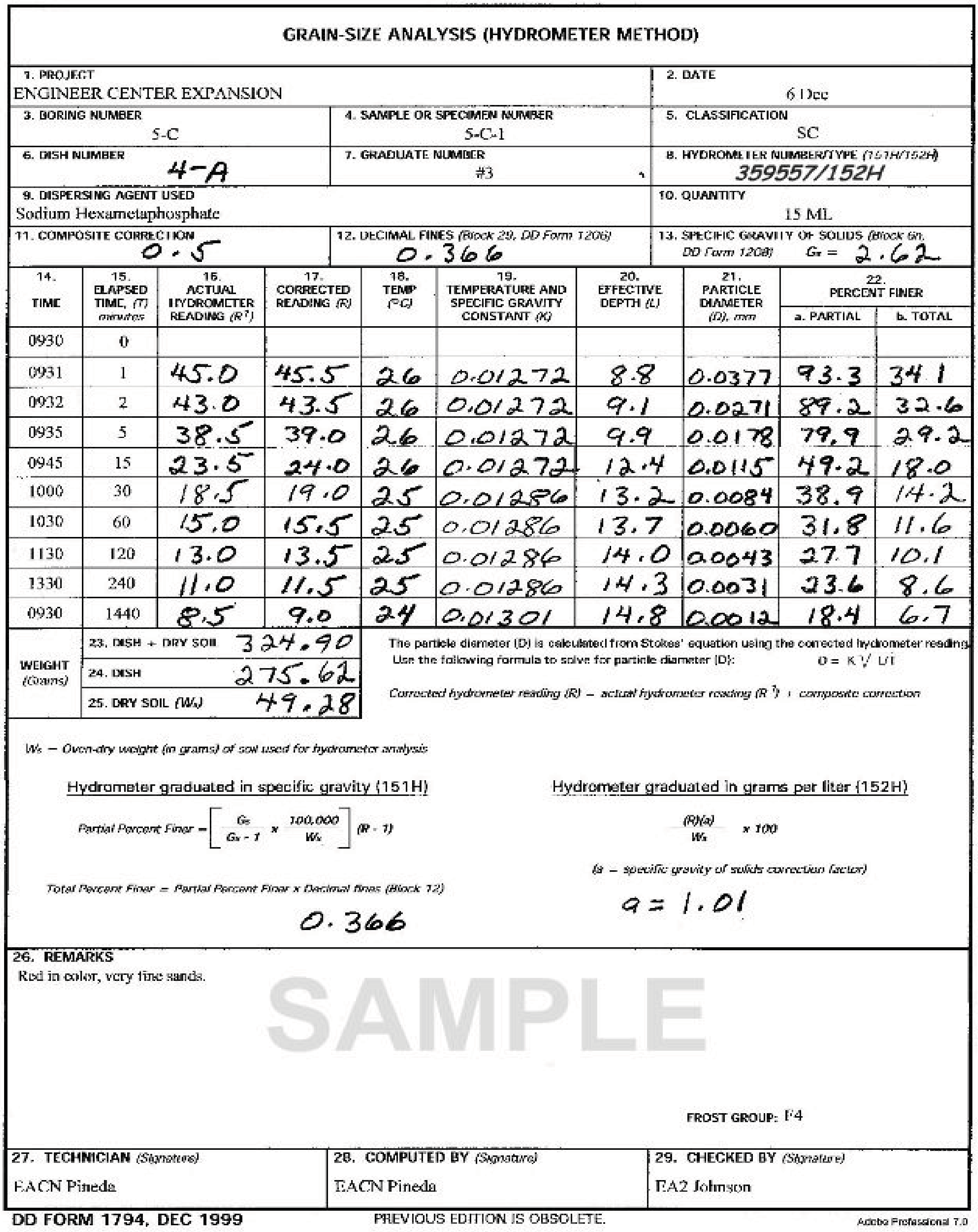
- The difference between the test temperature at each reading and the standard temperature of 68°F
- The effect of the dispersing agent on the liquid density of the soil-water suspension
- The difficulty of reading the hydrometer at the meniscus of the murky soil-water suspension.

Refer to ASTM D422 and/or FM 5-472/NAVFAC MO-330 for how to determine correction factors and apply them to obtain corrected readings.

You need to use the corrected readings to complete DD Form 1794's calculations for Columns 17, 19, 20, 21, 22a, and 22b for determining the percent passing and the particle sizes corresponding to each reading.

Larger particles in a soil-water suspension settle more rapidly than smaller particles; therefore, for each hydrometer reading, the percent passing is the percentage of soil remaining in suspension at the level at which the hydrometer measures the density of the soil-water suspension. That percentage, for each hydrometer reading, can be calculated using the previously referred to formulas and tables.

The particle sizes corresponding to each of those percentages is calculated on the basis of Stokes' law, $D = K\sqrt{\frac{L}{T}}$ that relates the terminal velocity of a free-falling sphere in a liquid to its diameter. Again, refer to FM 5-472/NAVFAC MO-330 to use the formula to calculate the sizes.



GRAIN-SIZE ANALYSIS (HYDROMETER METHOD)

1. PROJECT: ENGINEER CENTER EXPANSION
2. DATE: 6 Dec
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)*: 359557/152H
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 *(R')*	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') + composite correction

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

Hydrometer graduated in specific gravity (151H)

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

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

0.366

Hydrometer graduated in grams per liter (152H)

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

(a — specific gravity of solids correction factor)

a = 1.01

26. REMARKS

Red in color, very fine sands.

FROST GROUP: F4

27. TECHNICIAN *(Signature)*: EACN Pineda
28. COMPUTED BY *(Signature)*: EACN Pineda
29. CHECKED BY *(Signature)*: EA2 Johnson

DD FORM 1794, DEC 1999 PREVIOUS EDITION IS OBSOLETE. Adobe Professional 7.0

Figure 10-15 — Example grain size analysis (Hydrometer Method). DD Form 1794.

Test your Knowledge (Select the Correct Response)

1. Increasing the amounts of solids per unit volume of soil by mechanical means is called _____ effort.

   A. density
   B. compactive
   C. strengthening
   D. compressibility

2.0.0 CONCRETE and CONCRETE TESTING

Concrete has been one of the most economical, versatile, and universally used construction materials since the rediscovery of how the Romans used it, particularly underwater. It is one of the few building materials that constructors can produce directly on the jobsite in variable properties to meet a project's specific requirements.

This topic will build on your EA Basic foundation of knowledge by providing additional studies on materials used to produce concrete, and present further information about concrete testing.

2.1.0 Composition

Concrete is a synthetic construction material made by mixing cement, water and aggregate (fine and coarse) together in proper proportions. The following section provides information about each of these materials.

2.1.1 Cement

Cement is a substance that hardens with time and holds or entraps embedded objects or particles in a finite relationship to each other. Portland cement (usually used for concrete) is manufactured in a standardized process:

1. Grinding a mixture of limestone and clay or shale to make a fine "rawmix."
2. Heating the rawmix to ***sintering*** temperature in a cement kiln to form ***clinkers***.
3. Pulverizing the clinkers so that 95 percent of the material will pass through a No. 200 sieve to make cement.

Figure 10-16 — Example of clinkers.

The following paragraphs describe the various types of Portland cement:

- TYPE I — NORMAL PORTLAND CEMENT — all-purpose type used to make ordinary concrete pavements, buildings, bridges, masonry units, and the like.

- TYPE II — MODIFIED PORTLAND CEMENT — generates less heat during the curing process than Type I; more sulphur-resistant than Type I.

The hydration process generates heat that, in a large mass of concrete, can become high enough to affect the concrete adversely. Sulphur exists in water or soil having a high alkali content and has an adverse effect on the concrete.

- TYPE III — HIGH-EARLY-STRENGTH PORTLAND CEMENT — used where a high strength is needed quickly, for example, a demand for early use, or a need to reduce the period of protection against low or freezing temperatures.
- TYPE IV — LOW-HEAT PORTLAND CEMENT — heat-resistant quality of Type II, but to a higher degree; develops strength at a slower rate than Type I but helps prevent the development of high temperatures with attendant danger of thermal cracking upon later cooling.
- TYPE V — SULPHATE-RESISTANT PORTLAND CEMENT — higher degree of sulphate resistance than Type II; for use where high sulphate resistance is desired.

Some other types of cements are variations of the five types above or special types:

- TYPE IS — PORTLAND BLAST-FURNACE SLAG CEMENT — uses granulated slag (rapidly chilled or quenched from its molten state in water, steam, or air) interground with cement clinker at 25 to 65 percent of the total weight; for general use in concrete construction.
- TYPE IP — POZZOLAN [**pot**-suh-luh n] CEMENT — uses a mixture of 15 to 40 percent of ***pozzolan*** with the cement clinker; strength is not as great as concrete made with the same amount of Portland cement, but workability may be better for some uses.
- AIR-ENTRAINED CEMENT — resistant to severe frost action and to salts used for ice and snow removal; produced by adding air-releasing materials to the clinker as it is ground; may be controlled to a much greater extent by the use of admixtures with normal cements during mixing, resulting in a concrete with tiny, distributed, and separated air bubbles (up to millions per cubic foot).

  Entrained air bubbles improve the workability of fresh concrete by reducing the capillary and water channel structure within hardened concrete, thus restricting the passage of water. This prevents the build up of damaging water pressure in the pores when concrete is frozen. Therefore, for outdoor locations exposed to freezing weather, using air-entrained concrete greatly increases its durability.

  Types I, II, III, IS, and IP cements are available as air-entrained, and the letter *A* is added after the type to signify that it is air-entrained; for example, air-entrained pozzolan cement is known as Type IP-A.

In addition to the common seven types described above, five of which are available air-entrained, there are additional specialty types:

- WHITE CEMENT — made from selected materials to prevent coloring, staining, or darkening of finished concrete.
- WATERPROOFED CEMENT — has water-repellent materials added. The finished and set concrete has a water-repellent action.
- OIL WELL CEMENT — specially made to harden properly when used under high temperature in deep oil wells.

2.1.2 Identification of Cement

If you are an EA assigned to a construction battalion, you may be tasked with identifying an unknown material the supply department received. Your first effort should be to identify the material by obtaining (and translating if necessary) all labels, tags, shipping documents, manufacturing sheets, and all other papers that may contain applicable information.

If these do not identify the unknown material, your second effort should be to exercise the simple procedures outlined in the following paragraphs. Generally, they will supply enough information to permit a tentative, if not conclusive, identification.

There are many related or similar-appearing materials, so positive identification of cement requires a complete chemical analysis and physical tests.

Make the following tests to determine whether the material is a cement, and then attempt an identification of its type.

2.1.2.1 Hardening

1. Select a small sample and mix with enough water to make a plastic paste of a consistency similar to mortar.
2. Mold into a pat about 3 inches in diameter and 3/4 inch thick.
3. Observe the paste several times an hour to determine if it is setting (hardening). It has attained a final set when the surface is hard enough to be unmarked when a pencil point or a fingernail is pressed against it with moderate force.

If the sample sets within 1 to 10 hours, the material is probably a cement.

2.1.2.2 Color

If you have fairly well established that the material in question is a cement, color may serve as a means of further classification. If the material is:

- gray — likely to be a Portland cement
- brownish gray — may be a natural cement
- black — an aluminous cement
- white — probably hydraulic lime, plaster, or possibly white Portland cement

2.1.2.3 Air-Entrained Cement

To determine whether or not a given material contains an air-entraining agent:

1. Place a sample of the material in a glass cylinder to a depth of about 1 inch.
2. Add water to a depth of about 6 inches.
3. Shake the cylinder and its contents vigorously.

If a considerable volume of stable, persistent foam forms on the surface, the cement probably contains an air-entraining agent.

2.1.2.4 High-Early-Strength Cement

To recognize high-early-strength cement (Type III):

1. Make a batch of concrete using the unknown material.
2. Make a batch of concrete using a known cement.

Concrete containing high-early-strength cement will usually harden quicker than concrete containing regular Portland cement.

In addition, high-early-strength concrete molded into standard concrete beams and tested after 3 days for flexural strength should have a ***modulus of rupture*** more than 150 pounds per square inch higher than similar specimens containing regular Portland cement concrete.

A presentation of flexural strength testing will follow later in this chapter.

2.1.3 Water

Water is an important part of concrete mix chemistry; it makes the mix workable and starts hydration. Any substance in the water that retards or changes the hydration process is detrimental. A good rule of thumb is “if it’s good enough to drink, it may be used for concrete.”

2.1.3.1 Ordinary Water

Organic compounds, oil, alkali, and acid are a few of the substances found in some types of water; each has an effect on the hydration process.

- Organic material and oil tend to coat the aggregate and cement particles, thus preventing the full chemical reaction and adherence.
- Organic material may also react with the cement’s chemicals to create a weakened cementing action, thus contributing to concrete deterioration and structural failure.
- Alkalis, acids, and sulfates in the water also tend to react with the cement’s chemicals resulting in inadequate cementing and weakened concrete.

Water must be free of these substances to be used in concrete mix.

2.1.3.2 Seawater

The salts in seawater are normally thought of as corrosive, but seawater can sometimes be used in concrete mixing with satisfactory results.

You can expect a loss of 10 to 20 percent compressive strength when using the same amount of seawater as fresh water, but that can be compensated somewhat by reducing the water-cement ratio.

2.1.4 Aggregates

Where available, natural deposits of sand and gravel are normally used for aggregate material in concrete mixes. However, in some localities, natural deposits are hard to obtain, so large rocks must be crushed to form the aggregate. This increases a project’s costs from the additional steps to produce crushed aggregate and the mix requirement for more cement paste because of the crushed aggregate’s shape.

In addition, handling crushed aggregate requires additional care to prevent poor mixtures and improper dispersion of the aggregate sizes through the finished concrete. At times, mix designers may use local artificial aggregates, such as blast-furnace slag or specially burned clay.

2.1.4.1 Types of Aggregate

Aggregates are divided into two types:

- Fine aggregate — material that will pass a No. 4 sieve and will, for the most part, be retained on a No. 200 sieve.
    - Should have a rounded shape for increased workability and for economy as reflected by use of less cement.
    - Purpose is to fill the voids in the coarse aggregate and act as a workability agent.
- Coarse aggregate — material that will pass the 3-inch screen and will be retained on the No. 4 sieve.
    - Should have a rounded shape for increased workability and economy as reflected by use of less cement.
    - Even though the definition seems to limit the size of coarse aggregate, other considerations must be accounted for.

These two groups, when properly proportioned and mixed with cement, yield a strong and durable, almost voidless, stone. Aggregate must be equal to or better in strength and durability than the hardened cement to withstand the designed loads and the effects of weathering.

Its easy to understand that the coarser the aggregate, the more economical the mix. Larger pieces offer less surface area than an equivalent volume of small pieces, so using the largest permissible size of coarse aggregate permits a reduction in cement and water requirements.

There are restrictions, however, to an aggregate’s maximum size. Larger pieces can interlock and form arches or obstructions within a concrete form, thus allowing the area below the obstruction to become a void, or at best to become filled only with the finer particles of sand and cement. This creates a weakened area from the void or a cement-sand concentration area that does not leave proper proportions to adequately coat the rest of the aggregate.

The capacity of mixing equipment may limit the maximum aggregate size, but under normal conditions, coarse aggregate should not exceed the sizes given in *Table 10-1*.

Table 10-1 — Maximum Recommended Size of Course Aggregate.

Structure	**Minimum Dimension—inches**			
	2½ -5	**6-11**	**12-29**	**30 or more**
Reinforced wall, beams, and columns	½ - ¾	¾ – ½	1½ - 3	1½ - 3
Unreinforced walls	¾	1½	3	6
Slabs, heavily reinforced	¾ -1	1½	1½ - 3	1½ - 3
Slabs, lightly reinforced	¾ -1½	1½ - 3	3	3 - 6

Note: Maximum size not to exceed one fifth of minimum dimension of a wall or similar structure, one third of slab thickness for horizontal slab, or three fourth of minimum clear spacing between reinforcing bars.

2.1.4.2 Gradation

Gradation of aggregate — the quantity of each particle size used in the mix.

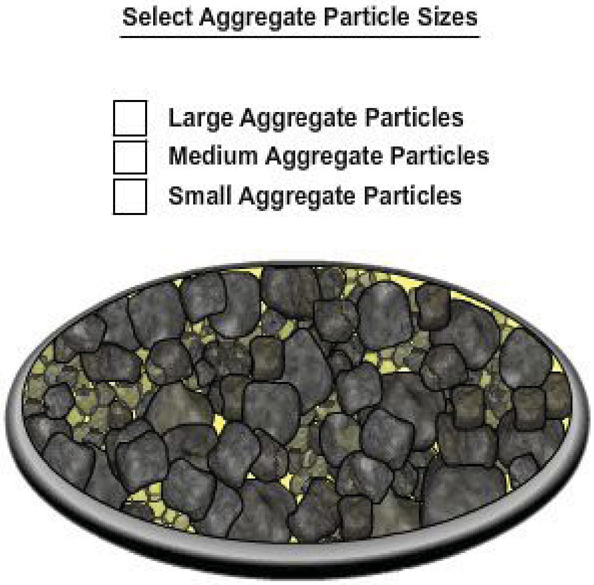


Figure 10-17 — Example of optimal aggregate gradation.

An over-proportion of coarse aggregate leaves voids and requires more cement paste, affecting the economy of the mix.

An over-proportion of fine aggregate prevents good bonding, increases the surface area that must be coated with cement paste, and weakens the concrete.

Good gradation results in a dense mass of concrete with a minimum volume of voids, an economical mix, and a strong structure.

Figure 10-17 shows a theoretical optimum aggregate gradation, but in practice the mix needs sufficient additional space for the cement to bond.

Optimum strength, watertightness, and durability in the hardened concrete require careful control of aggregate gradation.

2.1.4.3 Durability

Durability — the ability to resist weathering and load pressures.

Mineral particles that break down under applied loads, such as weak or easily crushed rock, will cause changes in the internal stresses, leading to a breakdown of the concrete.

Mineral particles or rocks that are absorptive or susceptible to swelling when saturated will disintegrate under certain weather conditions. Freezing moisture causes expansion stresses that can easily rupture absorptive rocks.

Radiant heat from the sun causes rocks to swell. Heat followed by sudden cooling (a shower or temperature drop) can cause some rocks to shrink and break down.

Aggregate must be chosen to withstand these forces of nature.

2.1.4.4 Deterioration

Deterioration — the corrosion of the internal reinforcing; degradation of the exposed surface; cracks, weakening, decay, or disintegration of hardness. In many cases, deterioration can be traced to the aggregate.

Excessive organic material in or on the aggregate prevents the cement paste from forming an adequate bond with the aggregate particles.

Excessive clay or fine silts adhering to the aggregate can prevent the cement paste from reaching the aggregate particles, resulting in a structurally weak concrete susceptible to breakdown by weathering.

Selected aggregates must be washed to remove silts, clays, and organic material to prevent deterioration.

2.1.4.5 Chemical Composition

Chemical composition — the mineral composition such as calcite, calcium carbonate or silica.

Any adverse chemical reaction between aggregate and cement (or any admixtures) in the presence of water can reduce the hardening and cementing process. Any reduction in the amount of water-cement paste caused by a chemical reaction reduces the amount available to bond to the total aggregate resulting in a condition similar to one caused by an insufficient amount of cement.

Selected aggregates need to be evaluated for chemical reaction with other components in the design mix.

2.1.5 Tests for Aggregates

ASTM D75 / D75M - 09 *Standard Practice for Sampling Aggregates*

For an aggregate test to be worthwhile, you must take the sample from representative supplies, the processed and ready-for-use aggregate, and sufficient samples from the processing plant discharge to represent all the material in the stockpile that may be used for the project.

Your sample should contain at least four times the material needed for testing, and then you need to reduce it to the testable size by the mixing and quartering you learned in EA Basic.

Take stockpile samples at or near the base, middle, and top of the pile; recombine three or four such samples.

Shoving a board into the pile just above the point of sampling will help prevent the material above the sampling point from falling or sifting into the sample.

Take unprocessed sources of sand and gravel by channeling exposed faces, or take them from pits if exposures are not available.

Be sure your samples include only materials from below the overburden or strip zone.

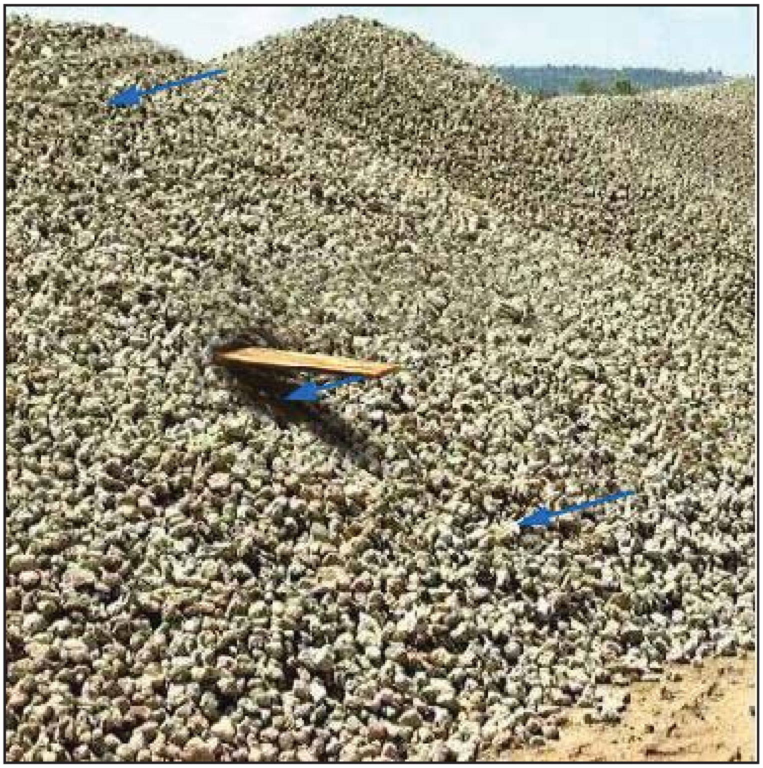


Figure 10-18 — Example of collecting representative aggregate samplings.

2.1.5.1 Tests for Gradation

ASTM C33 / C33M - 08 *Standard Specification for Concrete Aggregates*

ASTM C136 - 06 *Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates*

A sieve analysis will determine whether an aggregate is coarse or fine, and also identify the percentage distribution of larger and smaller sizes. You need this information to determine if the tested aggregate will make good concrete. Refer to ASTM C 136 for analysis methods. *Table 10-2* shows acceptable gradation limits.

Table 10-2 — Desirable Gradation for Aggregates in Concrete.

A. Coarse Aggregate

	Percent passing indicated sieve						
Sieve Size inches	**3**	**2½**	**2**	**1½**	**1**	**¾**	**½**
3	**100**						
2½	**88**	**100**					
2	**76**	**86**	**100**				
1½	**61**	**69**	**81**	**100**			
1	**44**	**49**	**58**	**72**	**100**		
¾	**33**	**38**	**44**	**55**	**76**	**100**	
½	**21**	**24**	**28**	**35**	**48**	**63**	**100**
3/8	**14**	**16**	**18**	**23**	**32**	**41**	**65**
No. 4	**……………………………………………………………………………**						

B. Fine Aggregate

Sieve Size U.S. Standard	**Percentages passing by weight**
4	**95-100**
8*	**80-100**
10	**75-95**
16*	**50-85**
20	**40-75**
30*	**25-60**
40	**20-50**
50*	**10-30**
60	**10-25**
100	**2-10**

***ATSM C 33 specifies U.S. Standard sieve sizes No. 8, 16, 30, and 50 instead of No. 10, 20, 40, and 60. Both ranges are provided for convenience.**

The American Society for Testing and Materials (ASTM) specifies fine aggregate grading limits. However, since many different gradings of fine aggregate can produce a good quality concrete, the engineer should compute the ***fineness modulus*** (FM) of the aggregate and compare it to the specified concrete class requirements.

The fineness modulus is an empirical factor that gives a relative measure of the proportions of fine and coarse particles in an aggregate. It is a value widely used to indicate the relative fineness or coarseness of a fine aggregate.

To obtain the fineness modulus:

1. Sieve a 500-gram sample of sand through a series of sieves (Nos. 4, 8, 16, 30, 50, and 100).
2. Convert the weight retained on each sieve into a cumulative percentage retained, starting with the No. 4 sieve.
3. Divide the sum of the six percentages by 100.
4. The resulting answer is the fineness modulus.

$$FM = \left(\sum Cumulative\ percent\ \ retained\right) \div 100$$

Table 10-3 provides an example of a typical FM calculation.

Table 10-3 — Sample Fineness Modulus Calculation.

Sieve Size	Cum. Mass Retained	Cum. % Retained
4.75 mm (No. 4)	31.5 g	6.3
2.36 mm (No. 8)	99.1 g	19.8
1.18 mm (No. 16)	195.6 g	39.1
600 µm (No. 30)	306.7 g	61.3
300 µm (No. 50)	367.2 g	73.4
150 µm (No. 100)	482.8 g	96.5

(Dry Weight of Original Sample = 500.3 g)

Fineness Modulus = (6.3 + 19.8 + 39.1 + 61.3 + 73.4 + 96.5) / 100 = 2.964

Fineness Modulus = 2.96

Typical fineness modulus values:

- Fine sand = 2.20 to 2.60
- Medium sand = 2.60 to 2.90
- Coarse sand = 2.90 to 3.20

2.1.5.2 Tests for Soundness

ASTM C666 / C666M - 03(2008) *Standard Test Method for Resistance of Concrete to Rapid Freezing and Thawing*

ASTM C88 - 05 *Standard Test Method for Soundness of Aggregates by Use of Sodium Sulfate or Magnesium Sulfate*

Soundness — the property of aggregate to resist disintegration when subjected to freezing and thawing.

Two methods are used to test for soundness. The freeze-thaw test method (ASTM C666) places concrete (with the aggregate in question) specimens in water and subjects it to alternate cycles of freezing and thawing.

The salt test method (ASTM C88), requiring considerably less equipment and time, immerses and saturates the aggregate in solutions of special salts (sodium sulfate or magnesium sulfate). The salt crystals are permitted to grow, which creates a disruptive force similar to freezing water.

2.1.5.3 Tests for Impurities

The quality of aggregate is another important consideration. Excessive quantities of clay or silt, shale, organic material or other water-absorbing particles can be detrimental to concrete's strength, watertightness, and durability.

2.1.5.3.1 Test for Material Finer Than No. 200 Sieve

ASTM C117 - 04 *Standard Test Method for Materials Finer than 75-µm (No. 200) Sieve in Mineral Aggregates by Washing*

The extremely fine mineral material (clay, silt, dust, or loam) occurring in most aggregates can affect concrete in two ways.

1. The added surface area of the fine particles picks up the cement paste and reduces the amount available to bind and hold the aggregate.
2. The small particles tend to float up to the surface (especially with wet mixes) when the concrete is finished, resulting in a surface covered by hairline cracks with a tendency for the fines to dust off when dry.

A small amount of fine material may improve workability, but exceeding 3 to 5 percent of the total weight of the aggregate is generally considered harmful to the concrete.

Refer to procedures in ASTM C117 and FM 5-472/NAVFAC MO-330 when testing for these fine materials. The general steps are:

- Oven-dry and weigh a sample of aggregate.
- Suspend dried sample in water and carefully pour through nest of sieves (No. 16 and No. 200) until wash water is clear.
- Oven-dry and weigh material remaining on sieves.
- Calculate percent of material finer than No. 200 sieve using the formula:

$$P = \frac{W_d - W_{dw}}{W_d} \times 100$$

Where:

$P =$ percentage of fines

$W_d =$ original dry weight of sample

$W_{dw} =$ dry weight after washing

The above method is accurate but time-consuming. When time is critical and less accurate results are acceptable, you can:

- Place a 1,000-gram sample into a quart mason jar to a depth of about 2 inches.
- Fill the jar three-fourths full of water.
- Shake vigorously.
- Allow to stand for 1 hour.

Silt and clay will form a layer above the sand; if more than 1/8 inch thick, the material has more than 3 percent fines and you need to wash it before using.

2.1.5.3.2 Test for Clay Lumps and Friable Particles

ASTM C142 - 97(2004) *Standard Test Method for Clay Lumps and Friable Particles in Aggregates*

Perform this test after determining the material finer than the No. 200 sieve. Refer to ASTM C 142 or FM 5-472/NAVFAC MO-330 for the size of samples you need and the specific test procedures. The general steps are:

- Spread sample in a thin layer on bottom of a flat pan.
- Cover with distilled water.
- After about 24 hours, break up all particles by crushing between fingers.
- Remove broken clay lumps and friable particles by wet sieving over appropriate one of the following:
    - aggregate—No. 20 sieve
    - No. 4 to 3/8 inch—No. 8 sieve
    - over 3/8 inch—No. 4 sieve
- Oven-dry and weigh material retained.
- Calculate percentage of clay lumps and friable particles using the formula:

$$P = \frac{W_1 - W_2}{W_1} \times 100$$

Where:

$P =$ percent of clay lumps and friable particles

$W_1 =$ original weight of test sample

$W_2 =$ weight of retained sample after wet sieving and drying

2.1.5.3.3 Test for Undesirable Lightweight Material

ASTM C123 - 04 *Standard Test Method for Lightweight Particles in Aggregate*

Soft, laminated pieces of aggregate, such as shale or ***chert*** (churt), are harmful to concrete, as well as coal and ***lignite*** (**lig**-nahyt). The latter are distinguished by the black or brownish black color of the particles. Often, visual examination of coarse aggregate will show these minerals. You can determine the quantity of these minerals by submersing the aggregate in a liquid of specific gravity with a density that allows the shale or other light particles to float and heavier particles to sink.

Refer to ASTM C123 or FM 5-472/NAVFAC MO-330 for specific testing procedures. The general steps are:

- Sieve dried sample over a No. 50 sieve (fine aggregate) and a No. 4 sieve (coarse aggregate).
- Weigh sample.
- Place in heavy liquid such as zinc chloride (specific gravity of 1.95 at 78°F).
- Agitate mixture to allow lightweight particles to rise to surface and skim off.
- Repeat until agitation causes no further particles to rise.
- Wash sample in alcohol.
- Dry and weigh it.
- Calculate percentage of undesirable, lightweight particles using the formula:

$$L = \frac{W_1}{W_2} \times 100$$

Where:

$L =$ percentage of lightweight material

$W_1 =$ dry weight of lightweight material

$W_2 =$ dry weight of initial sample retained on No. 50 sieve (fine aggregate) or No. 4 sieve (coarse aggregate)

2.1.5.3.4 Color Test for Organic Matter

ASTM C40 - 04 *Standard Test Method for Organic Impurities in Fine Aggregates for Concrete*

> Note: "*This test method is used in making a preliminary determination of the acceptability of fine aggregates with respect to the requirements of Specification C 33 that relate to organic impurities.* {Spec C33-Standard Spec for Concrete Aggregates}
>
> *The principal value of this test method is to furnish a warning that injurious amounts of organic impurities may be present. When a sample subjected to this test produces a color darker than the standard color, it is advisable to perform the test for the effect of organic impurities on the strength of mortar in accordance with Test Method C 87."*

ASTM C87 - 05 Standard Test Method for Effect of Organic Impurities in Fine Aggregate on Strength of Mortar

> Note: "This test method is of significance in making a final determination of the acceptability of fine aggregates with respect to the requirements of Specification C 33 concerning organic impurities.
>
> This test method is applicable to those samples which, when tested in accordance with Test Method C 40, have produced a ***supernatant*** liquid with a color darker than standard color plate No. 3 or color solution."

Any sand that gives a color darker than the standard of this test probably contains an excess of organic matter that will reduce the strength of the concrete in which the sand is used. If you determine that organic matter is present, it is possible that it can be removed by washing; if not, you should obtain better sand. If neither of these things can be done, it will be necessary to use a lower water-cement ratio and control the concrete production carefully to obtain the desired strength.

ASTM provides both a preliminary determination (C40) and a more definitive method (C87) of identifying inorganic impurities by color relative to the Standard Specification for Concrete Aggregates (C33). Note: FM 5-472/NAVFAC MO 330/AFJMAN 32-1221(I), July 2001, (Change 2) no longer promulgates a color test for organic matter.

2.1.5.4 Specific Gravity and Absorption, Surface Moisture

You must perform these tests on the aggregate to obtain the necessary calculations for designing a concrete mix.

For aggregates used in Portland cement concrete, make measurements to determine the bulk specific gravity of the aggregates in a saturated, surface-dry (SSD) condition.

Specific gravity is thus based on determining the total volume occupied by the aggregate particles, including the permeable pore space.

Absorption and surface moisture determinations are necessary to calculate the amount of mixing water used in a concrete mixture (*Figure 10-19*).

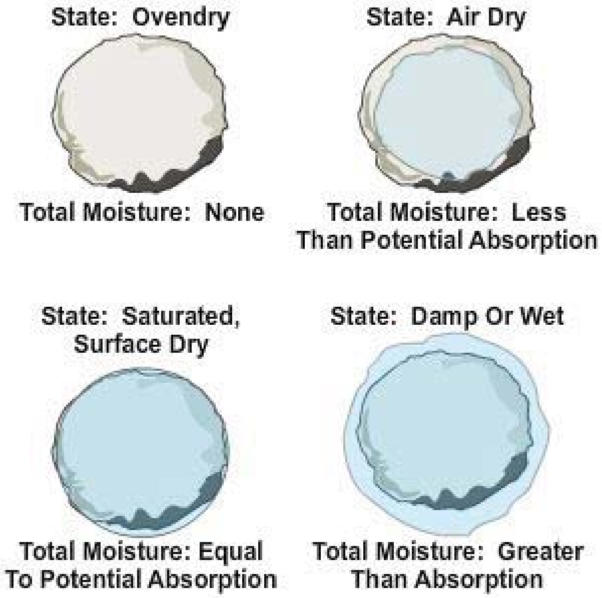


Figure 10-19 — Example of saturated-surface-dry.

Absorption, determined as a percentage, represents the moisture content of the aggregate when the aggregate is in an SSD condition.

Surface moisture is the moisture present in both fine and coarse aggregate, exceeding that which corresponds to an SSD condition.

2.1.5.4.1 Specific Gravity and Absorption, Coarse Aggregate

ASTM C127 - 07 *Standard Test Method for Density, Relative Density (Specific Gravity), and Absorption of Coarse Aggregate*

Refer to ASTM C127 or FM 5-472/NAVFAC MO-330 for specific testing procedures for bulk specific gravity of SSD coarse aggregate and the percentage of absorption. The general steps are:

- Dry a representative sample of aggregate (approximately 5,000 grams) to a constant weight at 110°C.
- Cool sample for 1 to 3 hours.
- Immerse in water.

- Allow it to soak for about 24 hours.
- Remove and dry to SSD condition by rolling in an absorbent cloth until visible films of water are removed and particle surfaces appear slightly damp.
- Weigh in SSD condition and record weight to nearest 0.5 gram.
- Immediately place sample into container or wire basket and determine immersed weight (or weight in water) at 23°C.
    - Ensure any entrapped air is removed by shaking container or basket while immersed.
- Record immersed weight to nearest 0.5 gram.
- Dry sample to a constant weight at 110°C.
- Cool for 1 to 3 hours.
- Weigh oven-dried sample.
- Record weight to nearest 0.5 gram.
- Calculate bulk specific gravity (SSD condition) and percentage of absorption using the formulas:

$$SSD\ bulk\ specific\ gravity = \frac{B}{B-C}$$

$$\%\ absorption = \left(\frac{B-A}{A}\right)\times 100$$

Where:

$A =$ weight of oven-dried sample in air (in grams)

$B =$ weight of SSD sample in air (in grams)

$C =$ immersed weight of saturated sample (in grams)

2.1.5.4.2 Specific Gravity and Absorption, Fine Aggregate

ASTM C128 - 07a *Standard Test Method for Density, Relative Density (Specific Gravity), and Absorption of Fine Aggregate*

Refer to ASTM C128 or FM 5-472/NAVFAC MO-330 for specific testing procedures for bulk specific gravity of SSD fine aggregate and the percentage of absorption. The general steps are:

- Dry representative sample of fine aggregate (about 1,000 grams) to a constant weight at 110°C.
- Cool.
- Immerse in water.
- Soak for about 24 hours.
- Spread on a flat, nonabsorbent surface.
- Stir to obtain uniform drying.
- Continue drying until approaches SSD condition.

- Place water-absorption cone (*Figure 10-20*) large end down on smooth surface and fill loosely.
- Lightly tamp surface 25 times with metal tamper.
- Lift cone vertically from sand and observe action.

If it retains its conical shape, free moisture is present; continue drying followed by tamping until reaching desired SSD.

If the sample slumps slightly, the fine aggregate has reached the desired SSD condition.

Figure 10-20 — Example of water-absorption cone and tamper.

- Weigh exactly 500 grams SSD sample.
- Place in partially water-filled pycnometer top-and-jar assembly (*Figure 10-21*).
- Fill with water to approximately 90 percent of capacity.
- Agitate to remove any entrapped air.
- Adjust water temperature to 23°C.
- Fill to calibrated capacity.
- Weigh to nearest 0.1 gram.
- Record weight.

Figure 10-21 — Example of pycnometer top-and-jar assembly.

- Remove sample from pycnometer.
- Dry to a constant weight at 110°C.
- Cool in air for about 1 hour.
- Weigh dried sample.
- Record to nearest 0.1 gram.

- Determine weight of pycnometer filled to calibrated capacity with water at 23° + 1.7°C.
- Record weight.
- Calculate bulk specific gravity of SSD fine aggregate and percentage of absorption using the formulas:

$$SSD\ bulk\ specific\ gravity = \frac{500}{B + 500 - C}$$

$$\%\ absorption = \left(\frac{500 - A}{A}\right) \times 100$$

Where:

$A =$ weight of the oven-dried specimen in air (in grams)

$B =$ weight of pycnometer filled with water (in grams)

$C =$ weight of pycnometer, sample, and water (in grams)

2.1.5.4.3 Surface Moisture

ASTM C70 - 06 *Standard Test Method for Surface Moisture in Fine Aggregate*

ASTM C566 - 97(2004) *Standard Test Method for Total Evaporable Moisture Content of Aggregate by Drying*

Surface moisture is the water present in both the fine and coarse aggregates, exceeding that which corresponds to an SSD condition. This water will become part of the mixing water when the aggregate is used in making concrete. The amount of mixing water used must be corrected to allow for its presence.

Refer to ASTM C70 or ASTM C566 for procedures used to determine the total moisture content and the percentage of surface moisture in either fine or coarse aggregate. The general steps are:

- Weigh sample of aggregate representative of material's moisture content.
- Record weight.
- Dry to a constant weight at 110°C.
  - Take care to avoid loss of material; sample is thoroughly dry when further heating causes, or would cause, less than 0.1 percent additional weight loss.
- Weigh oven-dried sample.
- Record weight.
- Calculate the total moisture content using the formula:

$$P = \left(\frac{W - D}{D}\right) \times 100$$

Where:

$P =$ total moisture content (percent)

$W =$ weight of original sample (in grams)

$D =$ weight of oven-dried sample (in grams)

The surface moisture is equal to the difference between the total moisture content and the absorption.

As an alternative, you can obtain a determination of surface moisture in fine aggregate by displacement method as follows:

- Select representative fine aggregate sample weighing not less than 200 grams.
- Weigh pycnometer filled to calibration mark with water.
- Record weight.
- Empty pycnometer of one half water.
- Place sample in pycnometer half filled with water.
- Add additional water to calibration mark.
- Remove all entrapped air.
- Weigh pycnometer, water, and sample.
- Record weight.
- Calculate weight of water displaced by sample using the formula:

$$V_s = W_c + W_s - W$$

Where:

$V_s =$ weight of displaced water (in grams)

$W_c =$ weight of water-filled pycnometer (in grams)

$W_s =$ weight of sample (in grams)

$W =$ weight of pycnometer, water, and sample (in grams)

- Calculate percent of surface moisture using the formula:

$$P = \left(\frac{V_s - V_d}{W_s - V_s} \right) \times 100$$

Where:

$P =$ percent of surface moisture

$V_s =$ weight of displaced water (in grams)

$W_s =$ Weight of sample (in grams)

$V_d =$ weight of sample in grams divided by the bulk specific gravity of the sample

2.2.0 Admixtures

Several admixtures (chemical agents) are available to improve workability, increase freezing and thawing resistance, and compensate for inadequate curing time and conditions.

2.2.1 Accelerators

Sometimes it is desirable to accelerate the hydration reactions. The result is a high-early strength and a higher rate of heat production. This combination can be useful in winter operations or sometimes in maintaining an accelerated production schedule.

Adding a chemical accelerator (typically calcium chloride- $CaCl_2$) to the mix will increase hydration (*Figure 10-22*).

Note: Be aware that $CaCl_2$ helps speed up the initial setting, but chloride ion leads to corrosion of metal (rebar and metal inserts).

The amount specified in the mix design is usually about 2% of the weight of cement and rarely more than 3%.

The main reaction with calcium chloride occurs within the first 3 days, and using it does not affect the ultimate strength of concrete.

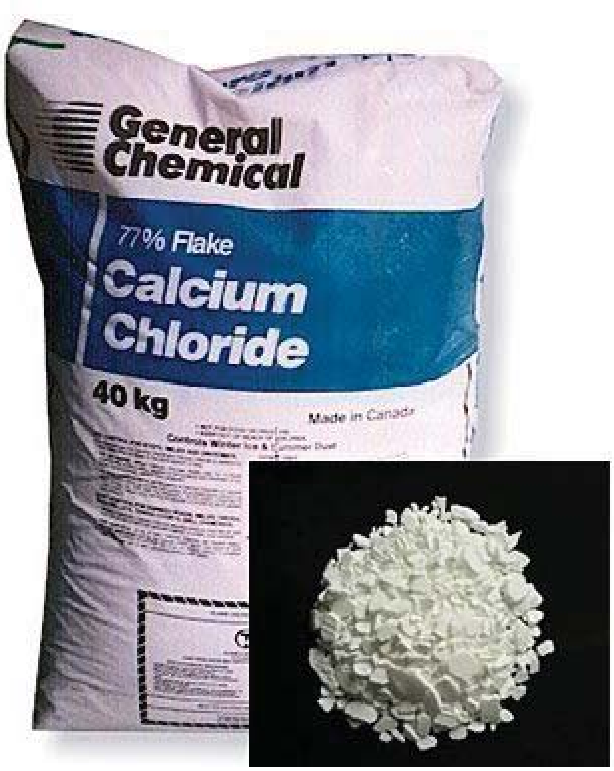


Figure 10-22 — Example of calcium chloride appearance and packaging (ASTM D98 Type 1).

2.2.2 Retarders

Retarders (retarding admixtures) are used to manage concrete in the opposite direction from accelerants, when excessively high heat and too rapid setting of concrete would prevent full hydration. Many materials retard setting of concrete, for example, fatty acids, starches, or sugars and sugar derivatives.

Retarders are known to delay hydration without affecting the long-term mechanical properties. They are used to offset the effect of high temperatures, which decrease setting times, or to avoid complications when unavoidable delays between mixing and placing occur.

Using of set retarders in concrete pavement construction:

- enables farther hauling, thus eliminating the cost of relocating central mixing plants
- allows more time for texturing or plastic grooving of concrete pavements
- allows more time for hand finishing around the headers at the start and end of the production day
- helps eliminate cold joints in two-course paving and in the event of equipment breakdown

Retarders can also be used to resist cracking due to form deflection that can occur when horizontal slabs are placed in sections.

2.2.3 Workability Agents or Plasticizers

Concrete's workability is governed by the amount of aggregate in the mix. Where aggregate reduction (or cement increase) is impractical, adding a plasticizer can increase workability.

Air-entraining agents, when used, are plasticizers as are calcium chloride (the same previously mentioned accelerant), lime and other pozzolans, and ***fly ash***.

Lime increases the cementing properties of cement, as do pozzolans combined with lime. Hydrated lime added to a concrete mix in making block and other concrete products can produce a denser, more water-resistant product. By adding greater plasticity to the mix, lime also produces concrete products with more precise edges and corners, and reduces loss through breakage.

As a byproduct from coal-burning power plants, fly ash is inexpensive (compared to cement) and used as a partial replacement of the cement (as much as 50%). Fly ash improves workability and reduces segregation, bleeding, and the heat of hydration. It changes both the plastic and the hardened properties of concrete.

Fly ash concrete will not be as watertight as a cement-only concrete, nor will it have as much initial strength, so you may have to make additional tests to determine when to remove any forms. Its final strength, however, will be as great as a cement-only concrete.

2.2.4 Densifiers

Some types of construction, prestressed structures for example, require dense concrete. The density is achievable when cement particles separate evenly throughout the mix or at least do not flocculate (attach to each other forming lumps).

A ***detergent*** admixture can be applied to disperse the particles individually and create a more uniform paste. These admixtures also reduce the formation of a cement gel that expands at the early stages of hydration, pushing the particles apart and thus increasing the volume. Prevention of this gel expansion results in a denser paste.

2.2.5 Waterproofing Agents

To a great extent, you can help control watertightness by lowering the water-cement ratio, but this may not always be practical; even with a low water-cement ratio, sometimes capillaries still form through the concrete. Densifying with a detergent, or adding an accelerator like calcium chloride (also a plasticizer) can improve watertightness.

2.2.6 Air-Entraining Agents

The greatest improvement in watertightness and resistance to deterioration under freezing and thawing is obtained by incorporating 4 to 6 percent, by volume, of entrained air into the mix. Air entrainment is the process whereby many small air bubbles are incorporated into concrete and become part of the matrix that binds the aggregate together in the hardened concrete. These air bubbles are dispersed throughout the hardened cement paste but are not, by definition, part of the paste. They provide small, uniformly spaced, discrete air voids that prevent the buildup of damaging pressures from the expansion of freezing water into ice.

Controlled additions of certain naturally occurring organic substances derived from animal and wood byproducts can materially increase the resistance of concrete in roadways to attack brought on by repeated freeze-thaw cycles and the application of deicing agents. Soaps, ***butyl stearate*** (ˈbyüd·əl ˈstirˈāt), some of the fine pozzolans, and several proprietary compounds are available for use as air-entraining admixtures with ordinary cements. These agents minimize the formation of capillaries and plug the tiny holes with a water-repellant or sealing material. Entrained air also increases the workability of fresh concrete.

2.3.0 Curing

Concrete does not develop its full strength until hydration (chemical process of curing) is complete. Curing takes place over an extended period, but the most critical period is from placement day through the 10th day. Moisture and the correct temperature within the mix are the key factors influencing the rate of cure

2.3.1 Temperature

55°–70°F (12.8°–21.1°C) — the ideal temperature range for concrete work. Above this, rapid evaporation creates a problem; below this, curing or setting is delayed.

At temperatures below 32°F (0°C) the hydration process stops. Although the chemical action of hydration gives off some heat, some method must be used to keep the heat within the structure. Cold weather construction may require heating the mix ingredients, or covering the emplaced concrete, or providing a heated enclosure, or all of these provisions.

In hot weather, concrete placers and finishers must take extra care to prevent a high temperature rise and drying the fresh concrete too rapidly. Moistening the aggregate with cool water is one way to lower the generated temperature. The water can be kept as passively cool as possible by applying reflective white or aluminum paint to water supply lines and storage tanks.

Dams, heavy retaining walls, large structure foundations, and other massive construction projects often cool the mixing water artificially or substitute ice for part of the water, although the ice must be melted by the time the concrete is fully mixed and ready to leave the mixer.

Mix designers may use cement replacement materials (pozzolans of diatomaceous earth, ***pumicites***, or fly ash) to lower concrete temperature by reducing the hydration heat, but pozzolans vary widely and, if used in excessive amounts, may negatively affect strength, air content, and durability.

2.3.2 Moisture

Concrete curing depends upon hydration in the presence of water. Moisture loss during the process (either by seepage or evaporation) prevents the complete chemical action and full development of optimum strength and watertightness. Subgrades on which the concrete will be placed should be saturated to delay, if not prevent, seepage, and wood forms should be thoroughly wetted if they have not been otherwise treated with a cure compound/bond breaker.

After finishing, one method used to reduce evaporation is to cover the concrete as soon as possible without marring the surface (*Figure 10-23*).

The covering may be a material such as burlap, straw, or plastic film, or it may be a chemical curing compound sprayed over the finished surface.

After the initial set is attained, water can be applied directly to the surface to keep the hydration process in action.

This could simply be a matter of damming a perimeter and flooding the surface.

Figure 10-23 — Examples of alternative methods to retain moisture during initial hydration.

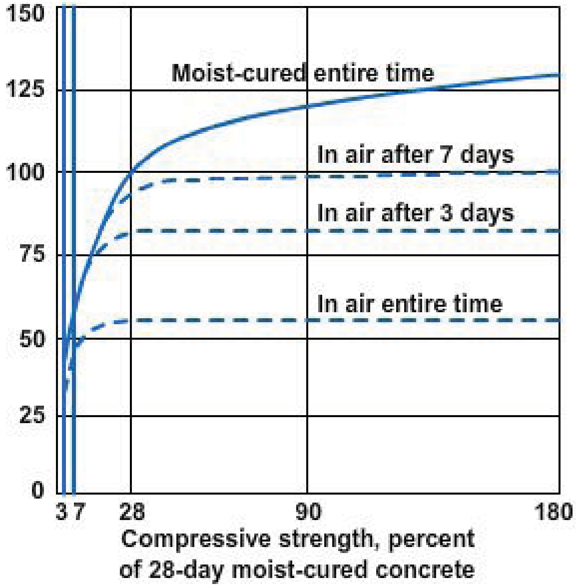


Figure 10-24 — Increase of concrete compressive strength with curing age.

This water application can be part of the temperature control.

Figure 10-24 demonstrates, as shown by curves, the increase of concrete compressive strength with age.

Note the almost doubling of strength between fully air-cured and fully moist-cured at the 28-day period.

Also note the long-time continuing gain in strength that occurs when constructors maintain proper temperature and moisture conditions.

2.4.0 Concrete Testing

Freshly mixed concrete needs several tests, such as slump, air content, and weight determination, to establish the quality of the recent mix. In addition, following a designated cure duration, the concrete needs strength tests to determine whether the hardened concrete satisfies the specified strength requirements of the mix design.

2.4.1 Slump Test

ASTM C143 / C143M - 09 *Standard Test Method for Slump of Hydraulic-Cement Concrete*

From your studies in EA Basic, you know that slump is the basic measure of workability or consistency of a concrete mix:

- Too little slump — the mixture may be too difficult to work into the forms and around any reinforcing steel, post-tension cables, or inserts.
- Too much slump — the mixture's ingredients may segregate with excessive bleeding or migration of water to the top surface, thereby increasing the water-cement ratio and resulting in a weak top layer with poor durability.

To determine whether a freshly mixed concrete satisfies the specified requirements for slump, you perform a slump test, which by now, you should be thoroughly familiar with. If you need a refresher, review the slump testing presentations in Chapter 16, EA Basic or FM 5-472/NAVFAC M0-330.

2.4.2 Air-Content Test

ASTM C231 - 09a *Standard Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method*

Air-entrained cements may be available for use in some military situations, but mix designers typically include an air-entraining admixture to the concrete mix.

The intent is to entrain enough air to improve the mixture's workability, durability, watertightness, and freeze-thaw resistance but not enough to substantially reduce strength.

The desired amount of air is generally from 4.0 to 7.5 percent of the total mix.

Perform ASTM C231 to determine the percentage (+ 0.5 percent) of entrained air in a plastic (fresh) concrete sample.

Figure 10-25 — Example of air-content test kit.

Equipment for determining the percentage of entrained air is included in a boxed test kit with the basic tool being a pressure type of indicator (*Figure 10-25*).

The equipment furnished in these kits varies with the manufacturers and there are many different air-entrainment meters currently fielded; replacements of old equipment may not be the same. For this reason, in performing this test, you need to follow the steps outlined in each kit manufacturer's user's manual.

Before beginning the test, you must calibrate the entrained-air indicator and determine the correction factor for the aggregate contained in the concrete. Do so by follow the guidance in the manufacturer's instruction book.

2.4.3 Unit Weight

ASTM C138 / C138M - 09 *Standard Test Method for Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete*

Concrete's unit weight (density) varies with the amount and density of the aggregate, the amount entrained air, the cement's contents, and the water. Buildings and pavements that use conventional concrete have a typical unit weight range of 140-150 pounds per cubic foot (pcf). Other types of concrete can range from 15 pcf for lightweight insulating concrete, to 400 pcf for heavyweight radiation shielding concrete.

You need a cylindrical metal measure (container) of either 1/10-, 1/5-, or 1/2-cubic-foot capacity to determine the unit weight of freshly mixed concrete. If necessary, calibrate the measure before performing the test procedures. To calibrate the measure:

- Determine tare weight of measure.
- Fill measure with water at room temperature.
- Determine temperature, density, and weight (in pounds) of water.
    - Use *Table 10-4* and interpolate if necessary to determine density of water.
- Calculate calibration factor of measure by dividing density of water by weight of water required to fill measure.

Table 10-4 — Density of Water.

Temperature		Density
$^{\circ}F$	$^{\circ}C$	lb/ft^3
60	15.6	62.366
65	18.3	62.336
70	21.1	62.301
75	23.9	62.261
80	26.7	62.216
85	29.4	62.166

Refer to ASTM 138 for procedures used to determine the unit weight of freshly mixed concrete. The general steps are:

- Fill measure with fresh concrete consolidated in three layers.
- Rod each layer.
- Tap sides of container 10 to 15 times (each layer) with rubber or rawhide mallet to remove air pockets.
- Strike off the top surface.
    - Take care to leave measure level/full.

- Clean excess concrete from exterior.
- Weigh to establish gross weight.
- Determine net weight of concrete by subtracting tare weight.
- Adjust net weight calculation to unit weight of 1-cubic foot.
    - Container example is 1/10-, 1/5-, or 1/2- cubic foot.
- Calculate unit weight by multiplying adjusted net weight by calibration factor.

2.4.4 Compressive Strength Test

ASTM C39 / C39M - 05e2 *Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens*

You need to perform compression tests on standard cylindrical specimens to determine the compressive strength of hardened concrete. These tests are used during the concrete mix design phase to evaluate performance and establish mix proportions that will provide the required strength. They are also used during the concrete placement phase for quality control of pours at the site.

“Compressive strength” is defined as the average of the strengths of all cylinders of the same age made from a sample taken from a single batch of concrete. To constitute a test, you must have a minimum of two cylinders and preferably three, so if you are performing tests at 7 and 28 day “breaks,” you need four or six specimens.

From your studies in EA Basic, you know the standard specimen is 6 inches in diameter by 12 inches long and is capped with a suitable material to provide a smooth-bearing surface on each end of the specimen (*Figure 10-26*).

You also learned the procedures for preparing and capping specimens.

If necessary, review those procedures; the following only presents procedures used to perform the compression tests on already prepared specimens.

Figure 10-26 — Typical concrete cylinder mold.

To perform the following compression test you need a compression-testing machine with a capacity of 250,000 pounds.

Compression testing machines are available in a variety of configurations both stationary and portable.

Figure 10-27 is an example of a portable machine with a test cylinder in place.

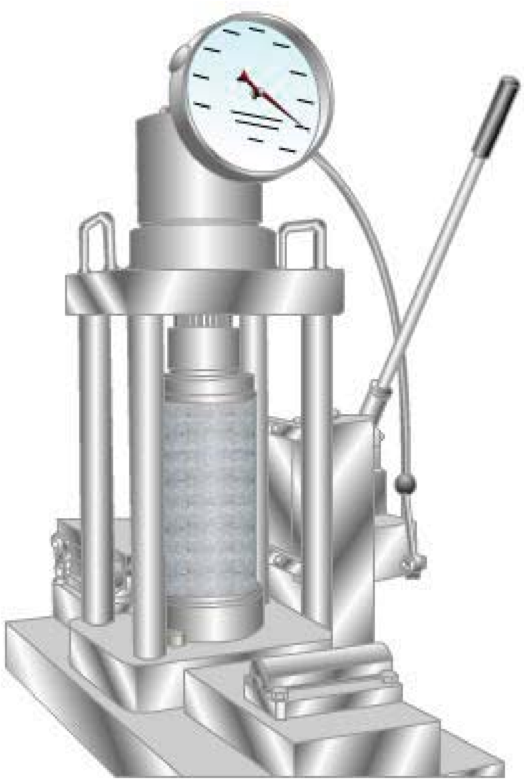


Figure 10-27 — Typical compression testing machine.

Refer to ASTM 39 or FM 5-472/NAVFAC M0-330 for specific procedures for conducting compressive strength of cylindrical concrete specimens. The general steps are:

- Prepare testing machine by cleaning bearing plates and, if needed, cleaning and lubricating spherical seat.
- Check the operation.
- Set gauge to zero.
- Keep previously prepared test specimen moist by covering with wet burlap during period between removing specimen from curing environment and testing.
    - Applies to each specimen you will test.
- Determine diameter of test specimen to nearest 0.01 inch by averaging two diameters measured at right angles to each other at mid-height of cylinder.
- Measure length including caps to the nearest 0.1 inch.
- Record dimensions on prepared data sheet.
- Place specimen on lower bearing block.
- Bring upper block almost to contact.
- Align axis of specimen with center of thrust of spherical head.
- Carefully and slowly bring spherical head into contact with specimen, rotating movable portion gently by hand so uniform seating is obtained.

- Apply test load continuously without shock at rate of 20 to 50 pounds per square inch (psi).
- Observe and record maximum load during test.
- Observe type of fracture and record any unusual features.
    - *Figure 10-28* shows a typical cylinder at the moment of fracture.
- Calculate the compressive strength of the concrete using the formula:

$$compressive\ strength = \frac{P}{A}$$

Where:

$P =$ maximum load (in pounds)

$A = \pi r^2$

Figure 10-28 — Typical compression test cylinder fracture.

For each tested specimen include:

- Identification
- Diameter
- Cross-sectional area, in square inches
- Maximum load in pounds
- Compressive strength to nearest 10 psi
- Type of break
    - Refer to *Figure 10-29*
- Defects in specimen or cap
- Age of specimen at test

Report the average compressive strength of all cylinders from the same concrete sample.

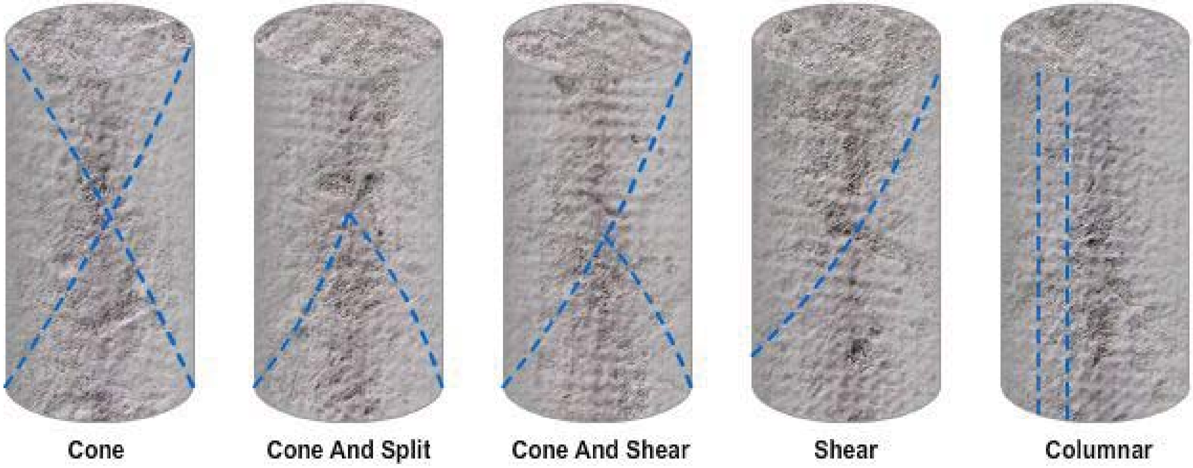


Figure 10-29 — Examples of compression test cylinder fracture types.

2.4.5 Flexural-Strength Test

ASTM C78 - 09 *Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)*

Flexural strength — also known as modulus of rupture, bend strength, or fracture strength, is defined as a material's ability to resist deformation under load.

A determination of flexural strength is frequently necessary to provide information for the design of an engineering structure. It may also be required as part of the design of concrete mixtures to check compliance with established specifications.

In the flexural-strength test, you apply a test load to the sides of a test beam. You can perform the test on beams sawn from existing concrete structures, but testing beams specifically cast for testing purposes is more common.

The standard test beam measures 6 inches by 6 inches by 21 inches. When you perform the test for mix-design purposes, you need at least five specimens for each mixture design being evaluated. You will break two per mix design at 7 days to permit an early evaluation of the mix, and break the remaining beams at 28 days.

You learned the procedures for preparing test beams in EA Basic; if necessary, refresh your knowledge of those procedures. The following only presents the procedures used to perform the test.

When you perform flexural-strength test, you use a concrete beam tester with third-point loading, as shown in *Figure 10-30*.

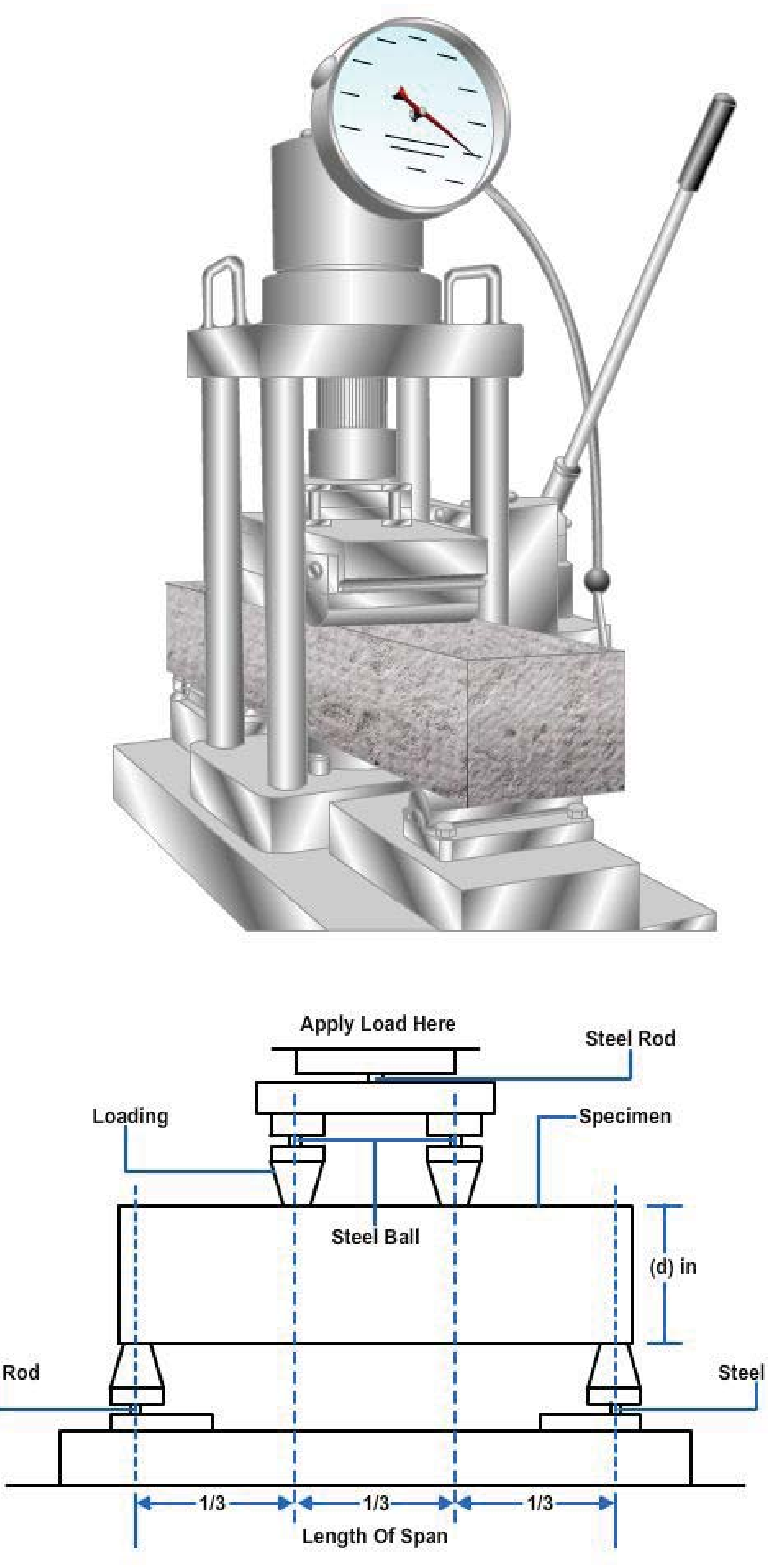


Figure 10-30 — Example of flexural-strength test assembly with 1/3 point loading.

As an alternative, you can make a testing assembly from the loading frame and specific attachments provided with the California bearing ratio (CBR) test set:

- breaker (third-point loading)
- 10,000-pound capacity proving ring

That alternate assembly is shown in *Figure 10-31*.

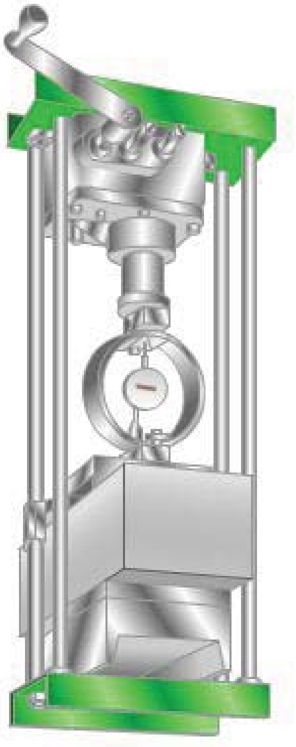


Figure 10-31 — Alternate testing assembly using CBR test equipment.

Refer to ASTM 78 or FM 5-472/NAVFAC M0-330 for specific procedures on performing this test to determine the flexural strength (modulus of rupture) of the test specimen to ± 10 psi.

The general steps are:

- Wear safety goggles throughout test.
- Assemble test apparatus and check functional operation.
- Measure length of span.
- Record measurement on a piece of paper.
    - Length of span is determined by measuring the distance from center to center of the two loading points (or supports) on the base of the apparatus.
    - Normal length of specimen is 21 inches and the normal length of span is 18 inches.
- Place specimen in tester.
- Bring loading surface into contact with test specimen.
    - If sample is too rough for contact, grind smooth.
- Zero the gauge.
    - Some apparatus are equipped with a hydraulic pump and corresponding gauge; others are equipped with a loading jack and proving ring.
- Apply load at a continuous rate that constantly increases extreme fiber stress at between 125 and 175 psi per minute.

  - This is an approximate load of 1,500 to 2,100 pounds per minute.
- Obtain total load (in pounds) at time of specimen failure.
- Record weight on paper provided.
  - On machines equipped with hydraulics, take the reading directly from the gauge.
  - For machines equipped with a proving ring, this reading is the product of the dial-gauge reading and the proving-ring constant.
- Determine and record width and depth of specimen (in inches) at point of failure (normally 6 x 6 inches).
- Determine point of failure in specimen and calculate modulus of rupture.

  A. If the specimen fails outside the middle third of the span length by more than 5 percent of the total span length, then the specimen is considered unusable and should be discarded (not more than 0.9 inches for an 18-inch span (18 x 0.05 = 0.9).

  B. If the specimen fails within the middle third of the span length, to calculate the modulus of rupture use the formula:

$$R = \frac{P \times L}{b \times d^2}$$

Where:

$R =$ modulus of rupture, in psi

$P =$ applied load, in pounds

$L =$ length of span, in inches

$b =$ width of specimen at failure point, in inches

$d =$ depth of specimen at failure point, in inches

  C. If the specimen fails outside the middle third of the length of span by not more than 5 percent of the span length, to calculate the modulus of rupture use the formula:

$$R = \frac{3P \times a}{b \times d^2}$$

Where:

$R =$ modulus of rupture, in psi

$P =$ applied load, in pounds

$b =$ width of specimen at failure point, in inches

$d =$ depth of specimen at failure point, in inches

$a =$ distance between the failure point and the nearest support, measured along the centerline of the bottom of the specimen, in inches

- Record information about test:
  - Some information may be unavailable at the time of the test.

1. Specimen's identification number
2. Average width to nearest 0.05 inch
3. Average depth to nearest 0.05 inch
4. Span length, in inches
5. Maximum applied load, in pounds
6. Modulus of rupture, to nearest 10 psi
7. Curing history (how specimen was cured) and apparent moisture content of specimen at time of test
8. Any defects noted in specimen
9. Age of specimen

Values of the modulus of rupture vary widely, depending on the concrete tested. Concrete pavement specifications frequently require modulus of rupture in excess of 600 to 650 psi (28-day curing, third-point loading). The flexural strength (modulus of rupture) generally may be expected to be approximately 15 percent of the compressive strength for comparable conditions of age and curing.

An approximate relationship between modulus of rupture and compressive strength can be calculated using the formula:

$$f'_C = \frac{R^2}{100}$$

Where:

$f'_C =$ compressive strength (in psi)

$R =$ modulus of rupture (in psi).

2.4.6 Other Concrete Strength Tests

ASTM C805 / C805M - 08 *Standard Test Method for Rebound Number of Hardened Concrete*

ASTM C900 - 06 *Standard Test Method for Pullout Strength of Hardened Concrete*

As an EA, you are expected be familiar with and know how to perform the two strength tests (compressive and flexural strength) just presented. However, these are not the only tests to determine the strength of hardened concrete.

Other methods available are the rebound method (ASTM C805) and the pullout test method (ASTM C900).

The rebound method employs a rebound hammer that measures the rebound of a spring-loaded plunger striking a smooth concrete surface. A rebound number reading indicates the compressive strength of the concrete.

In the pullout test, the enlarged end of a steel rod is cast into the concrete to be tested, and then the force required to pull the rod from the concrete is measured. The measured strength is the direct shear strength of the concrete.

A measurement of the in-place strength follows by correlating the measured compressive strength with the measured shear strength.

Test your Knowledge (Select the Correct Response)

2. The primary reason for the popularity of concrete in construction is its _____.

   A. economy
   B. versatility
   C. site availability
   D. all of the above

3.0.0 BITUMENS and BITUMINOUS-MATERIALS TESTING

Bituminous (bahy-**too**-muh-nuhs) pavements/surfaces are used as the top portion of a flexible pavement structure to provide a resilient, waterproof, load-distributing medium that protects the base course from the detrimental effects of water and the abrasive action of traffic. This section will provide information on the materials used in constructing bituminous surfaces, and the methods of testing these materials. For additional information and guidance, refer to FM 5-472/NAVFAC MO-330.

3.1.0 Bituminous-Pavement Materials

Bituminous-pavement materials are a mixture of mineral aggregates, mineral filler, and a bituminous material or binder. The coarse aggregate is stone or gravel too large to pass the No. 8 sieve; the fine aggregate is fine gravel and sand small enough to pass the No. 8 sieve but too large to pass the No. 200.

A small amount of fine rock dust (mineral dust) that passes the No. 200 sieve, and/or a small amount of mineral filler such as Portland cement, pulverized limestone (limestone dust), or silica and hydrated lime may also be included in a paving mix design.

3.1.1 Aggregates

Mineral aggregates may consist of crushed rock, crushed or uncrushed soils (including gravels and sands), slag, mineral filler, or a combination of some of these materials. In certain geographical areas, other materials may be used as aggregate including ***vesicular*** lava and coral. Because aggregates normally constitute 90 percent or more by weight of bituminous mixtures, their properties greatly affect the finished product.

The aggregate provides three basic functions in bituminous surfaces.

1. It transmits the load from the surface down to the base course. In pavement, this is accomplished through the mechanical interlock of the aggregate particles.
2. It withstands the traffic’s abrasive action. If a wearing surface were laid consisting of binder alone, it soon would be worn away by the abrasive action of tires.
3. It provides a nonskid surface. A portion of the aggregate extends slightly above the normal surface of the wearing mat, thereby providing a roughened surface for tires to grip.

3.1.2 Bituminous Cements

A bituminous material is the adhesive agent or binder in a bituminous mixture. This binder provides two functions:

1. It binds the aggregate together, holds it in place, and prevents displacement.
2. It provides a waterproof cover for the base and keeps surface water from seeping into and weakening the base material.

The binder's functions require it to be a waterproof substance having the ability to bind aggregate particles together. All bituminous materials possess these qualities due to being mainly composed of bitumen—a refined solid material that provides cementing ability, waterproofing properties, and the distinctive black color.

Bituminous materials are classified into two main groups—asphalts and tars. Both are available in several forms suitable for different procedures of mixing or application under wide variations in temperature. Some bituminous materials are solid or semisolid at room temperature. Other grades are a relatively viscous (thick) liquid at room temperature (77°F-25°C).

Mixing bituminous materials with solvents or water produces cutbacks or emulsions that are liquid at atmospheric temperatures. Such liquid asphalts and tars are used for cold mixes or are applied as sprays in building pavements.

3.1.2.1 Asphalts

Asphalt is obtained only from crude petroleum and has two general classes— natural and manufactured. Natural asphalts occur in lakes (as lake asphalt), pits, or rock structures (as rock asphalt). Manufactured asphalt is produced by distilling crude petroleum.

Military engineers are seldom concerned with natural asphalts because they are not usually available in those areas of interest. Therefore, this section addresses only the uses and testing of manufactured asphalts, which are some of the by-products from refining crude petroleum where crude oil vapors are separated into fuels, solvents, and lubricating oils with the residue reprocessed into asphalt or asphalt cement (*Figure 10-32*).

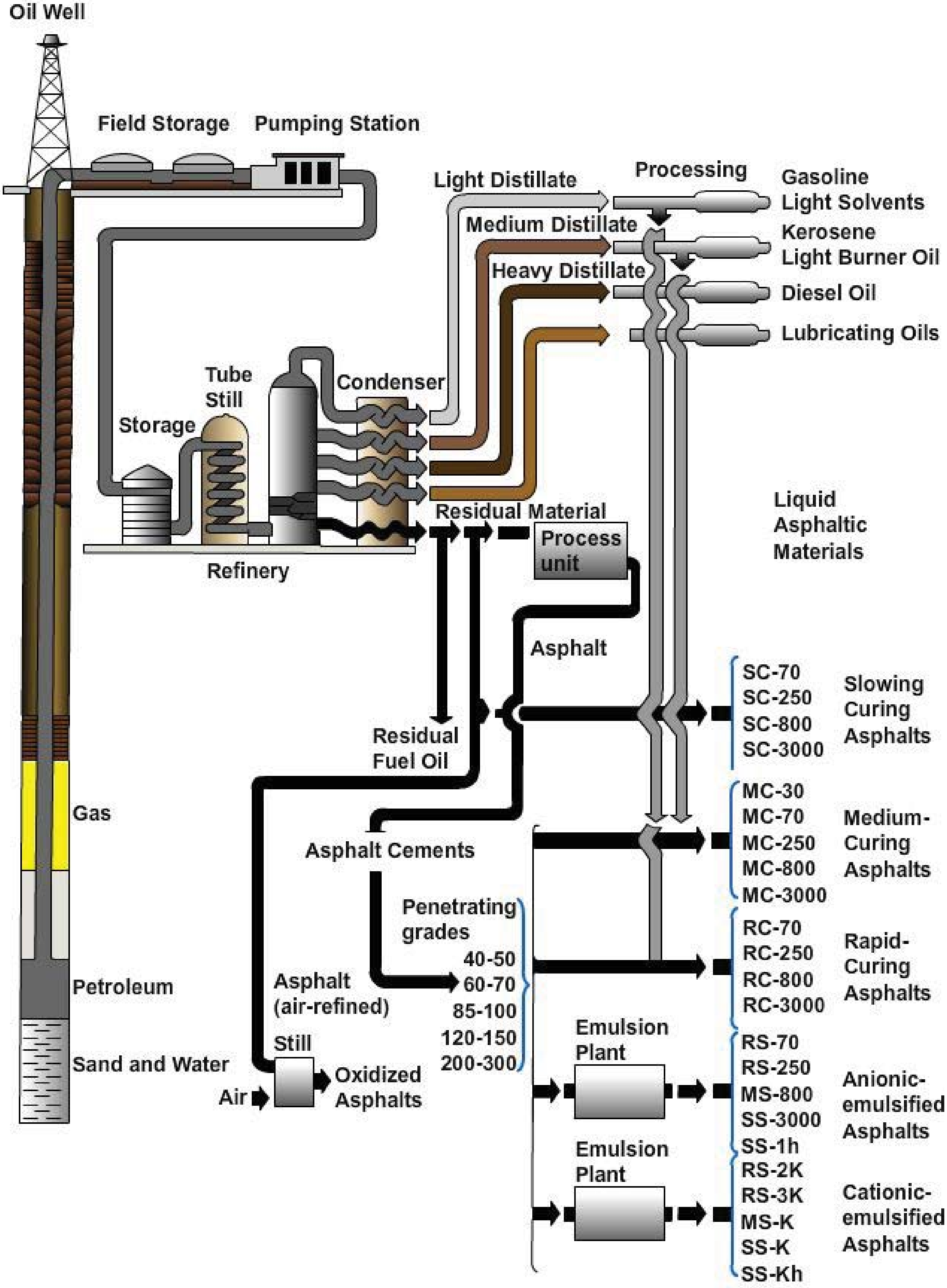


Figure 10-32 — Simplified flow chart — refining petroleum residual into asphalt.

The longer the process and the higher the temperatures, the harder the residue becomes because of the increased loss in volatiles. There are two well established grading scales for identifying asphalt cement:

1. Penetration grade--developed in the early 1900s.
   - Determined by the distance a standard needle under a standard load will penetrate a sample in a given time under a given temperature condition.
     - A correlating asphalt petroleum number from 00 to 7 is assigned to the penetration ranges.
     - *Table 10-5* lists the penetration ranges and correlating asphalt petroleum (AP) numbers presently recognized, along with the relative consistencies.

Table 10-5 — Penetration Grades and AP Numbers.

Penetration Grade	Asphalt Petroleum Number	Relative Consistency
40-50	7	Hard
60-70	5	
85-100	3	Medium Typical grades used in the U.S.
120-150	1	Soft
200-300	00	Softest Used for cold climates such as northern Canada

2. Viscosity grade--developed in the early 1960s.
   - Determined using a standard viscometer under standard conditions using special testing equipment (not in the NCF TOA) to measure the time that a given amount of liquid asphalt material will flow through a tube of standard dimensions under rigidly controlled temperature and pressure conditions.
     - Multiplying that measured time by a calibration factor for the equipment gives a numerical designation called ***kinematic viscosity***, measured in ***stokes*** (square centimeters per second) or centistokes (100 stokes).

In addition, there are two series of viscosity grades for asphalt cement.

- The AC series, based on original (as-supplied) asphalt binder samples, includes grades AC-2.5, AC-5, AC-10, AC-20, and AC-40.
- The AR series, based on aged residue asphalt binder samples, includes grades AR-1000, AR-2000, AR-4000, AR-8000, and AR-16000.

Viscosity is measured in poise (cm-g-s = dyne-second/cm^2, named after Jean Louis Marie Poiseuille). The lower the number of poises, the lower the viscosity and thus the more easily a substance flows. Therefore, AC-5 (viscosity is 500 ± 100 poise at 60° C [140° F]) is less viscous than AC-40 (viscosity is 4000 ± 800 poise at 60° C [140° F]).

Table 10-6 shows standard viscosity grades for the AC and AR grading systems from ASTM D 3381 and AASHTO M 226.

Table 10-6 — ASTM D 3381 and AASHTO M 226 Viscosity Grades.

Standard	Grading Based on Original Asphalt (AC)						Grading Based on Aged Residue (AR)				
AASHTO M 226	AC-2.5	AC-5	AC-10	AC-20	AC-30	AC-40	AR-10	AR-20	AR-40	AR-80	AR-160
ASTM D 3381	AC-2.5	AC-5	AC-10	AC-20	AC-30	AC-40	AR-1000	AR-2000	AR-4000	AR-8000	AR-16000

Normally, but not always, the lower viscosity-graded asphalts correlate with the softer asphalts having higher penetration values, and the higher viscosity-graded asphalts correlate with the lower penetration grades.

In lieu of the two well established grading scales, commercial and governmental agencies are transitioning to a grading system based on a more representative geographical location, the Superpave Performance Grading (PG) System.

The Superpave PG system was developed as part of the Superpave research effort to more accurately and fully characterize asphalt binders for use in hot mix asphalt (HMA) pavements. The PG system is based on the idea that an HMA asphalt binder’s properties should be related to the conditions under which it is used.

For asphalt binders, this involves expected climatic conditions as well as aging considerations. Therefore, the PG system uses a common battery of tests (as the older penetration and viscosity grading systems do) but specifies that a particular asphalt binder must pass these tests at specific temperatures dependent upon the specific climatic conditions in the area of intended use. Consequently, a binder used in a mountainous part of a state would be different than one used in lower elevations.

Superpave performance grading is reported using two numbers – the first being the average seven-day maximum pavement temperature (in °C) and the second being the minimum pavement design temperature likely to be experienced (in °C).

Thus, a PG 58—22 is intended for use where the average seven-day maximum pavement temperature is 58°C and the expected minimum pavement temperature is a —22°C. Notice that these numbers are pavement temperatures and not air temperatures.

All asphalt cements are solid or semisolid at room temperature and must be converted to a fluid state by heating, dissolving in a petroleum solvent (producing cutback asphalt), or emulsifying (producing emulsified asphalt) before they can be pumped or sprayed through pipes or nozzles and be mixed with aggregate.

3.1.2.2 Cutbacks

When heating equipment is not available or is impractical to use, asphalt cement can be made fluid by adding solvents (called cutter stock or flux oils). Cutter stock may be any one of the more volatile petroleum-distillate products (refer again to *Figure 10-32)*, and the resulting combination is called asphalt cutback. The solvent evaporates when exposure to air and leaves the asphalt cement to perform its functions.

The cutback's classification is based on the evaporation rate of the distillate in the mixture:

- Gasoline or naphtha (high volatility) produces a rapid-curing (RC) cutback.
- Kerosene (medium volatility) produces a medium-curing (MC) cutback.
- Fuel oil (low volatility) produces a slow-curing (SC) cutback.

The occasionally referred to "road oils" are a heavy petroleum oil in the SC grade of liquid asphalt. *Table 10-7* shows the percentage of components by grade for the three types of asphalt cutbacks.

Table 10-7 — Asphalt-cutback Composition (expressed in percent of total volume).

		Grades				
Type	**Components**	**30**	**70**	**250**	**800**	**3,000**
RC	Asphalt Cement		65	75	83	87
	Gasoline or Naphtha		35	25	17	13
MC	Asphalt Cement	54	64	74	82	86
	Kerosene	46	36	26	18	14
SC	Asphalt Cement		50	60	70	80
	Fuel Oil		50	40	30	20

As more cutter stock is mixed with a given amount of asphalt cement, a thinner liquid results. In practice, different amounts of cutter stock are added to a given amount of asphalt cement to obtain various viscosities, or grades, of cutbacks. The Army Corps of Engineers, and by extension NAVFAC through the joint services publication FM 5-472/NAVFAC MO-330/AFJMAN 32-1221(I), has approved a set of specifications for cutbacks based on kinematic viscosity.

The number assigned to each grade corresponds to the lower limit of kinematic viscosity as determined by a standard test. The upper limit of each grade is equal to twice the lower limit or grade number.

The units used in the test are centistokes. Thus, a number 70 cutback refers to a viscosity range of 70 to 140 centistokes. The other grades and their limits are 250 (250 to 500), 800 (800 to 1,600), and 3,000 (3,000 to 6,000). In addition, the MC has a 30 grade (30 to 60).

Figure 10-33 shows the scale of viscosity grades. The higher the viscosity, the thicker the liquid.

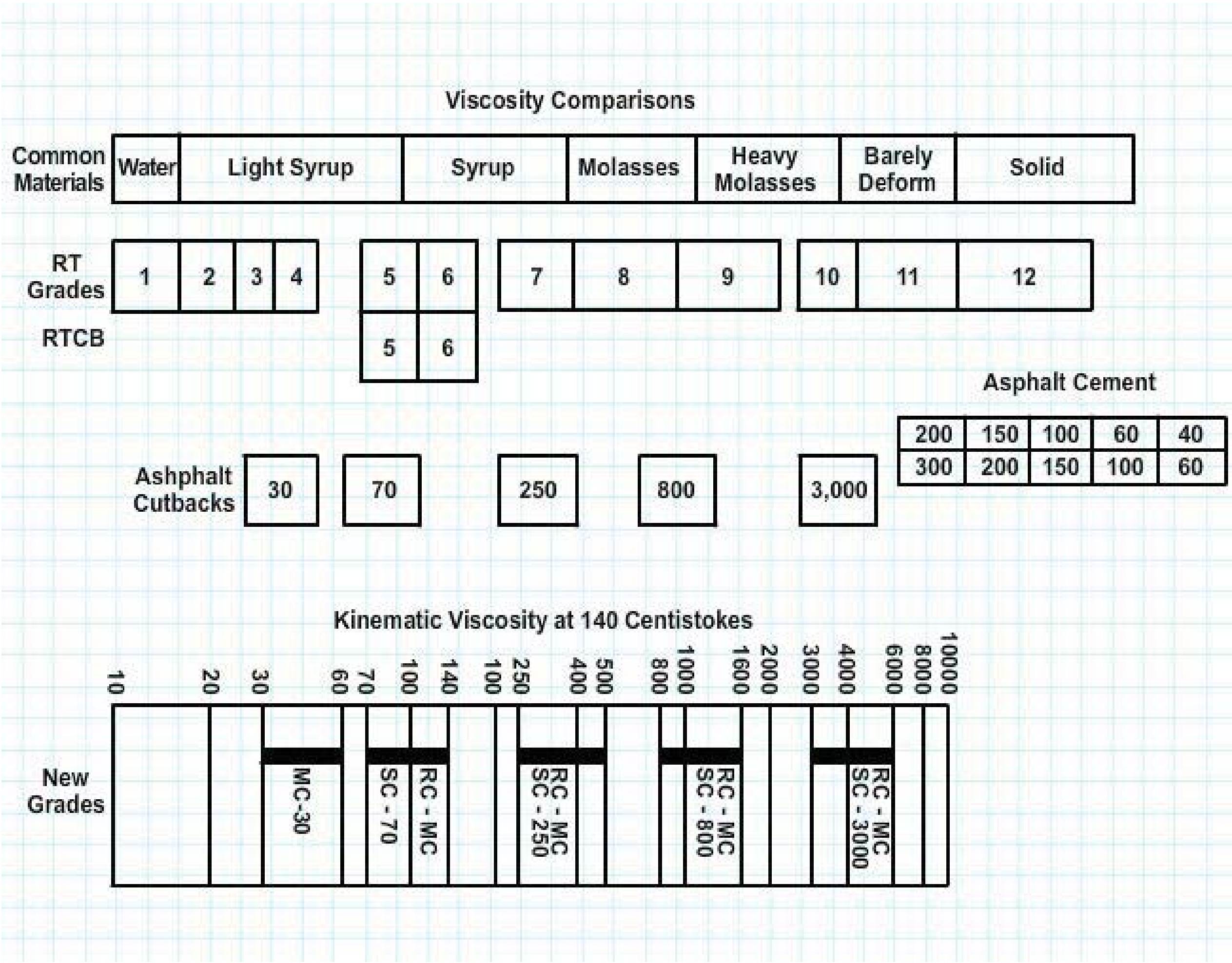


Figure 10-33 — Example of viscosity grades at room temperature.

Asphaltic penetrative soil binder is a special cutback asphalt composed of low penetration-grade asphalt and a solvent blend of kerosene and naphtha. It is similar in character to standard low-viscosity, MC cutback asphalt but differs in many specific properties. It is used as a soil binder and dust palliative.

3.1.2.3 Emulsions

Often, it is advantageous to use an asphalt material that is liquid at room temperature and yet will not burn; these are the properties of asphalt emulsions. Emulsified asphalt is a liquid mixture of asphalt, water, and emulsifier. Asphalt and water will not mix alone so a chemical agent (an emulsifying agent) must be added. Common emulsifying agents are soaps, colloidal clays, and numerous other organic agents.

In the emulsification process, warm asphalt is mechanically milled into very small globules (5-10 microns and smaller) and dispersed into the water treated with an emulsifying agent. The emulsifying agent keeps the asphalt globules apart from one another and suspended in the water, which allows the asphalt to be used at room and cold temperatures. After the emulsified asphalt is sprayed onto a surface or mixed with aggregates, the water evaporates and leaves only the asphalt residue behind to cement the aggregates together or waterproof the surface it was sprayed on.

Emulsions are classified according to the setting or breaking rate, which is the speed at which the emulsion breaks or the asphalt and water separate. This rate usually depends on the emulsifier used and the proportion of water to asphalt.

Emulsions are described as rapid-setting (RS), medium-setting (MS), and slow-setting (SS) and also by viscosity numbers. Because of this breaking rate, emulsions can also be grouped according to their ability to mix with damp aggregate. The RS emulsion breaks so fast that it cannot be mixed; therefore, it is called a non-mixing type. The MS and SS emulsions break slowly enough to permit good mixing until each particle of the aggregate is uniformly coated. Emulsions may also be satisfactorily used as a tack coat for bituminous pavements.

3.1.2.4 Road Tars

Despite the common use of the term ***tar pit***, such as the La Brea Tar Pits (*Figure 10-34*), no natural source of tars exists. Tars are products of coal distillation, and "coal tar," produced by one of several methods depending on the desired end product, is a general term applied to all varieties of tar obtained from coal. See *Figure 10-35*.

When bituminous coal is destructively distilled, coke and gas are formed. Tar, ammonia, light oils, sulfur, and phenol may be recovered.

Coke-oven tar is produced in the greatest amount; its chemical, physical, and adhesive characteristics make it most suitable for road-tar purposes.

Water-gas tar is obtained in the manufacture of carbureted water gas. The nature of the carbureting oil largely determines the character of the water-gas tar produced, and may vary widely in specific gravities, viscosities, and other physical and chemical properties.

Figure 10-34 — La Brea Tar (asphalt) pit.

Road tars are manufactured in 12 grades of viscosity (Refer again to *Figures 10-33* and *10-35*), and there are some special grades for use in rubberized-tar binders.

Grades 1 through 7 are liquid at room temperature, while grades 8 through 12 are semisolid or solid. The difference is due to the liquid coal distillates in the tar; the more distillate, the more liquid (or less solid) the tar. The road-tar cutbacks (RTCBs) are products of cutting back the heavier or harder grades with coal-tar distillates. RTCBs are manufactured in two viscosity grades (5 and 6) only.

Tar, which is insoluble in petroleum distillates, is sometimes mixed with oil-resistant, unvulcanized rubber to form a rubberized-tar binder material.

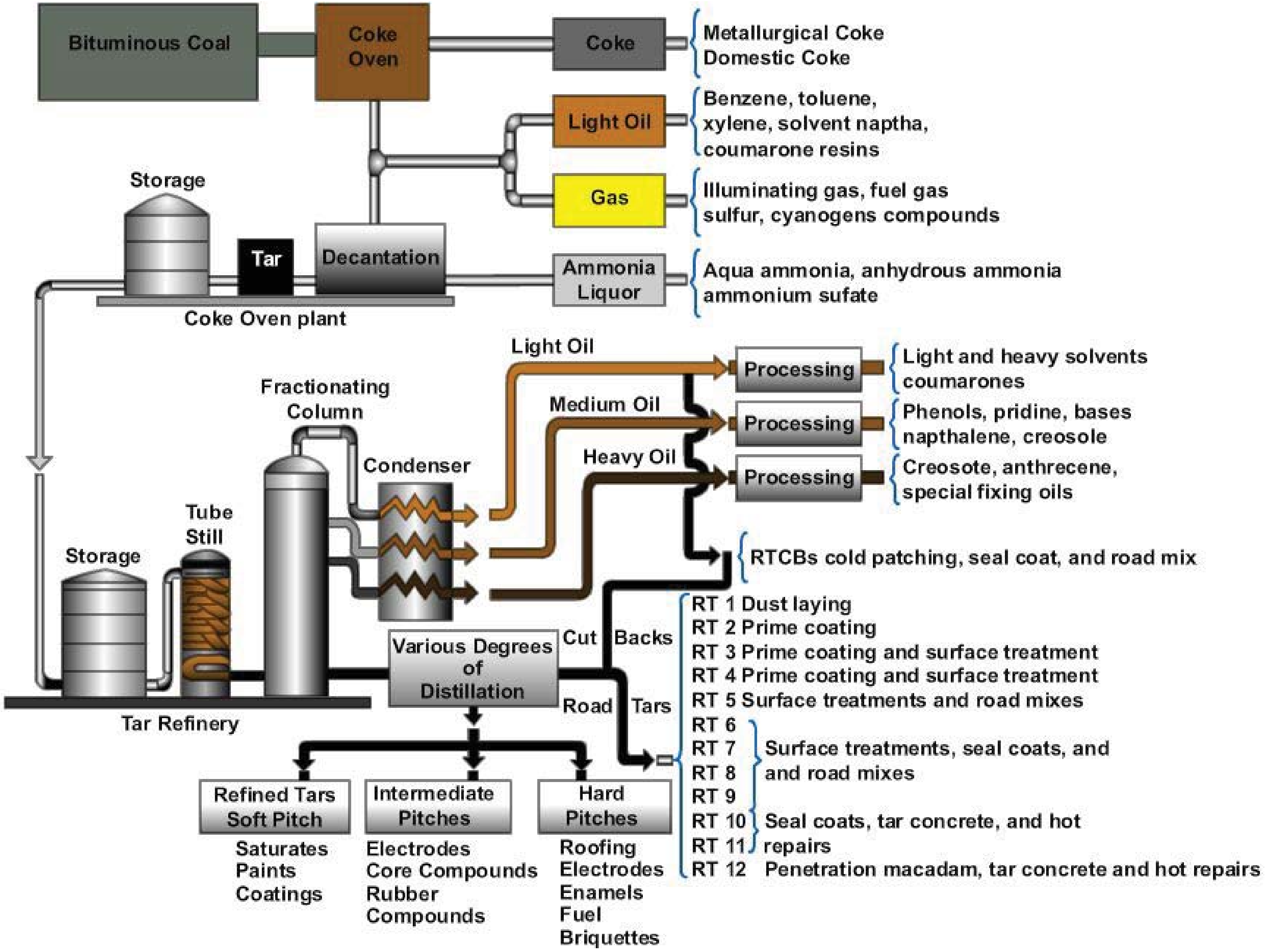


Figure 10-35 — Simplified flow chart — road tars from bituminous coals.

3.2.0 Characteristics and Uses of Bitumens

Selecting a particular bituminous material will depend upon the type of pavement, climatic conditions, seasonal factors, and availability of equipment, but in general, soft penetration grades of asphalt cement are preferred for use in cold climates, medium grades in moderate climates, and hard grades in warm climates. Similarly with asphalt cutbacks and tars, lighter grades are normally used in cold weather, heavier grades in warm weather. Refer to *Tables 10-8A* and *10-8B* for Characteristics, and *Tables 10-9A* and *10-9B* for Typical Uses of Bituminous Materials.

Be extremely cautious when handling bituminous materials. Asphalt cement, solid at room temperature, must be heated to high temperatures to make it workable as a binder material, and heated asphalt can cause severe burns in contact with the skin. In addition, vapors emitted by heating bituminous materials may be harmful if inhaled. Use care during heating to ensure proper ventilation.

Asphalt cutbacks contain highly flammable volatiles with vapors that will ignite at relatively low temperatures. The lowest temperature at which they will ignite is called the flash point. Note in *Table 10-8A*, the minimum flash point for RC-250, -800, and -3,000 is 80°F; for MC-30 and -70, about 110°F; for MC-250 to -3,000 and SC-70, about 150°F; and for the remaining SC grades, about 25° higher per grade up to 225°F for SC-3,000.

⚠ CAUTION ⚠

1. Spraying and mixing temperatures in many cases are above the flash point (*Table 10-8A*). Use extreme caution when handling these mixtures. Do not expose their vapors to an open flame.
2. Cutbacks may also be classified as an environmentally hazardous material. Check with unit and installation environmental representatives for further guidance as to proper storage, use, and disposal of these substances. If your unit's environmental representative is not known, consult your commander for assistance.

Each of the bituminous materials has advantages and disadvantages in construction.

Asphalt-cement cutbacks are flammable; asphalt pavements are susceptible to damage by the blast from jet planes, and can be dissolved by spilled petroleum products.

Tars, as products of coal, are not affected by petroleum derivatives. When used as a prime for base courses, tars seem to possess better penetration qualities than asphalts and are less susceptible to stripping (loss of bond to aggregate) in the presence of water. However, tars are affected by temperatures and have a wide range in viscosity, becoming so soft during warmer weather the pavement can rut, so brittle in colder weather the pavement can crack. The temperature susceptibility of tar binders is improved by blending with oil-resistant rubber. Asphalt pavements and tar pavements are generally ready for traffic within a few hours after placement since they can be used as soon as they reach normal temperature.

Asphalt emulsions are not flammable and are liquid at normal temperatures. Since they are mixed with water, they can be used with more damp aggregate than required for the cutbacks. Additional water may be added to the emulsion up to proportions of 1:3 for use in slurry seal coats. Because emulsions contain water, they have certain disadvantages. During freezing weather, the emulsions can freeze and the components separate. Emulsions are difficult to store for extended periods because they tend to break even in unopened drums. When shipped, the water in the emulsion takes up valuable space which could be used to transport hard-to-obtain materials.

Table 10- 8A – Characteristics of Bituminous Materials.

Material	Form	Grade Designa-tion	Temperature of Application Ranges				Flash Point (Min)		Remarks
			Spraying**		Mixing				
			°F	°C	°F	°C	°F	°C	
Penetrative soil binder	Liquid		130-150	55 - 65			80	27	Contains naphtha ***Caution: Highly flammable***
Cutback (RC)	Liquids—asphalt residues fluxed with more volatile petroleum distillate	RC-70	105-175	*41-79	95-135	35-57			RC cutbacks contain highly volatile naphtha cutter stock. Naphtha evaporates quickly, leaving an asphalt-cement binder, permitting early use of the surface. ***Caution: Highly flammable***
		RC-250	145-220	63-104	135-175	57-79	80	27	
		RC-800	180-255	*82-124	170-210	77-99	80	27	
		RC-3,000	*215-290	*102-143	200-240	93-116	80	27	
Cutback (MC)	Liquids—asphalt residues fluxed with more volatile petroleum distillate	MC-30	70-140	21-60	55-95	13-35	100	37	MC cutbacks contain less volatile kerosene cutter stock. Kerosene evaporates less rapidly than naphtha. ***Caution: Flammable.***
		MC-70	105-175	41-79	95-135	35-57	100	37	
		MC-250	145-220	63-104	135-175	57-79	150	65	
		MC-800	180-255	82-124	170-210	77-99	150	65	
		MC-3,000	215-290	102-143	200-240	93-116	150	65	
Cutback (SC)	Liquids—asphalt residues fluxed with more volatile petroleum distillate	SC-70	105-175	41-79	95-135	35-57	150	65	SC cutbacks contain slightly volatile diesel-fuel cutter stock. Diesel fuel evaporates slowly. ***Caution: Flammable***
		SC-250	145-220	63-104	135-175	57-79	175+	79+	
		SC-800	180-225	82-124	170-210	71-99	200+	93+	
		SC-3,000	215-290	102-143	200-240	93-116	225+	107+	
Asphalt cements	Solids	40-50			300-350	149-177			Penetrations 40 to 100 used for crack and joint fillers. Penetrations 70 to 300 used for plant mixes, penetration macadam, and surface treatment. Use test to determine flash point.
		60-70	285-350	141-177	275-325	135-163			
		85-100	285-350	141-177	275-325	135-163			
		120-150	285-350	141-177	275-325	135-163			
		200-300	260-325	127-163	200-275	93-135			
Powdered asphalt	Hard and solid asphalts ground to powder								Used with SC to produce extra tough road surfaces.

*** RC cutbacks are seldom used for spraying.**

**** Low temperature is based on a viscosity of 200 centistokes kinematic viscosity and the higher temperature is based on a 50-centistoke viscosity.**

Table 10- 8B – Characteristics of Bituminous Materials (Cont.)

Material	Form	Grade Designa-tion	Temperature of Application Ranges				Flash Point (Min)		Remarks
			Spraying**		Mixing				
			°F	°C	°F	°C	°F	°C	
Asphalt emulsions (RS)	Liquids—asphalt particles held in an aqueous suspension by an emulsifying agent	RS-1 RS-2 RS-2K RS-3K	50-140 50-140 50-140 50-140	10-60 10-60 10-60 10-60	Nonmixing 50-140 50-140 50-140	10-60 10-60 10-60 10-60			Freezing destroys emulsion. Use for road and plant mixes with coarse aggregates (SS). All emulsions with "K" suffix are cationic.
Asphalt emulsions (MS)	Liquids—asphalt particles held in an aqueous suspension by an emulsifying agent	MS-2 SM-K CM-K	50-140 50-140 50-140	10-60 10-60 10-60	50-140 50-140 50-140	10-60 10-60 10-60			
Asphalt emulsions (SS)	Liquids—asphalt particles held in an aqueous suspension by an emulsifying agent	SS-1 SS-1h SS-K SS-Kh	50-140 50-140 50-140 50-140	10-60 10-60 10-60 10-60	50-140 50-140 50-140 50-140	10-60 10-60 10-60 10-60			
Road tars	Liquids	RT-1 RT-2 RT-3	60-125 60-125 60-125	15-52 15-52 27-66					Priming oils. RT-4 through RT-12 not generally used.
RTCBs	Liquids	RTCB-5 RTCB-6	60-120 60-120	16-49 16-49					Patching mixtures. ***Caution: Flammable***
Rock asphalt	Solids								Mixed and used locally where found. Cutback may be added if necessary.

*** RC cutbacks are seldom used for spraying.**
**** Low temperature is based on a viscosity of 200 centistokes kinematic viscosity and the higher temperature is based on a 50-centistoke viscosity.**

Table 10- 9A – Typical Uses of Bituminous Materials.

Purpose or Use	**Grade or Designation**[1]		
	CB-Asphalt Cutback[2]		
	RC Rapid Curing	**MC Medium Curing**	**SC Slow Curing**
Dust palliative	DCA-70[3]	MC-30, -70, -250 APSB[4]	SC-70, -250
Prime coat:			
- Tightly bonded surfaces		MC-30	
- Loosely bonded, fine-grained surfaces		MC-70	SC-70
- Loosely bonded, coarse-grained surfaces		MC-250	SC-250
Tack coat	RC-250, -800	MC-250, -800	
Surface treatment and seal coat:			
- Coarse sand cover	RC-70, -250	MC-250, -800	
- Clean coarse aggregate cover	RC-250, -800, -3,000	MC-800	
- Graded gravel aggregate cover		MC-250, -800	SC-800
- Gravel mulch		MC-250	SC-250
Mixed in place road mix:			
- Open-graded aggregate:			
o Sand	RC-70, -250	MC-800	
o Maximum diameter 1 inch, high percentage passing No. 10		MC-800	
Macadam aggregate	RC-250, -800		
Dense-graded aggregate:			
- High percentage passing No. 200		MC-250	SC-250
- Maximum diameter 1 inch, medium percentage passing No. 200		MC-250, -800	SC-250, -800
Premix or cold patch:			
- Open-graded aggregate	RC-250	MC-800	SC-800
- Dense-graded aggregate		MC-250	SC-250
Cold-laid plant mix:			
- Open-graded aggregate:			
o Sand	RC-250, -800		
- Maximum diameter 1 inch, high percentage passing No. 10	RC-800		SC-800
o Macadam aggregate	RC-800, -3,000		
- Dense-graded aggregate:			
o High percentage passing No. 200		MC-800	SC-800
o Maximum diameter 1 inch, medium percentage passing No. 200		MC-800	SC-800
- Aggregate pre-coating followed with asphalt		MC-30	SC-70
Hot-laid plant mix	RC-3,000	MC-3,000	SC-3,000
Penetration macadam:			
- Cold weather	RC-800, -3,000		SC-3,000
- Hot weather			

[1] Prevailing temperature during construction also affects selection of bitumen and may be the determining factor rather than size and gradation of aggregate.

[2] Caution: Do not overheat aggregate when cutbacks are used to produce hot mixes.

[3] DCA-70 is a water emulsion of a polyvinyl acetate containing chemical modifiers (formerly UCAR-131). Proprietary product of Union Carbide Corporation, New York, NY.

[4] Asphaltic penetrative soil binder (APSB)

Table 10- 9B – Typical Uses of Bituminous Materials (Cont.)

Purpose or Use	**Grade or Designation**[1]		
	AC **Asphalt cement with a penetration of ---**	**MC** **Aniotic and cationic asphalt emulsion**	**SC** **Road tar and road tar cut back**
Dust palliative		SS-1, -1h	RT-1
Prime coat: - Tightly bonded surfaces - Loosely bonded, fine-grained surfaces - Loosely bonded, coarse-grained surfaces			RT-2 RT-3 RT-4
Tack coat	200-300	RS-1, -2	RT-4, -5, -6, -7, -8, -9
Surface treatment and seal coat: - Coarse sand cover - Clean coarse aggregate cover - Graded gravel aggregate cover - Gravel mulch	120-150, 200-300	RS-1, -2	RT -6, -7, -8, -9, -10
Mixed in place road mix: - Open-graded aggregate: o Sand o Maximum diameter 1 inch, high percentage passing No. 10		MS-2	RT-6
Macadam aggregate	85-100	MS-2	RT-7
Dense-graded aggregate: - High percentage passing No. 200 - Maximum diameter 1 inch, medium percentage passing No. 200		SS-1h SS-1	RT--5, -6, -7 RT -6, -7, -8, -9,
Premix or cold patch: - Open-graded aggregate - Dense-graded aggregate		MS-2	RT--5, -6, -7, -8, or RTCB-5, -6
Cold-laid plant mix: - Open-graded aggregate: o Sand - Maximum diameter 1 inch, high percentage passing No. 10 o Macadam aggregate - Dense-graded aggregate: o High percentage passing No. 200 o Maximum diameter 1 inch, medium percentage passing No. 200 - Aggregate pre-coating followed with asphalt		MS-2 MS-2 SS-1 SS-1	RT-4, -5, -6, -7, -8, -9
Hot-laid plant mix	85-100, 120-150		RT-11, -12
Penetration macadam: - Cold weather - Hot weather	120-150 85-100	RS-1 RS-1	RT-10, -11 RT-12

[1] **Prevailing temperature during construction also affects selection of bitumen and may be the determining factor rather than size and gradation of aggregate.**

[2] **Caution: Do not overheat aggregate when cutbacks are used to produce hot mixes.**

[3] **DCA-70 is a water emulsion of a polyvinyl acetate containing chemical modifiers (formerly UCAR-131). Proprietary product of Union Carbide Corporation, New York, NY.**

[4] **Asphaltic penetrative soil binder (APSB)**

3.3.0 Field Identification of Bitumens

The field tests discussed in this section are limited to the bitumen identification procedures, flash-point tests, and penetration tests. These tests are applicable to both tars and asphalts and are conducted to determine safe uses for a material.

Field identification of the available material's type and grade helps determine what type of surface can be constructed. With the type of surface known, the construction procedure can be established and scheduled, which will in turn determine the proper equipment and the necessary safety procedures. Aggregate materials must also be tested for acceptable bituminous construction use.

Field tests are performed to classify the bituminous paving materials as asphalt cement, asphalt cutback, asphalt emulsion, road tar, or RTCB, and to identify the viscosity grade.

To distinguish among the several asphaltic and tar products, you need to know something of their origin, physical properties, and the manner in which they are normally used. *Tables 10-8A/B* and *10-9A/B* provide some of this information, and the identification procedure shown in *Figure 10-36* is based on a consideration of the physical properties of the materials as listed in these tables.

Perform all tests away from open flames and in well ventilated areas. Also, ensure that all materials are properly disposed of according to local environmental policy.

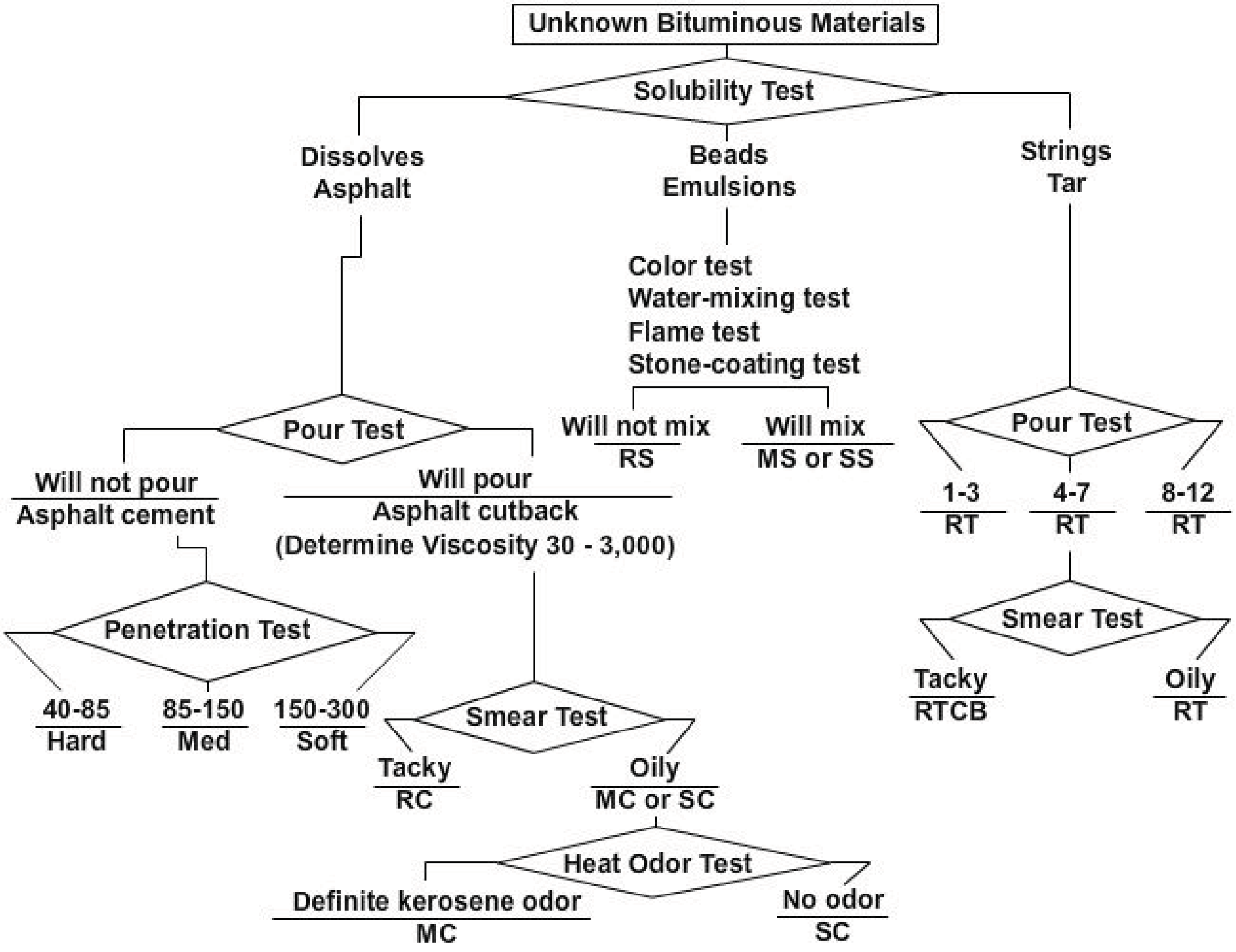


Figure 10-36 – Typical process for field identification of unknown bituminous materials.

3.3.1 Test for Solubility

To identify an unknown bituminous material, the first procedure is to determine, by a solubility test, whether it is an asphalt or a tar. Attempt to dissolve an unknown sample (a few drops, if liquid; enough to cover a nail head, if solid) by stirring it into any petroleum distillate such as kerosene, gasoline, diesel oil, or jet fuel. One or more of these distillates is usually available to an EA in the field.

Since asphalt is derived from petroleum, it will dissolve in the petroleum distillate, while road tar will not dissolve. If the sample is an asphalt, the sample distillate mix will consist of a dark, uniform liquid; asphalt cements or cutbacks will dissolve completely.

Asphalt in emulsions is also distinguishable as it dissolves and forms black beads or globules in the bottom of the container. Observed in the distillate container, a road-tar sample will appear as a dark, stringy, undissolved mass.

You can make another check by spotting a piece of paper or cloth with the mix. Asphalt dissolved in distillate will produce a brown to black stain; clear distillate above the settled tar will not cause a stain.

The solubility test provides a positive method of identification.

3.3.2 Tests for Asphalt Cement

When the solubility test determines that the bituminous material is an asphalt, perform the following procedures to determine if the specimen is an asphalt cement or a cutback.

- **Pour test** — The various grades of asphalt cement are solid at room temperature while cutbacks are liquid, and a pour test will distinguish between them.
    - Place a sample of the material in a small container and attempt to pour it.
        - If the material does not pour, it is an asphalt cement.
        - If the material pours, it is a cutback or an emulsion.

Note: At 77°F,even the highest penetration grade (200 to 300) of asphalt cement will not pour or immediately deform. The thickest asphalt cutback, however, will start to pour in about 13 seconds.

- **Penetration test** — The various grades of asphalt cement are distinguished principally by their hardness, as measured by a field penetration test. The information obtained may be sufficient for planning for or starting emergency construction. The exact penetration grade is not determined, but the field test will distinguish between hard, medium, or soft groups of asphalt cement.
    - Push a sharpened pencil or nail into the container of asphalt (at about 77°F) using about 10 pounds of force.
        - If only a slight penetration is made with considerable difficulty, a hard asphalt cement is present (penetration 40-85).
        - If the penetration is made with some difficulty, a medium asphalt cement is present (penetration 85-100).
        - If the penetration is made with ease, the asphalt cement is a soft asphalt cement in the high-penetration scale (penetration 150-300).

3.3.3 Tests for Asphalt Cutbacks

Three tests are used to determine the grade of an asphaltic cutback:

1. **Pour Test** — As already pointed out, an asphalt cement will not pour at 77°F, but a cutback will; if the material pours, it is an asphalt cutback. Now you can find the approximate viscosity grade number of the cutback.
    - Compare the flow to well known materials such as water, syrup, and others. Refer again to *Figure 10-33*. The cutbacks of a given viscosity grade will pour in a manner similar to the following:
        - 30—water
        - 70—light syrup
        - 250—syrup
        - 800—molasses
        - 3,000—barely deform

Note: If this test is made at a temperature below 77°F, the materials will appear more viscous (stiff) than at 77°F and the opposite if tested when warmer than 77°F.

After the pour test, the approximate viscosity grade of the cutback is known, but the type (RC, MC, or SC) is not.

2. **Smear Test** — Perform the smear test to determine if a cutback is an RC.
    - Make a uniform smear of the substance on a piece of glazed paper or other nonabsorbent surface. Volatile materials, if present, will evaporate.
        - RC materials are cut back with a very volatile substance; most of the volatiles will evaporate within 10 minutes. The surface of the smear then becomes extremely tacky.
        - Lighter grades (MC and SC) will remain fluid and smooth for some time. An MC will not result in a tacky surface for a matter of hours. SC materials may require several days.

    Perform a prolonged smear test to identify an 800- or 3,000-grade MC or SC cutback. This is necessary because these grades contain such small quantities of cutter stock that they may become tacky in the 10-minute period specified above.

    - Place a thin smear of the material on a nonabsorbent surface and let it cure for at least 2 hours.
        - If the material is an MC or SC, the smear will be uncured and still quite sticky.
        - If the material is not an MC or SC, the smear will be hard or just slightly sticky.
        - If the material is an RC-3,000, it will cure completely in 3 hours.
        - If the material is an RC-800, it will take about 6 hours to cure.

NOTE

Even after 24 hours, an MC or SC will still be sticky.

3. **Heat-Odor Test** — The main difference between MC material and SC material: MC material is cut back with kerosene, SC with diesel or a low-volatility oil class.

In this test, apply heat to the sample to drive off the kerosene, if it is present, and make it show up in the form of an odor.

- Heat the unknown sample (*using minimal heat*) in a closed container to capture the escaping vapors.
    - An MC sample will have a strong petroleum or kerosene odor.
    - An SC sample will have no kerosene or petroleum odor but may have a faint odor of hot motor oil.

The ability to differentiate between the RC, the MC, and the SC is an essential part of field identification.

3.3.4 Tests for Asphalt Emulsions

Asphalt emulsion, a mixture of asphalt, water, and an emulsifying agent, is another asphaltic material used in paving. Refer to *Table 10-8B*. The anionic emulsions specifications cover three types of asphalt emulsion—RS grades 1 and 2, MS grade 2, and SS grades 1 and 1h.

1. **Solubility Test** — The solubility test will make an emulsion's identity known by forming into globules or beads that fall to the bottom of the container of petroleum distillate. During this test, the emulsion will present a distinctive dark brown color, while all other bituminous materials are black.
2. **Water-Mixing Test** — If mixed with water, an emulsion will accept the extra water and still remain a uniform liquid. The sample and water will mix uniformly if the material is an emulsion. This test is positive since no other bituminous material will mix with water.
3. **Flame Test** — Since an emulsion contains water, a small piece of cloth saturated with it will not burn if a flame is applied. The other bitumens will burn or flame.
4. **Stone-Coating Test** — After establishing that the material is an emulsion, determine whether the emulsion is a mixing grade (MS or SS) or a non-mixing grade (RS).
    - Mix a small amount (6 to 8 percent by weight) with damp sand using a metal spoon. Exercise care not to add so much emulsion to the sand as to saturate it.
        - An MS or SS emulsion will mix easily and coat all the particles completely (as well as the mixing spoon) with a uniform coating of asphalt.
        - An RS emulsion will break so quickly it will not be possible to mix it with sand. It breaks immediately, gumming up the spoon with the relatively hard original asphalt cement.

3.3.5 Tests for Tars

There are three tests for road tars—the solubility test, the pour test, and the smear test.

1. **Solubility Test** — As determined earlier, if the unknown bituminous material does not dissolve during the solubility test but forms a stringy mass, the material is a tar (Refer to *Figure 10-36*). The next step is to determine its viscosity grade.

2. **Pour Test** — By comparing the flow of the material to that of common materials (Refer to *Figure 10-33*), the viscosity of the tar may be closely estimated. The grades run from RT-1 to RT-12 and vary in consistency from very fluid to solid.
3. **Smear Test** — If, during the pour test, the identified tar seems to be in the range of an RT-4 to RT-7 material, perform a smear test to determine whether it is a road tar or an RTCB.
   - Perform the smear test in the manner previously described for cutback asphalt.
     - The material is a road tar if the material remains with the same amount of stickiness.
     - If it shows a great increase in stickiness in 10 minutes, it is an RTCB.
     - If field identification yields a grade of about 5 or 6, it is not important to determine whether the road-tar cutback is RTCB-5 or RTCB-6 since both are used under approximately the same conditions.

3.4.0 Laboratory Tests of Bitumens

Field identification tests can identify the material during expedient conditions or until more detailed tests can be performed. They can determine whether the material is an asphalt or a tar and whether it is a cutback or an emulsion.

Laboratory testing provides a more positive identification, but that is not the only purpose of the various laboratory tests. For example, you may need to perform specific gravity testing (described earlier in the concrete section and in FM 5-472/NAVFAC MO-330) as part of a larger testing procedure, or to check the uniformity of successive asphalt shipments.

Bituminous materials are manufactured to meet specifications established by the federal government, the State Highway and Transportation Officials (AASHTO), and the American Society for Testing and Materials (ASTM). These specifications define the extreme limits permitted in the manufacture of the material and assure the user that the material will possess definite characteristics and fulfill the project requirements.

Tests to verify that a material conforms to specifications include:

- Determining specific gravity
- Solubility
- Analysis by distillation
- Softening point

As an EA, you should be able to perform some of the following laboratory tests; others you are less likely to perform but should be aware of. However, these tests are described for your information and, when equipment is available, are used to identify the material beyond field identification, furnish information for mix design, or establish safe-handling procedures.

3.4.1 Identification Tests

The bitumens laboratory identification kit contains number of bitumen samples in all the recognized categories. To use the kit, bring an unidentified sample to approximately the same temperature as the kit samples and simply follow the instructions that come with the kit; make an identification based on similarity of color, feel, consistency, odor, and ductility (stretchability).

A bituminous material suitable for pavement has a considerably higher ductility than one suitable only as a waterproofer, roofing binder, or crack filler. Any crude method of determining the presence (or absence) of ductility, such as stretching the material like an elastic, will indicate whether the sample lies somewhere in the category of pavement material.

A test for ductility comparison involving two or more samples is outlined in FM 5-472/NAVFAC MO-330. In this test, dumbbell-shaped specimens of asphalt are molded under standard conditions, conditioned in a water bath to standard temperature (usually 77°F), then extended at the rate of 5 centimeters per minute until the threads connecting the two ends break. The difference in centimeters between the final length at the break and the original length is the ductility.

3.4.2 Distillation Test

If an unknown bitumen proves to be an asphalt (has an odor indicating a distillate such as kerosene or naphtha, you can perform a distillation test to indicate the character and approximate grade.

Remember, the basic material for RC and MC is asphaltic cement, that is, penetration asphalt. However, for SC the basis is not asphaltic cement but an asphalt residual oil too fluid to be penetration-tested for grade.

RC, MC, and SC all contain a distillate, that is, a volatile liquid that evaporates during the curing process. For RC and MC, the distillate is highly volatile and evaporates quickly; for SC, it is considerably less volatile.

The RC, MC, or SC grades increase with the ratio of bitumen to distillate; the higher the percentage of bitumen, the more solid the material will be, and, therefore, the higher the grade. For RC and MC, the percentage of bitumen for a given grade is essentially the same, as shown in *Table 10-10*, an expanded version of *Table 10-7*.

Table 10-10 – Asphalt-cutback Composition by Percent.

		Grades				
Type	**Components**	**30**	**70**	**250**	**800**	**3,000**
		⟶				
RC	*Asphalt Cement*		*65*	*75*	*83*	*87*
	Gasoline or Naphtha		35	25	17	13
MC	*Asphalt Cement*	*54*	*64*	*74*	*82*	*86*
	Kerosene	46	36	26	18	14
SC	*Asphalt Cement*		*50*	*60*	*70*	*80*
	Fuel Oil		50	40	30	20

For example, with MC-30, the percentage of bitumen is 54 with the percentage of distillate determined by subtracting the percentage of bitumen from 100, or 46 percent. For SCs, the bitumen percentages are somewhat lower.

A distillation test provides you with the information to determine the bitumen percentage and hence, if the material is SC, RC, or MC. The distillate evaporation rate will indicate whether it is RC or MC, since naphtha or gasoline will evaporate much more rapidly than kerosene.

Figure 10-37 shows the apparatus used in distillation testing.

Place a measured quantity (by volume) of the bitumen in a distillation flask that has a thermometer running through the stopper.

Heat the flask and contents.

As the temperature rises, distillate is given off in the form of vapor.

A condenser returns the vapor to liquid form, and the liquid (distillate) is caught in a volumetric beaker.

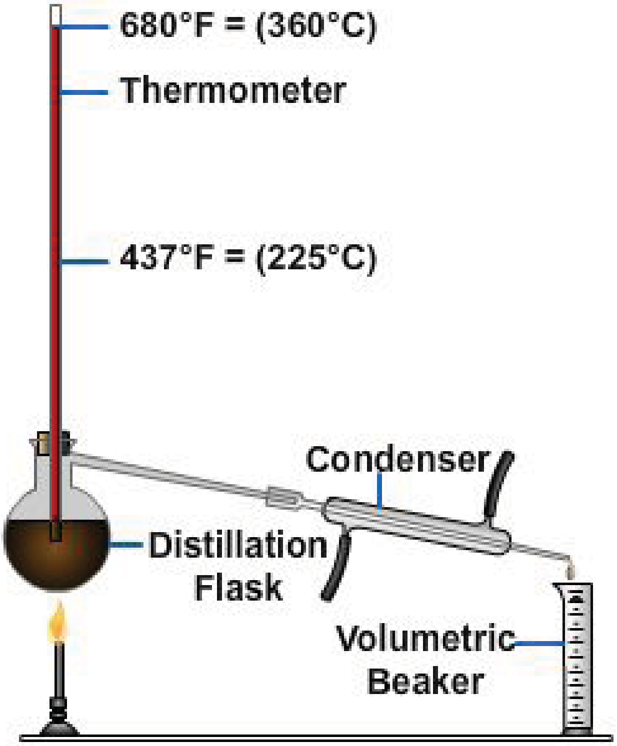


Figure 10-37 – Example of apparatus for bitumen distillation testing.

The test will indicate what you can expect by application and use of the materials. Distillation ranges are:

- RC — 374° - 680°F (190° - 360°C)
- MC — 437° - 680°F (225° - 360°C)
- SC — only at 680°F (360°C)
- Road tars — 338° - 572°F (170° - 300°C)
- Tar-rubber blends — 170° - 355°F (76.7° - 179.4°C)

The amount distilled is expressed as a percentage of the total, and the residue is the difference between the distillate and the total. Percentages of distillation may be as little as 1 percent for tar-rubber distilled at 338°F (170°C) to as much as 59 percent when you heat RC and MC cutbacks or tars to the higher temperatures.

Record the volume of bitumen remaining in the flask. If the residue is solid enough to be tested, it must be asphaltic cement; the original material was either RC or MC, and you can subject it to the penetration test. If it is not solid enough for penetration testing, the original material was SC.

Finally, you can determine the grade by calculating the percentage of bitumen and comparing it with the ranges previously given.

3.4.3 Flash Point Tests

Flash point of a bitumen containing a volatile distillate — the temperature at which it begins to give off ignitable vapor.

Flash-point testing's principal purpose is to determine maximum safe mixing and applying temperatures. However, these tests can also aid in identifying a bitumen.

Refer to *Table 10-8A* again. You can see that RC and MC grades have flash points below 175°F. MC-250 to 3,000 and SC-70 have flash points around 150°F, but the other SC grades have flash points above 175°F.

Figure 10-38 – Example of a Tag open-cup flash point tester.

When you are testing for a flash point below 175°F, use the Tag open-cup equipment shown in *Figure 10-38*.

When you are testing for flash points above 175°F, use the **Cleveland open-cup** equipment shown in *Figure 10-39*.

Figure 10-39 – Example of a Cleveland open-cup flash point tester.

When you use either of these testers, follow the procedures described in FM 5-472/NAVFAC MO-330. While there are important procedural differences in the equipment, flash-point testing using either equipment is generally similar:

- Use the equipment to heat the test sample at a prescribed rate of temperature increase.
- When the temperature reading on the thermometer nears the estimated flash point on *Table 10-8A*, use an alcohol torch to begin passing a flame across the surface of the sample.
- When the test flame produces a distinct flicker or flash on the surface of the sample, you have reached the flash point.
- Read the thermometer and record the temperature.

3.4.4 Penetration Test

Figure 10-40 shows an asphalt penetrometer used to determine the grade of asphalt cement.

Figure 10-40 – Example of an asphalt penetrometer.

To perform the test:

- Bring needle into contact with surface.
- Release to exert a pressure of 100 grams.
- Read penetrated distance on the dial (to the nearest 0.01 centimeter) seconds after releasing needle.

Reported penetration is the average of at least three tests on the same material whose values do not differ more than four points between maximum and minimum.

In addition to grade determination, the penetration test is useful for other purposes, such as detecting overheating or prolonged heating of asphalts in storage tanks. Also, when the asphalt is extracted from a pavement, the penetration test is useful in determining how the asphalt has changed with age and weathering. For detailed procedures refer to FM 5-472/NAVFAC MO-330.

3.5.0 Tests on Aggregate

The qualities that largely affect bituminous paving and the quality of the resulting pavement include:

- Angular shape
- Rough surface
- Hardness
- Gradation
- Grain distribution

Larger, coarse aggregate particles are the main structural members of the pavement, but if the mix were nothing but large particles, there would also be many unfilled voids between adjacent particles. The fewer voids the mixture has, the more dense the pavement and, therefore, the more durable it is. Ideal density is obtained by filling the voids between the largest particles with progressively smaller particles through the whole range of sizes from coarsest to finest.

Common practice divides the aggregates used for bituminous paving into three categories:

- Coarse aggregate (retained on No. 10 sieve)
- Fine aggregate (retained on No. 200 sieve)
- Mineral filler (Usually, 65 percent or more will pass No. 200 sieve.)

The size distribution will determine how many voids will remain and helps establish how much bitumen will be needed.

Just as they do for concrete mix designs, EAs must be able to perform tests on aggregates to determine their acceptability for bituminous construction. One test is the grain size distribution test done by sieve analysis, using the same procedure described for soil analysis in EA Basic. You also need to perform tests for mineral dust and specific gravity as presented in the following paragraphs.

3.5.1 Test for Mineral Dust

Mineral dust — In bituminous paving, particles finer than the No. 200 sieve.

To measure the amount of mineral dust in a selected sample, perform a washed sieve analysis (see EA Basic), using the No. 40 and No. 200 sieves. Discard all the material passing the No. 200 sieve, return the materials remaining on the sieve to the original washed sample, oven-dry, and weigh. The amount of mineral dust is then calculated, using the following formula:

$$Percent\ finer\ than\ No.200 = \frac{W_O - W_W}{W_O} \times 100$$

Where:

$W_O =$ Original dry weight

$W_W =$ Washed dry weight

3.5.2 Test for Specific Gravity

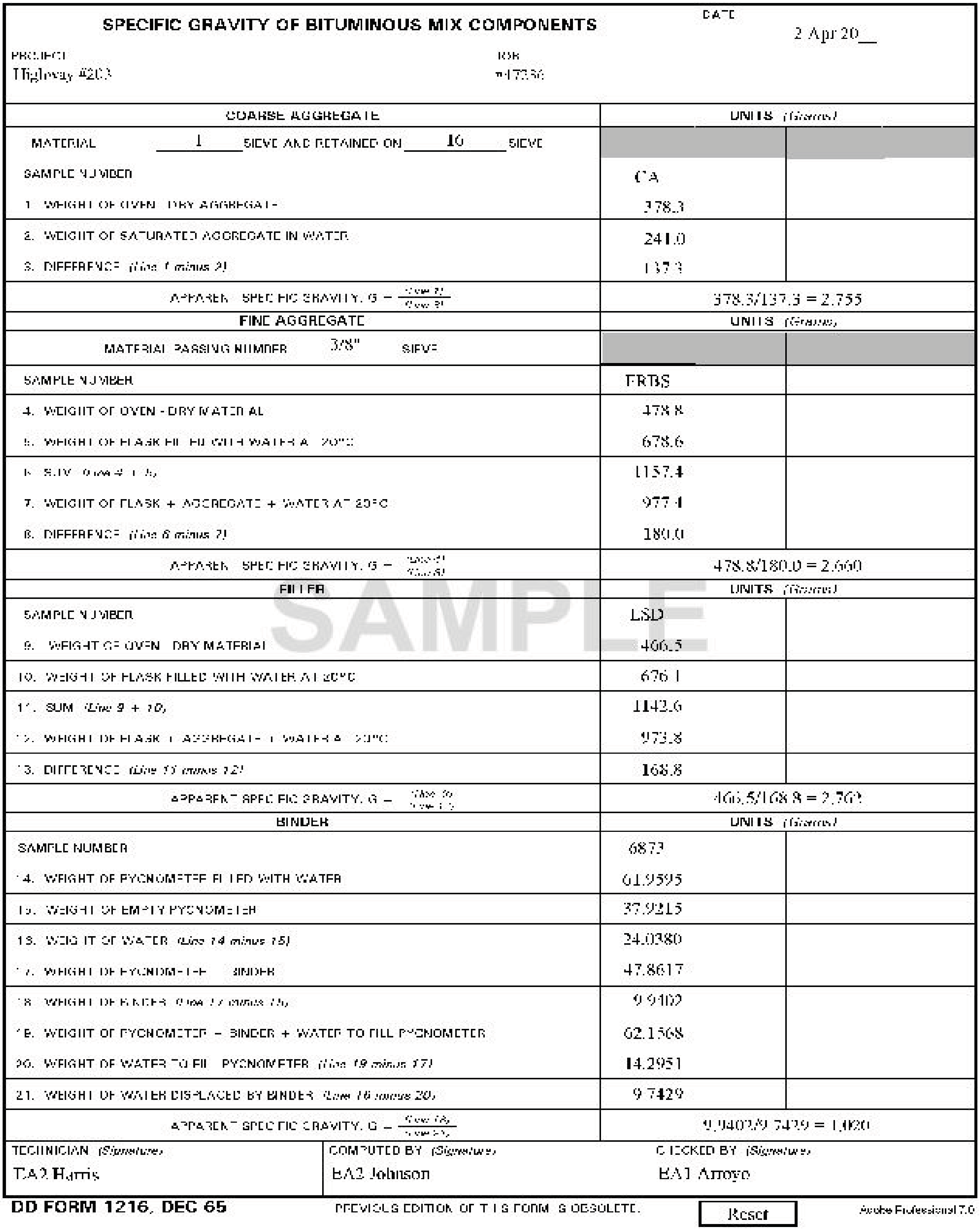
In bituminous paving mixtures, you need the specific gravities of aggregates to compute the percent of air voids and percent of voids filled with bitumens.

Apparent specific gravity used with aggregate blends showing water absorption of less than 2 1/2 percent is based upon the apparent volume of the material, which does not include those pore spaces in the aggregate that are permeable to water. Bulk-impregnated specific gravity is used for aggregate blends with 2 1/2 percent or greater water absorption The methods for determining absorption were discussed earlier in the discussion of concrete aggregates. You can determine apparent specific gravity by using the methods described in FM 5-472/NAVFAC MO-330 for apparent and bulk specific gravity. As an alternative, you may also determine apparent specific gravity using the Dunagan buoyancy apparatus shown in *Figure 10-41*.

Figure 10-41 – Example of a Dunagan buoyancy apparatus.

Perform the following steps to determine the apparent specific gravity:

- Select about 5,000 grams of aggregate from sample.
    - Do not include particles smaller than 3/8-inch sieve.
- Wash to remove any dust or other coating.
- Dry to constant weight in oven.
- Record total weight on DD Form 1216 (*Figure 10-42*).



SPECIFIC GRAVITY OF BITUMINOUS MIX COMPONENTS

DATE: 2 Apr 20__

PROJECT: Highway #203

JOB: #17336

COARSE AGGREGATE	UNITS *(Grams)*	
MATERIAL 1 SIEVE AND RETAINED ON 16 SIEVE		
SAMPLE NUMBER	CA	
1. WEIGHT OF OVEN - DRY AGGREGATE	378.3	
2. WEIGHT OF SATURATED AGGREGATE IN WATER	241.0	
3. DIFFERENCE *(Line 1 minus 2)*	137.3	
APPARENT SPECIFIC GRAVITY, $G = \frac{\text{Line 1}}{\text{Line 3}}$	378.3/137.3 = 2.755	
FINE AGGREGATE	UNITS *(Grams)*	
MATERIAL PASSING NUMBER 3/8" SIEVE		
SAMPLE NUMBER	FRBS	
4. WEIGHT OF OVEN - DRY MATERIAL	478.8	
5. WEIGHT OF FLASK FILLED WITH WATER AT 20°C	678.6	
6. SUM *(Line 4 + 5)*	1157.4	
7. WEIGHT OF FLASK + AGGREGATE + WATER AT 20°C	977.4	
8. DIFFERENCE *(Line 6 minus 7)*	180.0	
APPARENT SPECIFIC GRAVITY, $G = \frac{\text{Line 4}}{\text{Line 8}}$	478.8/180.0 = 2.660	
FILLER	UNITS *(Grams)*	
SAMPLE NUMBER	LSD	
9. WEIGHT OF OVEN - DRY MATERIAL	466.5	
10. WEIGHT OF FLASK FILLED WITH WATER AT 20°C	676.1	
11. SUM *(Line 9 + 10)*	1142.6	
12. WEIGHT OF FLASK + AGGREGATE + WATER AT 20°C	973.8	
13. DIFFERENCE *(Line 11 minus 12)*	168.8	
APPARENT SPECIFIC GRAVITY, $G = \frac{\text{Line 9}}{\text{Line 13}}$	466.5/168.8 = 2.763	
BINDER	UNITS *(Grams)*	
SAMPLE NUMBER	6873	
14. WEIGHT OF PYCNOMETER FILLED WITH WATER	61.9595	
15. WEIGHT OF EMPTY PYCNOMETER	37.9215	
16. WEIGHT OF WATER *(Line 14 minus 15)*	24.0380	
17. WEIGHT OF PYCNOMETER + BINDER	47.8617	
18. WEIGHT OF BINDER *(Line 17 minus 15)*	9.9402	
19. WEIGHT OF PYCNOMETER + BINDER + WATER TO FILL PYCNOMETER	62.1568	
20. WEIGHT OF WATER TO FILL PYCNOMETER *(Line 19 minus 17)*	14.2951	
21. WEIGHT OF WATER DISPLACED BY BINDER *(Line 16 minus 20)*	9.7429	
APPARENT SPECIFIC GRAVITY, $G = \frac{\text{Line 18}}{\text{Line 21}}$	9.9402/9.7429 = 1.020	

TECHNICIAN *(Signature)*	COMPUTED BY *(Signature)*	CHECKED BY *(Signature)*
EA2 Harris	EA3 Johnson	EA1 Arroyo

DD FORM 1216, DEC 65 PREVIOUS EDITION OF THIS FORM IS OBSOLETE. Reset Adobe Professional 7.0

Figure 10-42 – Data sheet for bituminous mix components. DD Form 1216.

- Immerse in water at 59° - 77°F (15° – 23.8°C) for 24 hours.
- Place in copper bucket filled with water.
- Turn bucket and aggregate sharply back and forth to remove any air.
- Suspend bucket from brass hanger and bring water level to overflow pipe.
- Determine submerged weight using weights placed in scoop on right-hand pan.
- Record weight.
- Calculate apparent specific gravity using self-explanatory computations on DD Form 1216.

3.6.0 Mix Design Tests

Mixture design tests for bituminous pavement are carried out on samples mixed and compacted in the laboratory. They are performed to identify the appropriate mix to meet the project's quality specifications in three areas:

- optimum bitumen content
- optimum aggregate content
- required gradation

Mixes with various combinations of bitumen, aggregate, and gradations are prepared, compacted to specified density, and tested. Design engineers can then determine the project's optimum values from the test results.

Mix design test procedures vary considerably. This chapter will present only a general description of typical procedures. Refer to the mix design chapter in this course or FM 5-472/NAVFAC MO-330 for additional information.

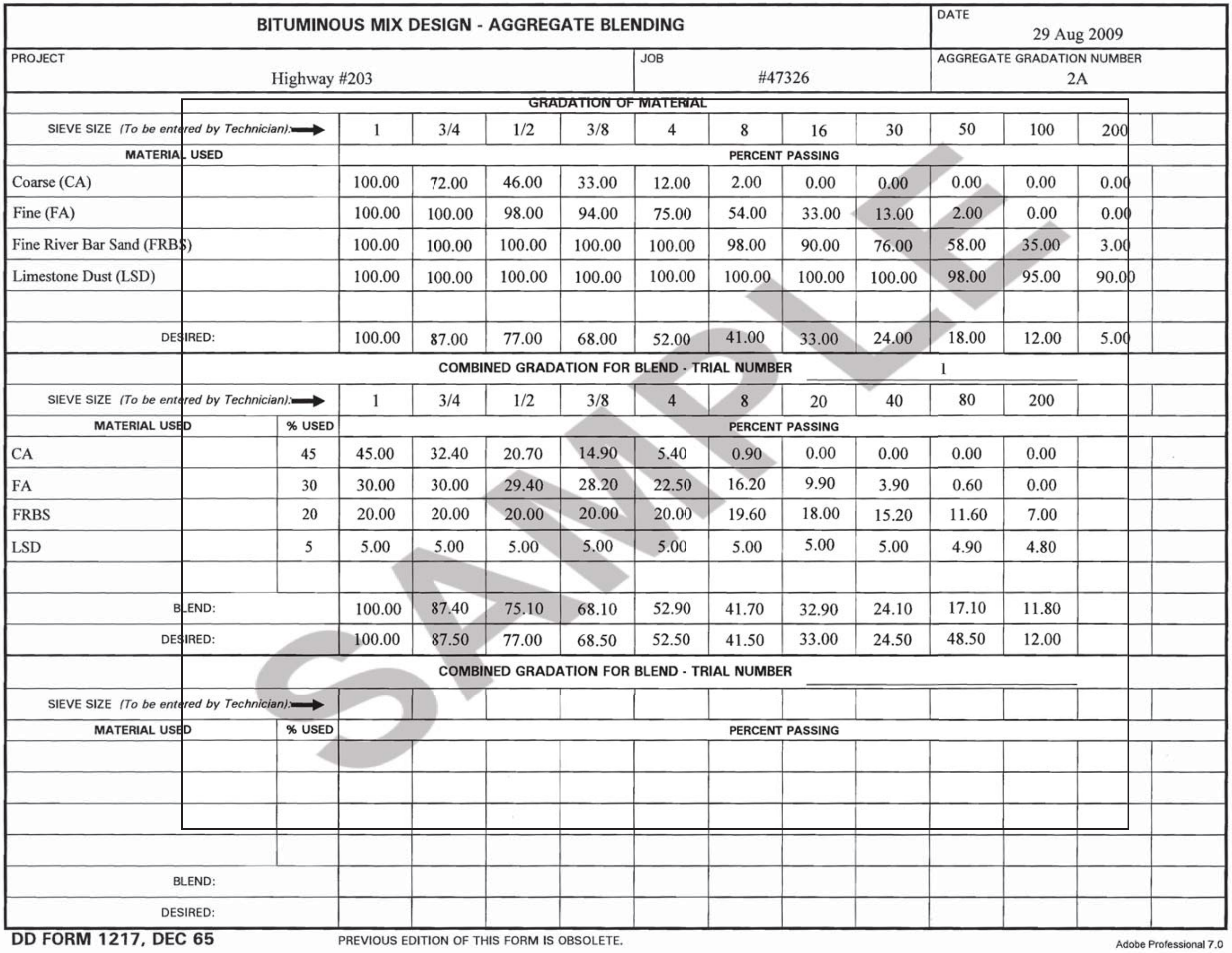
3.6.1 Selection of Sample Bitumen Contents

Just to get the laboratory mix tests started, you must estimate bitumen content. Tests are typically made with a minimum of five contents: two above and two below the one estimated. Bitumen content is expressed in terms of percentage (by weight) of bitumen in the mix, commonly from 3 to 7 percent, depending upon the type of binder used and the specification requirements.

3.6.2 Preparation of Aggregate

To prepare a quantity of the selected blend aggregate sufficient to make the required number of test samples, you dry the material at 230°F, separate it into several size ranges by sieving, and perform a sieve analysis of each range. From this procedure, design engineers can determine trial percentages for the test blends.

Following the test blends made with these trial percentages, you make another sieve analysis, this time to determine a blending gradation, such as shown in *Figure 10-43* on DD form 1217.



BITUMINOUS MIX DESIGN - AGGREGATE BLENDING

DATE: 29 Aug 2009

PROJECT: Highway #203

JOB: #47326

AGGREGATE GRADATION NUMBER: 2A

GRADATION OF MATERIAL

SIEVE SIZE *(To be entered by Technician)* →	1	3/4	1/2	3/8	4	8	16	30	50	100	200	
MATERIAL USED	**PERCENT PASSING**											
Coarse (CA)	100.00	72.00	46.00	33.00	12.00	2.00	0.00	0.00	0.00	0.00	0.00	
Fine (FA)	100.00	100.00	98.00	94.00	75.00	54.00	33.00	13.00	2.00	0.00	0.00	
Fine River Bar Sand (FRBS)	100.00	100.00	100.00	100.00	100.00	98.00	90.00	76.00	58.00	35.00	3.00	
Limestone Dust (LSD)	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	98.00	95.00	90.00	
DESIRED:	100.00	87.00	77.00	68.00	52.00	41.00	33.00	24.00	18.00	12.00	5.00	

COMBINED GRADATION FOR BLEND - TRIAL NUMBER 1

SIEVE SIZE *(To be entered by Technician)* →		1	3/4	1/2	3/8	4	8	20	40	80	200		
MATERIAL USED	**% USED**	**PERCENT PASSING**											
CA	45	45.00	32.40	20.70	14.90	5.40	0.90	0.00	0.00	0.00	0.00		
FA	30	30.00	30.00	29.40	28.20	22.50	16.20	9.90	3.90	0.60	0.00		
FRBS	20	20.00	20.00	20.00	20.00	20.00	19.60	18.00	15.20	11.60	7.00		
LSD	5	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	4.90	4.80		
BLEND:		100.00	87.40	75.10	68.10	52.90	41.70	32.90	24.10	17.10	11.80		
DESIRED:		100.00	87.50	77.00	68.50	52.50	41.50	33.00	24.50	48.50	12.00		

COMBINED GRADATION FOR BLEND - TRIAL NUMBER ______

SIEVE SIZE *(To be entered by Technician)* →													
MATERIAL USED	**% USED**	**PERCENT PASSING**											
BLEND:													
DESIRED:													

DD FORM 1217, DEC 65 PREVIOUS EDITION OF THIS FORM IS OBSOLETE. Adobe Professional 7.0

Figure 10-43 – Data sheet for aggregate gradations of trial blends. DD Form 1217.

The following is an explanation of *Figure 10-43*:

- The aggregate was sifted into four categories.
    - Coarse aggregate (CA)
    - Fine aggregate (FA)
    - Fine river bar sand (FRBS)
    - Limestone dust (LSD), a commonly used mineral filler
- 100 percent of the coarse aggregate consisted of material that would not pass the No. 16 sieve.
- 87 percent of fine aggregate consisted of material that would not pass the No. 30 sieve.
- 97 percent of the FRBS consisted of material that would not pass the No. 200 sieve.
- These three sieves, then, were the ones used to make the original broad separation.
- Limestone dust was added to the extent of 5 percent.

After the sample was broadly divided, a sieve analysis was made of each broad division category, as shown. This analysis was studied by experts, who estimated, among other things, the probable void percentages that would exist in pavements made with the aggregate used in various combinations, and the aggregate percentages that would minimize the void percentages.

For trial blend No. 1, these percentages are listed under “percent used.” The percentages are 45 coarse, 30 fine, 20 FRD, and 5 LSD. A blend containing these percentages was made, and again the material in each category was sieve-analyzed, as shown. From these individual analyses, the blend analysis (that is, the sieve analysis for the mixed blend) was determined by adding together the percentages in each column.

Thus an aggregate gradation for the blend was obtained. If tests showed that this particular gradation produced a mix that met the specifications for the pavement, this gradation would be specified for the aggregate used in the highway.

3.6.3 Specimen Mixing and Compacting for Testing

To prepare an aggregate blend for testing:

- Thoroughly mix enough aggregate blend for two specimens (about 3,000 grams).
- Heat to desired mixing temperature.
- Trough the aggregate blend.
- Heat test amount of bitumen to mixing temperature.
- Pour into trough.
- Mix aggregate and bitumen thoroughly.
    - Use mechanical mixer if available.
- Place mix in compaction mold.
- Compact with tamper.

  - Give number of blows required to produce density attained under traffic for which pavement is being designed.
    - NAVFAC DM-5.4, *Civil Engineering* specifies 50 blows for secondary roads and 75 blows for primary roads. Seventy-five blows produce the equivalent of a tire pressure of 200 psi; 50 blows produce the equivalent of a tire pressure of 100 psi.

After compaction, place the mold in a bearing-ratio jack and extract the sample with extraction equipment.

3.6.4 Density and Voids Determination

You should determine the density of the specimens by weighing in air and in water. Open-textured or porous specimens directly weighed in water will give erroneous results because of water absorption, so you must use other means to determine the volume of the specimen.

One means of measuring the volume of a porous specimen is to coat it with paraffin to seal all the voids and then weigh the coated specimen in air and in water with a correction factor for the weight and volume of the paraffin.

The difference between these two weights, in grams, will give you the volume of the specimen in cubic centimeters. You can then determine the unit weight (density) in pounds per cubic foot for each specimen by multiplying the specific gravity of the specimen by 62.4 pounds (weight of 1 cubic foot of water). Before carrying out the calculations for percent of voids, you must know the specific gravity of the aggregate blend and the asphalt content used.

3.6.5 Stability and Flow Determination

ASTM D6927 - 06 *Standard Test Method for Marshall Stability and Flow of Bituminous Mixtures.*

NOTE

The ASTM D1559-89 *Test Method for Resistance of Plastic Flow of Bituminous Mixtures Using Marshall Apparatus* referred to in FM 5-472/NAVFAC MO-330 has been withdrawn without replacement (Withdrawn 1998).

Figure 10-44 – Marshall stability testing head mounted in CBR jack.

Refer to FM 5-472/NAVFAC MO-330 for a full discussion of the method used to test for stability and flow.

Figure 10-44 shows the apparatus used for testing stability and flow of a mix design specimen.

It shows a Marshall stability testing head containing the specimen, mounted on the plunger of a bearing-ratio jack.

This test head consists of upper and lower breaking heads, and a 5,000-pound proving ring with a dial installed in the jack.

The test for stability is made by applying pressure gradually, about 2 inches per minute, and reading the maximum pressure the specimen sustains before failing.

The test for flow is carried out simultaneously by holding a flow meter over the testing head guide rod (vertical rod shown running through the testing heads) and reading the meter at the instant the specimen fails under pressure. This reading indicates the flow value of the specimen in inches to the nearest 0.01 inch.

4.0.0 HAZARDOUS-MATERIAL PRECAUTIONS

There are exacting individual definitions for the terms *hazardous material, hazardous chemical,* and *hazardous substance,* but for conceptual simplicity, you can lump them all together and simply say that these materials, because of quantities, concentration, or hazardous properties, can pose a substantial hazard to the environment or to human safety and health. These materials include risks associated with flammability, toxicity, corrosivity, and reactivity.

From studying this chapter, you can readily see how many of the materials you test or use for testing in the laboratory fall within the above definition:

- Heated asphalt can cause severe burns in contact with skin.
- Asphalt cutbacks are highly flammable with low flash points.
- Some chemicals you use in materials testing are highly toxic and corrosive.
- Other chemicals react with water, forming explosive gases.
- Not all hazardous materials an EA uses are confined to the laboratory.

For these and other reasons, all such materials must be handled, used, stored, and disposed of properly and with caution. As a crew leader, you must recognize the threat hazardous materials pose to all personnel present on the jobsite, and take action to prevent mishaps.

Material Safety Data Sheets (MSDS) must be received and maintained for all hazardous materials utilized in your work space. They indicate hazards associated with exposure to a specific material, identify personal protective equipment and other safety required precautions, as well as provide first aid or medical treatment required for exposure.

By federal law, a crew leader is required to inform his or her crew members of the risks and all safety precautions associated with any hazardous material present on the jobsite. A good time for you to do this is during your daily standup safety lectures.

One safe practice concerning hazardous materials is not to draw more material than will be used in one day. Storing hazardous materials in a workspace or on the jobsite requires approved storage containers. Some materials require separate storage; for example, flammable materials and corrosive materials cannot be stored together.

Excess hazardous materials or hazardous waste products must be disposed of through an authorized hazardous material disposal facility. When in doubt about storage requirements or disposal procedures, check with your supervisor, safety officer, or hazardous materials representative.

Summary

Many of the soils, concrete, and bitumen testing procedures in this chapter were detailed and specific in their procedural steps. The necessity to apply these tests will depend on your unit's assigned mission and projects. Consequently, your opportunities to perform these tests may be numerous or very limited, thus affecting your familiarity and proficiency in performing them.

As an Engineering Aid, these tests fall under your rate responsibilities and duties to perform, so you must have a general knowledge and awareness of the necessary equipment, general steps, and basic procedures. However, sometimes it is just as important to know where to find information as it is to try to retain total information.

To remain current with viable testing equipment and procedures, you need to periodically refer to the latest publications of the American Society for Testing and Materials (ASTM), the American Association of State Highway and Transportation Officials (AASHTO), and FM 5-472/NAVFAC MO 330/AFJMAN 32-1221(**I**) *Materials Testing*.

Trade Terms Introduced in this Chapter

∑	Uppercase Greek letter Sigma used as a symbol to indicate *summation*, the addition of a set of numbers; the result is their sum or total.
Bituminous	Any of various flammable mixtures of hydrocarbons and other substances, occurring naturally or obtained by distillation from coal or petroleum, that are a component of asphalt and tar and are used for surfacing roads and for waterproofing.
Butyl stearate	A liquid that solidifies at approximately 19°C; mixes with vegetable oils and is soluble in alcohol and ethers but insoluble in water; used as a lubricant in polishes as a plasticizer, and as a dye solvent.
Chert	A compact rock consisting essentially of microcrystalline quartz.
Clinkers	The solid material produced by the cement kiln stage that has sintered into lumps or nodules, typically of diameter 3-25 mm; used in the manufacture of Portland cement.
Detergent	Any of a group of synthetic, organic, liquid or water-soluble cleaning agents that, unlike soap, are not prepared from fats and oils, are not inactivated by hard water, and have wetting-agent and emulsifying-agent properties.
Empirical	Derived from or guided by experience or experiment. Depending upon experience or observation alone, without using scientific method or theory, esp. as in medicine.
Fineness modulus	A measurement of the coarseness or fineness of a given aggregate. FM is an index of the fineness of an aggregate--the higher the FM, the coarser the aggregate. For a fine aggregate, FM is calculated from the cumulative percentages of aggregate retained on sieves No. 4, 8, 16, 30, 50, 100 divided by 100.
Fly Ash	Fine particulate ash sent up by the combustion of a solid fuel, such as coal, and discharged as an airborne emission or recovered as a byproduct for various commercial uses; used chiefly as a reinforcing agent in the manufacture of bricks, concrete, etc.
Kinematic viscosity	The coefficient of viscosity of a fluid divided by the density, usually measured in stokes.

Lignite	A soft, brownish-black coal in which the alteration of vegetable matter has proceeded further than in peat but not as far as in bituminous coal; also called *brown coal*.
Modulus of rupture	Ultimate strength determined in a flexure or torsion test. In a flexure test, modulus of rupture in bending is the maximum fiber stress at failure. In a torsion test, modulus of rupture in torsion is the maximum shear stress in the extreme fiber of a circular member at failure. Alternate terms are flexural strength and torsional strength.
Pozzolan	A material which, when combined with calcium hydroxide, exhibits cementitious properties. Pozzolans are commonly used as an addition (the technical term is "cement extender") to Portland cement concrete mixtures to increase the long-term strength and other material properties of Portland cement concrete, and in some cases reduce the material cost of concrete. The most commonly used pozzolan today is fly ash, one of the residues generated in the combustion of coal.
Pumicites	Widely used to make lightweight concrete or insulative low-density breeze blocks. When used as an additive for cement, a fine-grained version of pumice called pozzolan is mixed with lime to form a light-weight, smooth, plaster-like concrete.
Sintering	A method for making objects from powder by heating the material in a sintering furnace below its melting point (solid state sintering) until its particles adhere to each other.
Stokes	A unit of kinematic viscosity equal to the viscosity of a fluid in poises divided by the density of the fluid in grams per cubic centimeter.
Supernatant	Floating above or on the surface; the clear fluid above a sediment or precipitate.
Tar pit	More accurately known as an asphalt pit; a geological occurrence where subterranean bitumen leaks to the surface, creating a large puddle, pit, or lake of asphalt.
Vesicular	A small cavity formed in volcanic rock by entrapment of a gas bubble during solidification.
Water-gas	A synthesis gas containing carbon monoxide and hydrogen, made by passing steam over red-hot coke; a useful product but requires careful handling because of the risk of carbon monoxide poisoning.

Additional Resources and References

This chapter is intended to present thorough resources for task training. The following reference works are suggested for further study. This is optional material for continued education rather than for task training.

Asphalt Technology and Construction Practices, Instructors Guide, 2d ed., The Asphalt Institute, College Park, Md., 1983.

ASTM C33 / C33M - 08 *Standard Specification for Concrete Aggregates*

ASTM C39 / C39M - 05e2 *Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens*

ASTM C40 - 04 *Standard Test Method for Organic Impurities in Fine Aggregates for Concrete*

ASTM C70 - 06 *Standard Test Method for Surface Moisture in Fine Aggregate*

ASTM C78 - 09 *Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)*

ASTM C87 - 05 *Standard Test Method for Effect of Organic Impurities in Fine Aggregate on Strength of Mortar*

ASTM C88 - 05 *Standard Test Method for Soundness of Aggregates by Use of Sodium Sulfate or Magnesium Sulfate*

ASTM C117 - 04 *Standard Test Method for Materials Finer than 75-µm (No. 200) Sieve in Mineral Aggregates by Washing*

ASTM C123 - 04 *Standard Test Method for Lightweight Particles in Aggregate*

ASTM C127 - 07 *Standard Test Method for Density, Relative Density (Specific Gravity), and Absorption of Coarse Aggregate*

ASTM C128 - 07a *Standard Test Method for Density, Relative Density (Specific Gravity), and Absorption of Fine Aggregate*

ASTM C136 - 06 *Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates*

ASTM C138 / C138M - 09 *Standard Test Method for Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete*

ASTM C142 - 97(2004) *Standard Test Method for Clay Lumps and Friable Particles in Aggregates*

ASTM C231 - 09a *Standard Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method*

ASTM C566 - 97(2004) *Standard Test Method for Total Evaporable Moisture Content of Aggregate by Drying*

ASTM C666 / C666M - 03(2008) *Standard Test Method for Resistance of Concrete to Rapid Freezing and Thawing*

ASTM C805 / C805M - 08 *Standard Test Method for Rebound Number of Hardened Concrete*

ASTM C900 - 06 *Standard Test Method for Pullout Strength of Hardened Concrete*

ASTM D75 / D75M - 09 *Standard Practice for Sampling Aggregates*

ASTM D422 - 63(2007) *Standard Test Method for Particle-Size Analysis of Soils*

ASTM D698 - 07e1 *Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort* (12 400 ft-lbf/ft^3 (600 kN-m/m^3))

ASTM D1557 - 07 *Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort* (56,000 ft-lbf/ft^3 (2,700 kN-m/m^3))

ASTM D1556 - 07 *Standard Test Method for Density and Unit Weight of Soil in Place by the Sand-Cone Method*

ASTM D1883 - 07e2 *Standard Test Method for CBR (California Bearing Ratio) of Laboratory-Compacted Soils*

ASTM D6927 - 06 *Standard Test Method for Marshall Stability and Flow of Bituminous Mixtures*

ASTM D6938 REV A 2008-JUN-01,*Standard Test Method for In-Place Density and Water Content of Soil and Soil- Aggregate by Nuclear Methods (Shallow Depth)*

FM 5-472/NAVFAC MO 330/AFJMAN 32-1221(I) (Change 2) *Materials Testing,* Headquarters, Department of the Army, Washington, DC, 1 July 2001

Kosmatka, Steven H., and William C. Panarese, *Design and Control of Concrete Mixtures*, 13th ed., Portland Cement Association, Skokie, Ill., 1990.

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