Chapter 16

Materials Testing: Soil and Concrete

Topics

1.0.0 Soil Origin

2.0.0 Physical Characteristics of Soils

3.0.0 Soil Classification

4.0.0 Soil Sampling

5.0.0 Soil Testing

6.0.0 Concrete Testing

To hear audio, click on the box.

Overview

Natural earth is the ultimate foundation for any road, airfield, building, or other structure. Regardless of their designated purpose, all structures are supported by one of the earth's construction materials: soil. Because soil is the ultimate foundation for any project, it may be the most important of all building materials. Just as a poorly constructed and weak concrete foundation will not support a building, neither will a poorly "constructed" and weak soil foundation support a well-constructed concrete foundation.

This chapter will offer the definition of soil, and introduce you to the different types of soil you may encounter during the wide range of projects Seabees undertake.

It will also present the basic properties and characteristics of soil and explain the importance those characteristics play in determining adequacy and classification for use as a construction material.

As an EA, you will be responsible for collecting soil samples and performing certain testing .This chapter will provide guidance on those procedures as well as explain their importance in properly and correctly identifying and classifying the many types of soil that exist in nature.

Finally, this chapter will also acquaint you with various tests for concrete and explain their purposes and importance as well. You will learn how to perform certain tests yourself and how to prepare concrete samples for other tests that will be performed by EAs that are more senior.

Whether the project is a structure with concrete or a road or revetment without concrete, soil is the foundation, and you as an EA, must gain the skills to determine its usefulness.

Objectives

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

1. Identify the different types of soil origins.
2. Identify the physical characteristics of soils.
3. Describe the different classifications of soil.
4. Describe the procedures associated with soil sampling.
5. Describe the procedures associated with soil testing.
6. Describe the procedures associated with concrete testing.

Prerequisites

None

This course map shows all of the chapters in Engineering Aid Basic. The suggested training order begins at the bottom and proceeds up. Skill levels increase as you advance on the course map.

Topographic Surveying and Mapping	↑	E
Indirect Leveling/Level and Traverse Computations		N
Care and Adjustment of Survey Equipment		G
Materials Testing: Soil and Concrete		I
Direct Leveling and Basic Engineering Surveys		N
Horizontal Control		E
Direct Linear Measurements and Field Survey Safety		E
Surveying: Elements and Equipment		R
Construction Drawings		I
Electrical: Systems and Plans		N
Mechanical: Systems and Plans		G
Concrete and Masonry		AID
Wood and Light Frame Structures		B
Drafting: Projections and Sketching		A
Drafting: Geometric Construction		S
Drafting: Fundamentals and Techniques		I
Drafting: Equipment		C
Mathematics and Units of Measurement		
Engineering Aid Rating		

Features of this Manual

This manual has several features which make it easy to use online.

- Figure and table numbers in the text are italicized. The figure or table is either next to or below the text that refers to it.
- The first time a glossary term appears in the text, it is bold and italicized. When your cursor crosses over that word or phrase, a popup box displays with the appropriate definition.
- Audio and video clips are included in the text, with an italicized instruction telling you where to click to activate it.
- Review questions that apply to a section are listed under the Test Your Knowledge banner at the end of the section. Select the answer you choose. If the answer is correct, you will be taken to the next section heading. If the answer is incorrect, you will be taken to the area in the chapter where the information is for review. When you have completed your review, select anywhere in that area to return to the review question. Try to answer the question again.
- Review questions are included at the end of this chapter. Select the answer you choose. If the answer is correct, you will be taken to the next question. If the answer is incorrect, you will be taken to the area in the chapter where the information is for review. When you have completed your review, select anywhere in that area to return to the review question. Try to answer the question again.

1.0.0 SOIL ORIGIN

One entry in Merriam-Webster's Online Dictionary defines soil as "the upper layer of earth that may be dug or plowed and in which plants grow." While that may be one correct definition and perfectly satisfactory to many groups of people, it does not address the precision required by civil engineers and soil technicians.

For engineering and construction purposes, a more precise definition is this one, found in Maintenance and Operation Manual 330 (MO-330) "Soil is a heterogeneous aggregation of uncemented or weakly cemented mineral grains enclosing voids of various sizes. These voids may contain air, water, organic matter, or different combinations of these materials." As you progress through this chapter, the aptness of this definition for construction will become obvious, but let us consider where soil comes from first.

1.1.0 Soil Formation

Soil formation is a continuous and evolutionary process still in action today. The Earth's crust consists of rock, which geologists classify into three groups:

- Igneous — formed by cooling from a molten state
- Sedimentary — formed by the accumulation and cementing of the particles and remains of plants and animals
- Metamorphic — formed from existing rocks that have been subjected to heat and pressure

Exposed to the atmosphere, rock undergoes a physical and chemical process called ***weathering,*** which decomposes the rock into a loose, incoherent mixture of gravel, sand, and finer material. This process over a sufficient length of time disintegrates the three rock types and produces soils of various designations.

1.2.0 Residual Soil

Residual soil is any soil that remains in place during the weathering process. A mantle of residual soil will reflect the characteristics of the underlying parent rock from which it was derived.

1.3.0 Transported Soil

Transported soil is any soil that moved to a place other than its original location during the weathering process. Transported soils often bear properties induced by its mode of transportation such as water, wind, ice, and the force of gravity.

1.3.1 Alluvial Soil

Alluvial [*uh*-**loo**-vee-*uh*l] soil is formed when a river or stream with decreasing velocity gradually loses its soil-transporting capacity. As a river's velocity diminishes, it does not have sufficient power to keep the large soil particles in suspension, and they settle to the riverbed.

Typically, over time this further decreases the river's velocity, which causes smaller particles to settle. As the river becomes slow and sluggish (as in the lowlands where the gradient becomes small), it transports only the extremely fine particles in suspension. These finite particles settle at the mouth of the river where they form deltas of fine-grained soil. Prime examples of this are the Mississippi, Nile, Ganges, and Mekong Deltas. (*Figure 16-1*)

Figure 16-1 — Example of alluvial soils transported to form deltas.

1.3.2 Marine Soil

Marine soil is also formed from materials carried into the seas by streams, but it includes material eroded from the beaches by the tidal action of the waves. This tidal and wave action carries part of the marine soil material out into deep water deposits while another part of it is heaped back upon the beaches along the coast.

1.3.3 Lacustrine Soil

Lacustrine [l*uh*-**kuhs**-trin] soils are transported soils deposited in freshwater lakes. They are typically fine-grained soils, the result of being brought into freshwater lakes by streams or rivers.

1.3.4 Aeolian Soil

Aeolian [ee-**oh**-lee-*uh*n] soils are transported by wind rather than water. The build up of heavier sand grain deposits from wind are called “dunes,” and the finer particles (generally transported farther) are deposited to form a material called loess [**loh**-es]. Dune deposits seldom contain material larger than sand size while loess is a fine-grained, unstratified accumulation of clay and silt.

1.3.5 Glacial Soil

Glacial soil (or drift) is material transported by an advancing ice sheet. It could have been pushed ahead, carried upon, or carried within the ice. As glaciers melt, deposits of various forms occur, such as these:

- Moraine [m*uh*-**reyn**] — a mass of till (boulders, pebbles, sand, and mud) deposited by a glacier, often in the form of a long ridge. Moraines typically form because of the plowing effect of a moving glacier.
- Kame [**keym**] terrace — an irregularly shaped hill or mound composed of sand, gravel and till that accumulates in a depression on a retreating glacier.
- Esker [**es**-ker] — a long, narrow, steep-sided ridge of coarse sand and gravel deposited by a stream flowing in or under a melting sheet of glacial ice.
- Outwash plane — a glacial outwash plain formed of sediments deposited by melting water at the terminus of a glacier.

1.3.6 Colluvial Soil

Colluvial [k*uh*-**loo**-vee-*ahl*] soil consists of mixed loose earth material that has accumulated at the base of a hill through the action of gravity, such as piles of talus, avalanche debris, and sheets of detritus moved by soil creep or frost action.

Test your Knowledge (Select the Correct Response)

1. What source provides a more precise definition of soil for engineering and construction purposes?

   A. Merriam-Webster's Online Dictionary
   B. American Society for Testing and Materials
   C. Maintenance and Operation Manual 330
   D. American Society of Civil Engineers

2.0.0 PHYSICAL CHARACTERISTICS OF SOILS

The physical characteristics of soils aid in determining their engineering characteristics and are the basis of any soil classification system. In North America, the most common engineering classification systems for soils are the Unified Soil Classification System (USCS) and the American Association of State Highway and Transportation Officials (AASHTO).

The Seabees, the military in general, and civilian engineering each use a system of soil classification to identify and determine the suitability of soils for both vertical and horizontal construction projects.

As an EA, your knowledge of these physical characteristics will aid in determining the degree to which local soils can be used in engineering projects to support traffic loads or to serve as a subgrade or foundation material.

2.1.0 Particle Size

The size of the particle grains in the soil mass determines how the soils are divided into groups. An EA identifies the particle grain sizes by using sieves.

A sieve is a screen attached across the end of a shallow cylindrical frame. (*Figure 16-2*) The screen permits particles smaller than the openings to fall through while retaining larger ones. When sieves of different sizes are stacked so the largest screen openings are at the top and the smallest at the bottom, soil can be separated into particle groups based on size.

Figure 16-2 — Typical sieves used for particle size identification.

The amount remaining on each sieve can then be measured and described as a percentage by weight of the entire sample.

Table 16-1 shows only four of many size groups used in the Unified Soil Classification System.

Finer particles passing the No. 200 sieve that exhibit plasticity and strength when dry are called clays; those exhibiting non-plasticity and little strength when dry are called silt.

Table 16-1 — Sample of Four Size Groups Used in the Unified Soil Classification System (USCS).

Size groups	Sieve Size	
	Passing	Retained on
Cobbles----------------	No Maximum size*---------------	3 in.
Gravels-----------------	3 in.------------------------------------	No. 4
Sands-------------------	No. 4----------------------------------	No. 200
Fines--------------------	No. 200-------------------------------	No minimum size
*In military engineering, maximum size of cobbles is accepted as 40 inches, based upon maximum jaw opening of the crushing unit.		

2.2.0 Particle Shape

The shape of the particles influences the strength and stability of a soil. Bulky and platy (*Figure 16-3*) are two general shapes recognized in the USCS and they may be located within the same geological area.

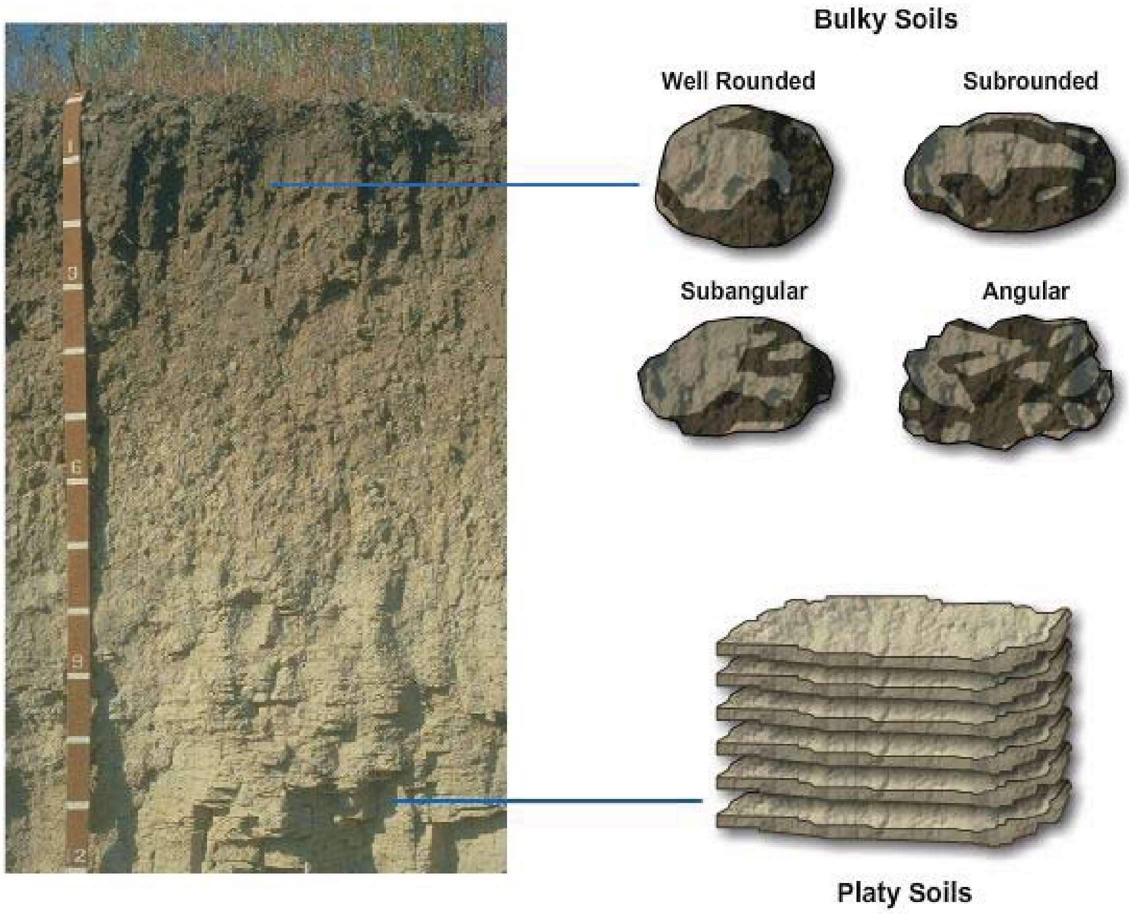


Figure 16-3 — Examples of bulky and platy particle shapes.

2.2.1 Bulky

Cobbles, gravel, sand, and silt particles cover a large range of sizes; however, they are all bulky in shape. The term "bulky" is confined to particles that are relatively large in all three dimensions, as contrasted to platy particles, in which one dimension is small as compared to the other two.

The bulky shape has the following four subdivisions listed in descending order of desirability for construction:

- Angular —recently broken up particles characterized by jagged projections, sharp ridges, and flat surfaces. Seldom found in nature because of weathering, angular gravels and sands are generally the best materials for construction because of their interlocking characteristics but must usually be produced artificially by crushing.
- Subangular — particles that have been weathered to the extent that the sharper points and ridges have been worn off.
- Subrounded — particles that have been further weathered and are still somewhat irregular in shape but have no sharp corners and few flat areas. Frequently found in streambeds, if composed of hard, durable particles, subrounded material is adequate for most construction needs.

- Rounded — particles weathered to the point that all projections have been removed, with few irregularities in shape remaining. Usually found in or near streambeds or beaches, they resemble spheres of varying sizes.

2.2.2 Platy

Platy (or flaky) particles have flat, plate-like grains with two dimensions much larger than the third. Clay is a common example. Because of their shape, platy particles have a greater contact area for moisture and are undesirable for construction purposes.

2.3.0 Gradation

The sizes and shapes of soil particles deal with properties of the individual grains in a soil mass. Gradation describes the distribution of the different size groups within a soil sample. (*Figure 16-4*)

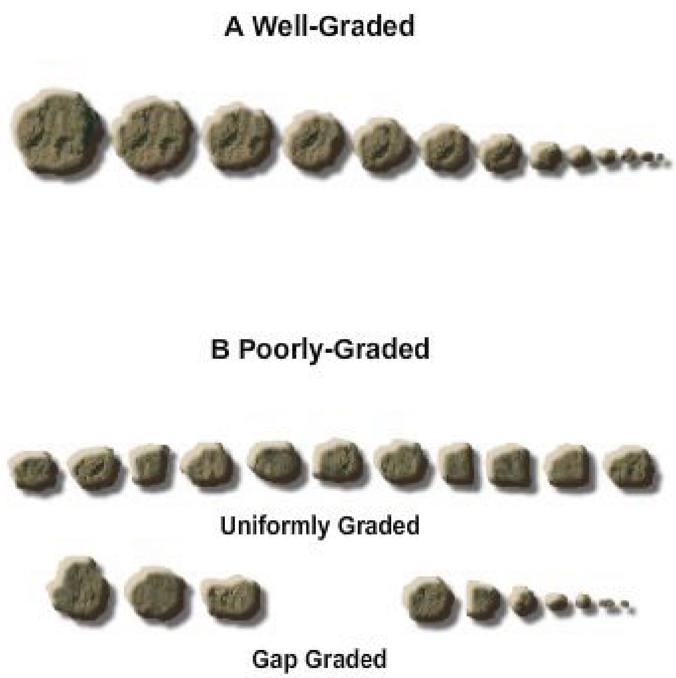


Figure 16-4 — Examples of well-graded and poorly-graded graduations.

The soil may be well-graded, or poorly-graded.

Well-graded soils (*Figure 16-4, view A*) must have a good range of all representative particle sizes between the largest and the smallest. All sizes must be represented, and no one size should be either overabundant or missing.

Poorly-graded soils (*Figure 16-4, view B*) contain a narrow range of particle sizes or lack some intermediate sizes.

Uniformly graded soils are those with a limited range of particle sizes. Soils with some intermediate sizes not well represented or missing are called gap, step, or skip graded.

2.4.0 Compactness

Compactness refers to how closely a mass of soil particles are packed together; for a given unit of volume, the closer the packing, the greater its compactness and weight.

In a dense structure with a high degree of compactness, closely packed soil particles interlock with smaller grains filling the voids between the larger particles. With each particle closely surrounded by other particles, grain-to-grain contact is increased. This lessens the tendency for individual grain displacement under load, and the soil is capable of supporting heavier loads. Usually, well-graded coarse materials are dense and exhibit strength and stability under load.

In a loose structure, the particles lack compactness and are not packed as closely together as possible. Loose, open structures have voids, which will lead to foundation settlement or to road disintegration when traffic loads are applied.

2.5.0 Specific Gravity

Specific gravity, designated by the symbol G_s is defined as the ratio between the weight per unit volume of a material and the weight per unit volume of water at a stated temperature—usually 20°C. Using the system international (SI) (metric) system, you can determine specific gravity by the following formula:

$$\text{Specific gravity } G_s = \frac{weight\ of\ sample\ in\ air\,(g)}{weight\ of\ sample\ in\ air\,(g) - weight\ of\ sample\ submerged\,(g)}$$

Specific gravity varies between 2.60 and 2.80 for most inorganic soils. While tropical, iron-rich ***laterite*** [**lat**-*uh*-rahyt], as well as some other lateritic soils, can have a specific gravity of 3.0 or more, sand particles (composed of quartz) have a specific gravity of about 2.65 and clays can have values as high as 3.50.

The solids of soil particles are composed of minerals with a specific gravity greater than 2.60. Any specific gravity values smaller than that are an indication of the possible presence of organic matter.

2.6.0 Soil Moisture

A soil's moisture content is often the most important factor affecting its engineering characteristics. Water may enter from the surface or move through the subsurface layers by gravitational pull, capillary action, or absorption. Moisture to some degree is present in most cases and it influences the various soils differently. Moisture probably has the greatest effect upon soil behavior when the soil is subjected to loading.

2.6.1 Sources of Water in Soils

Soil moisture may come from surface or subsurface water, gravity, capillary action, or absorption.

- Surface water — from precipitation or runoff, which enters the soil through openings between particles. It may adhere to the particles or penetrate the soil to some lower layer.
- Subsurface water — collected or held in pools or layers beneath the surface by a restricting layer of soil or rock and constantly acted upon by one or more external forces.
- Gravity-controlled water — seeks a lower layer and moves through the voids or spaces until it reaches some restriction such as bedrock or an impervious layer of soil with openings or voids are so small it prevents water passage.
- Capillary moisture — voids or spaces form continuous tunnels or tubes causing the water to rise in the tubes by capillary action; the smaller the tube, the stronger the capillary action. Water rises higher in finer soils which have smaller interconnected voids. The area of moisture above a free water layer or pool is called the capillary fringe.
- Atmosphere absorption moisture — moisture evaporates from the soil surface, which draws more moisture from the soil below that also evaporates. This process continues until the soil is in an air-dry condition (the moisture in the soil

is in equilibrium with the moisture vapor in the air). In an air-dry state, the moisture in the soil is in the form of thin films of water surrounding individual soil particles. This is called hydroscopic moisture. Hydroscopic moisture is the result of naturally occurring electrical forces binding the water molecules to the soil particles. This moisture may be removed from air-dried soil by heating the material in an oven at a controlled temperature for 24 hours or until attaining a constant weight.

The term "moisture content" (symbol W) is used to define the amount of water present in a soil sample. It is the ratio of the weight of water to the weight of the solid mineral grains (weight of dry soil) expressed as a percentage.

Moisture content $W = \frac{weight\ of\ water}{weight\ of\ dry\ soil}\ x\ 100$

When a wet soil is air-dried in the laboratory without the use of controlled heating, the amount of hydroscopic moisture remaining in the air-dried soil is called the hydroscopic moisture content, also expressed as a percentage of the weight of the dry soil.

2.6.2 Plasticity

Plasticity is a property of the fine-grained portion of a soil that allows it to be deformed beyond the point of recovery without cracking or changing volume appreciably. Some minerals (quartz powder for example) cannot be made plastic no matter how fine the particles or how much water is added.

On the other hand, all clay minerals are plastic and can be rolled into thin threads at certain moisture contents without crumbling. Since practically all fine-grained soils contain some clay, most of them are plastic and the degree of plasticity is a general index to the clay content of a soil.

"Fat" and "lean" are terms sometimes used to distinguish between highly plastic and slightly plastic soils. For example, fat clay is highly plastic while lean clay is only slightly plastic.

Plasticity is determined by observing the different physical states that a plastic soil passes through as moisture conditions change. The boundaries between the different states (described by the moisture content at the time of change) are called consistency limits or ***Atterberg*** limits.

The liquid limit (LL) is the moisture content corresponding to the arbitrary limit between the liquid and plastic state of a soil. Above this value, the soil is presumed to be a liquid and behaves as such by flowing freely under its own weight. Below this value, provided the soil exhibits a plastic state, it deforms under pressure without crumbling.

The plastic limit (PL) is the moisture content corresponding to the arbitrary limit between the plastic and semisolid state. Above this value, the soil is no longer pliable and crumbles under pressure.

The plasticity index (PI) is the numerical difference in moisture content between the two limits, or the plastic range. It defines the range of moisture content within which the soil is in a plastic state. The equation is $PI = LL - PL$.

The shrinkage limit (SL) is the water content boundary where further loss of moisture will not result in any more volume reduction. Beyond this point, further drying does not reduce the volume but may cause cracking.

2.6.3 Effects of Soil Moisture

Moisture affects coarse-grained soils much less than fine-grained soils. Coarser soils have larger void openings, which drain more rapidly, and capillary action is practically nonexistent in gravels and sands containing few fines. If coarse soils are above the groundwater table, they will not retain large amounts of water.

Also, since the particles in gravelly and sandy soils are relatively large (compared to clay and silt particles), they are heavy in comparison to the films of moisture that might surround them.

On the other hand, moisture in the voids of fine-grained soil has considerable effect on the light, small, sometimes microscopic, particles. Clays often undergo large volume changes with variations in moisture content, as the shrinkage cracks in a dry lakebed can demonstrate. Consequently, unpaved clay roads that may be solid enough when sun-baked will often lose stability and turn into slick mud during rainy weather. (*Figure 16-5*)

Figure 16-5 — Examples of clay road under dry and wet conditions.

Besides swelling and losing stability when wet, clays retard water drainage due to their flat, platy shapes and small size. Since drainage is of the greatest importance, especially in horizontal construction such as airfield pavement for example, design engineers must know if subsurface clay exists at the project site. As addressed earlier, plasticity is the characteristic by which you can identify clay in the project's soil particles.

2.7.0 Organic Soils

Organic soils contain mineral grains but with a conspicuous admixture of vegetable matter. Soils of organic origin are formed by the growth and subsequent decay of plant life, by an accumulation of inorganic particles such as skeletons or shells of organisms, or by a combination of both. An organic soil may be organic silt, organic clay, or it may be a highly organic soil, such as peat or meadow mat with little silt or clay particles.

Organic soils are most often black in color, and usually have a characteristic musty odor. Organic soils are usually easily compressible with poor load-bearing properties.

2.8.0 Effects of Soil Characteristics

Soil characteristics are a definitive measure of the soil's suitability to serve some intended construction purpose. An understanding of these characteristics is essential for determining the first step in preparing the earth's foundation for a structure's foundation, or the subgrade for road or other horizontal project.

1. Dense, solid soil withstands greater applied loads (has greater load-bearing capacity) than loose soil.
2. Particle size has a definite relation to load-bearing capacity. Coarse-grained soils can be compacted to a greater density than fine-grained soils because the smaller particles tend to fill the spaces between the larger ones.
3. The shape of the grains affects the bearing capacity. Angular particles tend to interlock, form a denser mass, and become more stable than rounded particles, which can roll or slide past one another.
4. Well-graded soils with a good range of particle sizes minimize voids. Poorly-graded soils, with their lack of one or more sizes, leave more or greater voids and comprise a less dense mass.
5. Moisture content and consistency limits aid in describing the suitability of a soil. Typically, coarse-grained sandy or gravelly soil has good drainage characteristics for use in its natural state. Fine-grained clayey soil with a high plasticity index may require considerable treatment, especially if used in a moist location.

Test your Knowledge (Select the Correct Response)

2. What initially determines how soils are divided into groups?

   A. Gradation of the soil particles
   B. Moisture of the soil particles
   C. Shape of the soil particles
   D. Size of the particle grains in the soil mass

3.0.0 SOIL CLASSIFICATION

Soil type is an important factor when selecting the proper location on which to construct any structure or facility, or when determining any necessary soil import amendment to a predetermined location.

With the existing soil accurately identified and described, its suitability as foundation material or for supporting traffic as a subgrade base can be determined, or it can be evaluated for use as an aggregate, filler, or binder for an engineered compaction mixture.

3.1.0 Classifying Soils

The Unified Soil Classification System (USCS) is a common soil classification and reference system that has a universal interpretation. In this system, all soils are divided into three major divisions.

3.1.1 Coarse-Grained Soils

Coarse-grained soils have a soil mass where at least half of the material, by weight, is larger than (retained on) a No. 200 sieve. (*Table 16-2*) This division is further divided as gravels and sands. If more than half of the coarse fraction, by weight, is retained on a

No. 4 sieve, it is classified as a gravel. If less than half is retained on a No. 4 sieve, then it is a sand. Gravels and sands are further subdivided into additional categories dependent upon the amount and characteristics of any plastic fines the soil sample contains.

Table 16-2 — USCS Classification for Coarse-Grained Soils.

Coarse grained soils At least 50% retained on No.200 (0.075 mm) sieve	Gravel > 50% of coarse fraction retained on No.4 (4.75 mm) sieve	clean gravel <5% smaller than #200 Sieve
		gravel with >12% fines
	Sand < 50% of coarse fraction retained No.4 (4.75 mm) sieve	clean sand
		sand with >12% fines

3.1.2 Fine-Grained Soils

Fine-grained soils have a soil mass where more than half of the material, by weight, is smaller than (passes) a No. 200 sieve. (*Table 16-3*) The fine-grained soils are not classified by grain size distribution but according to plasticity and compressibility.

Table 16-3 — USCS Classification for Fine-Grained Soils.

Fine grained soils More than 50% passes No.200 (0.075 mm) sieve	silt and clay liquid limit < 50	inorganic
		organic
	silt and clay liquid limit ≥ 50	inorganic
		organic

3.1.3 Highly Organic Soils

Highly organic soils, such as peat, have too many undesirable characteristics for consideration as foundations or use as construction material. The USCS has reserved a special classification for these soils but without any further laboratory criteria.

These soils are usually readily identifiable in the field by their distinctive color, odor, spongy feel, and frequently fibrous textures from their common components: decomposed or decomposing leaves, grass, branches, or other fibrous vegetable matter.

3.2.0 Classification Tests

These three basic classifications, or divisions, are not the complete description of the USCS or the methods used to classify soils. There are further and more detailed descriptors of soils within the Unified Soil Classification System and in the American Society for Testing and Materials (ASTM) International ASTM D2487 - 06e1, and ASTM D2488. However, as an EA, you will be performing some of the basic tests (sieve analysis and Atterberg limits) and you need to understand why you are performing the tests and how the results are used. You must also know the importance of ensuring that your test results are correct and reliable. Additional soil testing information is available in EA Advanced, NAVFAC MO-330, *Materials Testing,* or one of numerous commercial publications on soil mechanics.

Test your Knowledge (Select the Correct Response)

3. **(True or False)** Existing project site soil may be identified for its construction suitability or for use as an engineered compaction mixture.

   A. True
   B. False

4.0.0 SOIL SAMPLING

In construction, for both the planning and building phases, it is vital to have as much engineering information as possible about the subsurface conditions at the site area.

That information includes:

- Location, extent, and condition of the soil layers
- Elevation of the groundwater table and bedrock
- Drainage characteristics of the surface and subsurface soils
- Location of possible borrow areas from which soil and other mineral-product materials may be "borrowed" for a construction operation

This information is gathered through soil survey exploration of the proposed area.

These multifaceted surveys consist of:

- Collecting soil samples
- Soil testing by laboratory or field procedures, or both
- Soil classification
- Development of soil profiles

In the full scope of soil surveying, your primary concern, as an EA, is gathering soil samples and conducting certain of the laboratory soils tests.

4.1.0 Sampling Methods

Collecting soil samples in the field for testing is called soil sampling.

There are three principal methods of soil sampling. They include taking samples from:

1. the surface
2. already existing excavations
3. test pits and test holes

Depending on the project's scope, expediency, and permanency, available time for soil sampling will determine which method is used and the extent to which sampling is done.

Soil sampling from test pits provides the most satisfactory results for studying the natural soil conditions as well as collecting undisturbed soil samples.

Figure 16-6 — Example of a soil sampling test pit.

A test pit is an open excavation large enough for a person to enter. (*Figure 16-6*) Usually dug by hand, digging can be expedited by power equipment (clamshell, dragline, bulldozer, backhoe, power-driven auger) when available.

Excavations below the groundwater table require using caissons or lowering the water table.

Excavations to 5 feet or more may require shoring and bracing to prevent cave-ins.

Load-bearing tests can also be performed on the soil in the bottom of the pit.

The most common method of test hole exploration is by hand auger. (*Figure 16-7*) Best suited to cohesive soils, it can also be used on less cohesive soils above the water table providing the individual aggregate diameter is smaller than the auger's bit clearance.

Usually used for work at shallow depths, with pipe extensions a powered earth auger may be used to a depth of about 30 feet in relatively soft soils.

These samples are completely disturbed but satisfactory for determining soil profile, classification, moisture content, compaction capabilities, and similar soil properties.

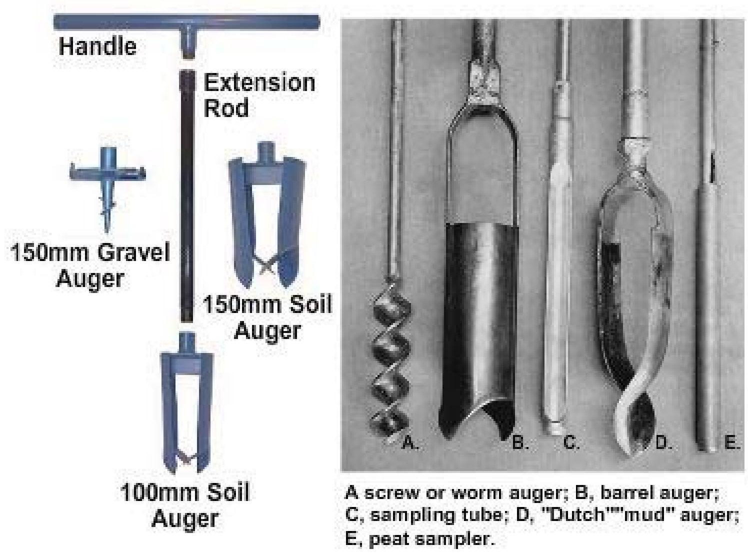


Figure 16-7 — Examples of hand augers for test hole soil sampling.

In a hasty soil survey, under expedient conditions or limited time, the number of test pits and test holes is kept to a minimum by using existing excavations for soil sampling.

In a deliberate survey, where time and conditions allow a more thorough soil sampling operation, test holes are used extensively and augmented by test pits, governed by the judgment of the engineering officer.

Table 16-4 shows various methods of soil exploration and sampling in a condensed form.

Table 16-4 — Methods of Soil Exploration and Sampling.

Common name of method	Materials in which used	Method of advancing the hole	Method of sampling	Value for foundation purposes
Auger boring	Cohesive soils and less cohesive soils above groundwater elevation	Augers rotated until filled with soil and then removed to surface	Samples recovered from material brought up in augers	Satisfactory for highway exploration at shallow depths
Well drilling	All soils, rock, and boulders	Churn drilling with power machine	Bailed sample of churned material or clay socket	Clay socket samples are dry samples. Bailed samples are valueless.
Rotary drilling	All soils, rock, and boulders	Rotating bits operating in a heavy circulating liquid	Samples recovered from circulating liquid	Samples are of no value.
Test pits	All soils. Lowering of groundwater may be necessary.	Hand digging or power excavation	Samples taken by hand from original position in ground	Materials can be inspected in natural condition and place.

4.2.0 Tagging Samples

For gathering information and compiling an accurate interpretation of the collected soil data, you must label your soil samples correctly and systematically. Review the following scenario for soil in a given area that is to be tested (such as a proposed structure's site).

The officer in charge of soil exploration decides how many soil sampling points are needed and where they must be located to produce a representative test of the soil in the area. This information is recorded in a sketch like the one shown in *Figure 16-8*. Refer to this figure often to follow the scenario.

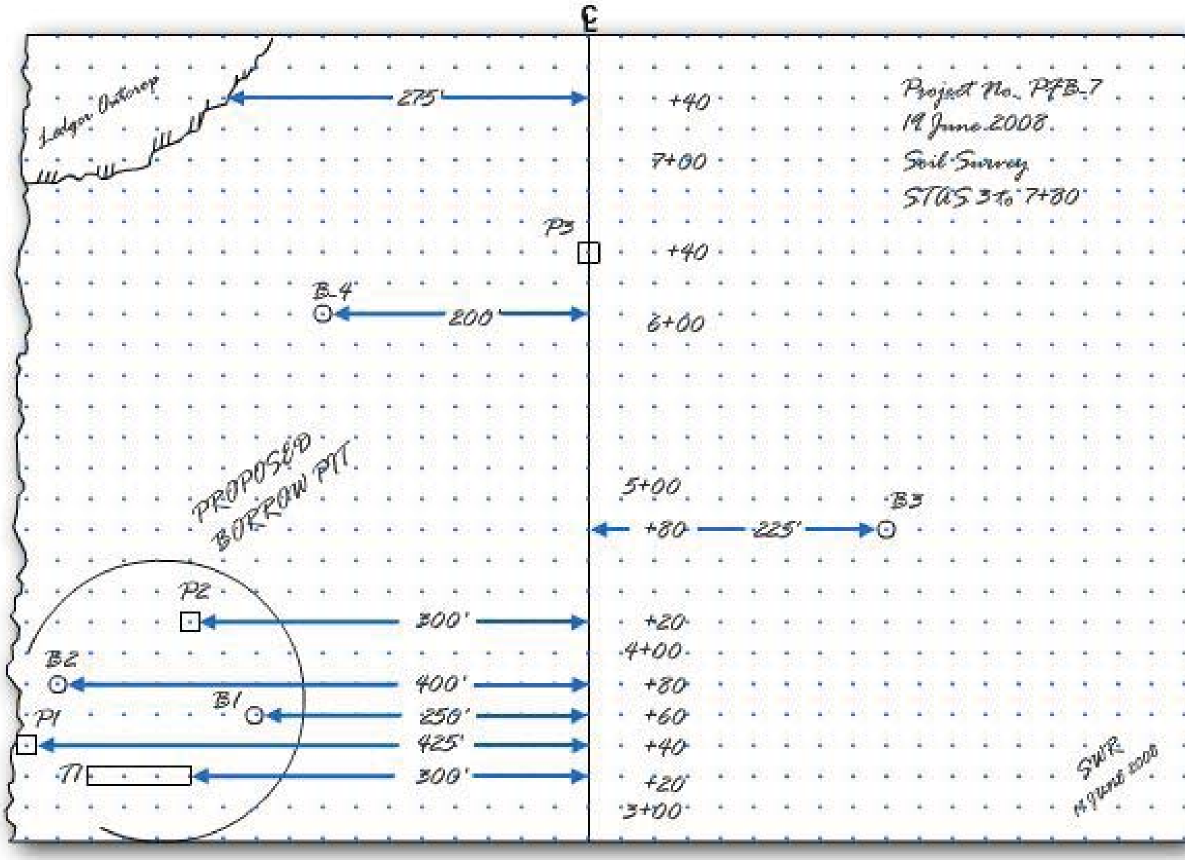


Figure 16-8 — Example of a sketch identifying soil sampling points.

This sketch shows the locations of the designated exploratory points along a highway's centerline with the point locations referenced by the centerline stations and the distances from the centerline.

Left of the centerline, between stations 2 + 80 and 4 + 60, there is a proposed borrow pit from which soil will be taken for fill.

Five samples are taken from there.

- Trench T1, a 75-foot trench located at station 3 + 20, 300 feet left of the highway centerline
- Pit P1, a 20-foot-square pit at station 3 + 40, 425 feet left of the centerline
- Boring B1 at station 3 + 60, 250 feet left of the centerline
- Boring B2 at station 3 + 80, 400 feet left of the centerline
- Pit P2, a 20-foot-square pit at station 4 + 20, 300 feet left of the centerline

In addition to the borrow pit exploration, the officer in charge of the soil exploration designated other locations.

- Boring B3 at station 4 + 80, 225 feet to the right of the centerline
- Boring B4 at station 6 + 00, 200 feet to the left of the centerline
- Pit P3, a 20-foot-square pit at station 6 + 40 on the centerline

Each sample is tagged according to the location from which it was taken and the locations are given in consecutive numbers.

For the scenario in *Figure 16-8*, the numbers might run from the bottom up, with T1 being No. 1; P 1 as No. 2; B1 as No. 3; and so on. A sample is tagged with the project symbol (in this case PFB 7) and the location symbol such as T1, P2, or B4, for example.

If more than one sample is taken from the same location, you need to use additional numbers. For example, a sample taken from B2 may be tagged ‘‘PFB 7-B2-4, bag 1 of 6.” This means the soil sample came from Boring pit No. 2, at location No. 4, as the first of six bags.

The sample’s identification should be printed on two tags with a marking pencil or pen, one placed inside the bag, the other tied on the outside. Gummed labels may be similarly used to identify samples placed in moisture content boxes, cylinders, or jars.

4.3.0 Disturbed Samples

Disturbed samples are those taken by hand scoops, auger borings, shovels, or any other convenient hand tool but with no attempt to obtain or maintain the material in its natural state of structure or density.

Figure 16-9 — California Bearing Ratio (CBR) test equipment.

These samples can be used for mechanical analysis, plasticity, specific gravity, frost susceptibility, compaction, and laboratory compacted ***California Bearing Ratio (CBR)*** tests. (*Figure 16-9*) The size of the sample taken will depend upon the tests to be performed.

4.3.1 Individual Samples

When taking individual samples from a pit, trench, or exposed face, first shave off any loose and dried soil to obtain a fresh surface and clearly expose any soil variations. (*Figure 16-10*)

Then take a typical sample of each type of soil or any soil requiring additional investigation while being sure to label the sample number by layer.

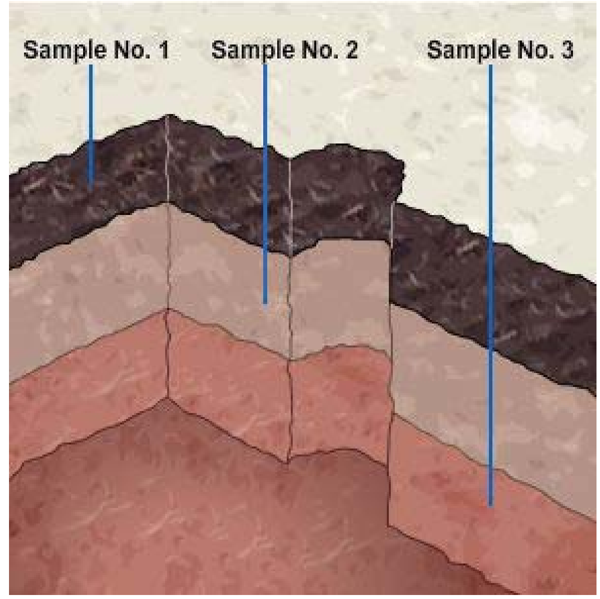


Figure 16-10 — Example of collecting soil samples from an exposed face.

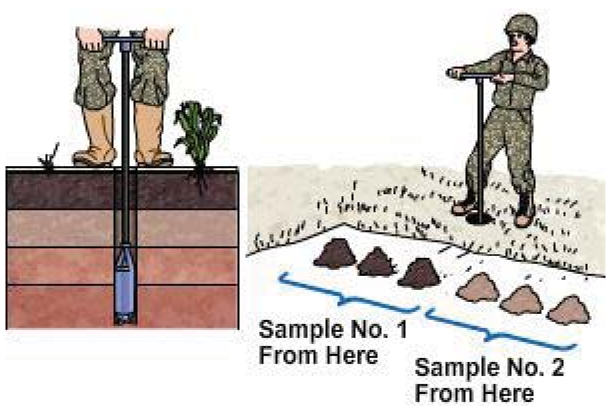


Figure 16-11 — Example of collecting individual soil samples with a hand auger.

When taking individual samples from hand auger holes, place typical portions of the collected soil along a row in the correct order according to depth and retrieval, as shown in *Figure 16-11*.

4.3.2 Composite Samples

A composite sample is a representative mixture of all soil within:

- A soil mass to be investigated
- An existing stockpiled material
- A windrow of soil excavated from a trench

A test sample is taken in the laboratory from a composite sample by quartering, which will be explained later in this chapter.

To take composite samples from test pits, trenches, or power shovel cuts, take the following steps:

1. Remove any overburden or surface soil intended for waste.
2. Shave off any loose and dried soil to obtain a fresh surface for taking the sample.
3. Excavate a channel of uniform cross section from top to bottom, depositing the soil onto a quartering cloth, canvas, or tarpaulin, as shown in *Figure 16-12.*

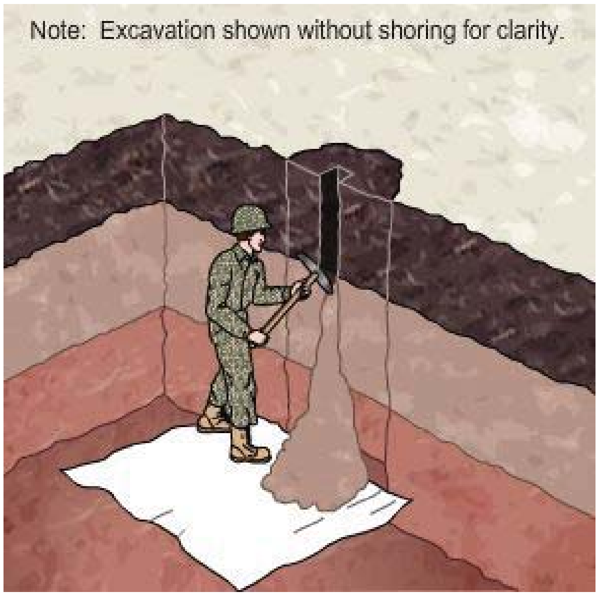


Figure 16-12 — Example of taking a composite soil sample from an exposed face.

Collect and bag all the removed material to ensure that the sample contains the correct cross sectional proportions.

To take composite samples from auger holes, remove the overburden and then collect all the material excavated from the hole without bothering to “place typical portions of the collected soil along a row” as done for individual soil sampling.

To take composite samples from stockpiles or windrows, take particular care.

When excavated material is placed in piles or rows, the coarse material tends to roll to the bottom, leaving the finer material on the top.

To compensate for this in a stockpile, after clearing the surface, take the sample from a full height strip.

To collect a sample from a small windrow, excavate and bag material from a short section, as shown in *Figure 16-13*.

Figure 16-13 — Example of taking a composite soil sample from a windrow.

4.3.3 Moisture Content Samples

To draw a complete soil profile and accurately ascertain the physical properties of soils obtained from test borings or pits, planners need to know the natural moisture content of the soil samples.

The natural moisture content is determined from samples taken in the field and placed in a container, which is then sealed to prevent loss of moisture by evaporation.

Generally, 100 grams of soil are enough to determine the moisture content of fine-grained soils, but soils containing gravel require larger samples.

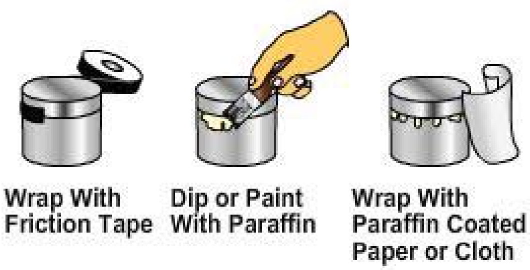


Figure 16-14 — Example of sealing a sample container to retain moisture content.

Normally, moisture content samples are placed in metal dishes (canisters) with tight-fitting covers. However, any clean, sealable container may be used.

If the moisture content test will be performed within 1 day of the sample collection, sealing the container is not required.

If a longer interval will elapse between sampling and testing, the containers should be sealed. (*Figure 16-14*)

4.4.0 Undisturbed Samples

Soil samples that are cut, removed, and packed with the least possible disturbance are termed “undisturbed samples.” (*Figure 16-15*)

As carefully as possible, these samples are taken in their natural structures with layers, void ratio, and moisture content preserved.

Figure 16-15 — Example of undisturbed soil sample with surface layer.

Undisturbed samples are used for determining the in-place density (unit weight) and investigating the strength by the CBR (or unconfined compression) tests in the laboratory. These samples may be shipped to more completely equipped laboratories for shear, consolidation, or other strength tests.

An undisturbed sample can be taken as a:

- chunk sample — cut by hand with a shovel and knife
- cylinder sample — obtained by a CBR mold equipped with a sampling cutter, or by using a cylindrical sampler in an alternate expedient method

The method chosen will depend on the available equipment, the tests required, and the type of soil being sampled. Frequently it will require a great deal of ingenuity in adapting the sampling devices and their usage to the job conditions.

Cohesionless samples must be kept in the sample container (cylinder method whenever possible) and handled without jarring or vibration until ready for testing. However, some soils are too hard or contain too many stones to permit cylinder sampling and can be taken only by cutting out chunk samples by hand.

Whatever method is used, all undisturbed samples must be handled with care. The sample must be packed in the container for shipment without allowing its structure to change, including its moisture content during sampling and shipment

4.4.1 Chunk Samples

The chunk sample is the simplest type of undisturbed sample. However, chunk samples can be obtained only from soils that will not deform, break, or crumble while being removed. *Figure 16-16* shows the process of taking a chunk sample from a level surface, such as a subgrade or the bottom of a test pit.

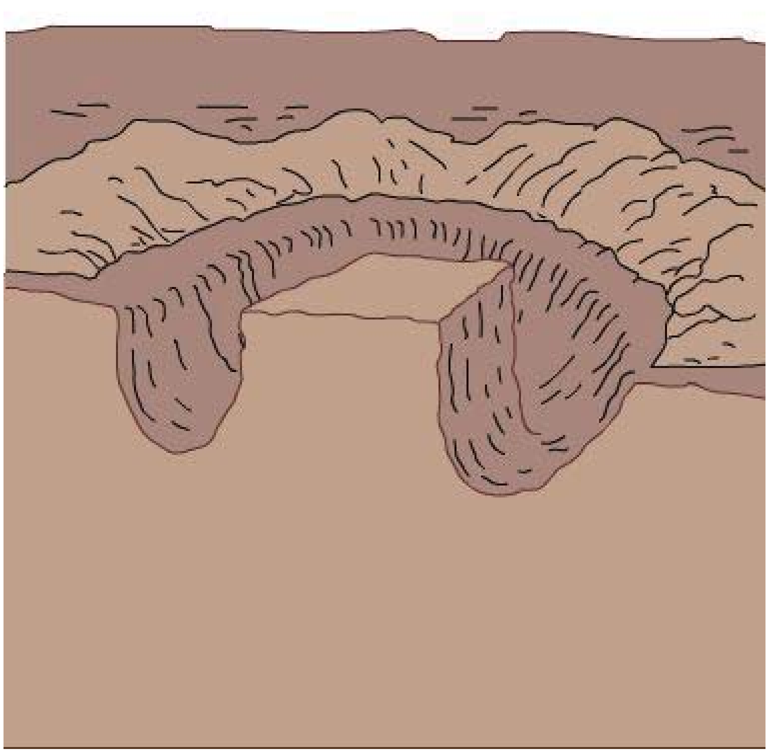


Figure 16-16 — Example of taking a chunk sample from a level surface.

After smoothing the ground surface and marking the outline of the chunk, the first step is to excavate a trench around the chunk.

Then deepen the excavation and trim the sides of the chunk with a knife.

Finally, using a knife, trowel, or hacksaw blade, cut off the chunk at the bottom and carefully remove it from the hole.

When taking a chunk sample from the vertical face of a test pit or trench, the process is similar except for the extra work effort and care needed to remove the soil from behind the intended sample. (*Figure 16-17*)

Smooth the surface of the face and mark the chunk outline.

Excavate the soil from the top, sides, and back of the chunk.

Shape the chunk with a knife

Cut it off and carefully remove it.

Figure 16-17 — Example of taking a chunk sample from a vertical surface.

After removing a chunk sample from a hole or wall, you need to seal it.

Figure 16-18 — Example of applying paraffin layers in coats.

One method is to apply three coats of melted paraffin. (*Figure 16-18*)

Allow each coat to cool and become firm before applying the next coat.

This gives adequate protection for strong samples that will be used within a few days.

For chunk samples that are weak, or may not be used within a few days, additional protection is required.

Wrap them with cheesecloth or other soft cloth, and then seal them with paraffin. (*Figure 16-19*)

If no cloth is available, reinforce the sample with several loops of friction tape or twine, taking extra precautions in this operation so the sample is not damaged.

Then apply three additional coats of paraffin.

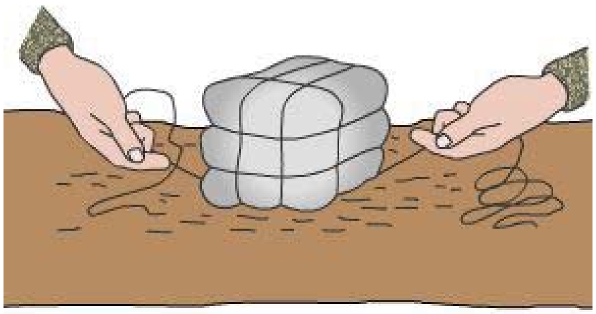


Figure 16-19 — Example of applying additional cloth and twine protection.

After wrapping the sample and applying the first brush coat, as an alternative to applying the three additional coats of paraffin, you can dip the entire sample in melted paraffin. (*Figure 16-20*)

Of course, this requires a larger container and more paraffin, but this method also provides a more uniform coating that can be built up to 1/8 inch or more in thickness by repeatedly dipping the sample.

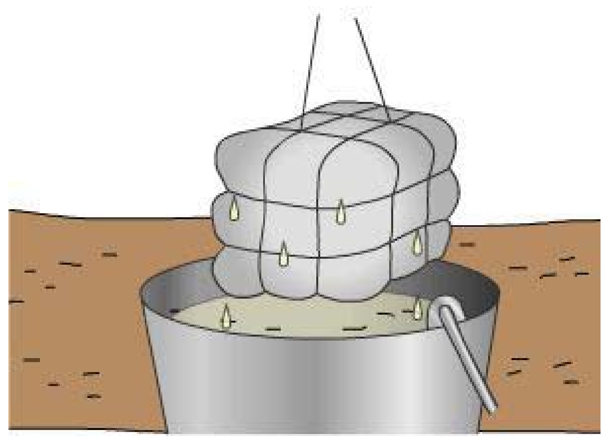


Figure 16-20 — Example of applying layers of paraffin protection by dipping.

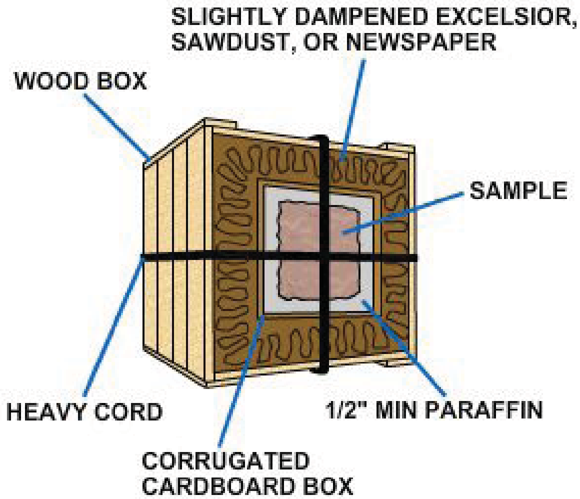


Figure 16-21 — Example of packaging a chunk sample for shipment to a laboratory.

For shipping a chunk sample to a laboratory, for example from a battalion's remote detail site to the main body site, still further protection is required.

This can be accomplished by applying multiple layers and coats of cloth and paraffin or by packing the paraffin-thickened chunk sample in a cardboard box with excelsior or sawdust and shipping it in a wooden box. (*Figure 16-21*)

4.4.2 Cylinder Samples by CBR Mold

To collect undisturbed samples for CBR or density tests, the cylinder method may be used for samples from soft, fine-grained soils. A CBR compaction mold is fitted with an extension collar, a sampling collar, and a cutting edge. (*Figure 16-22*)

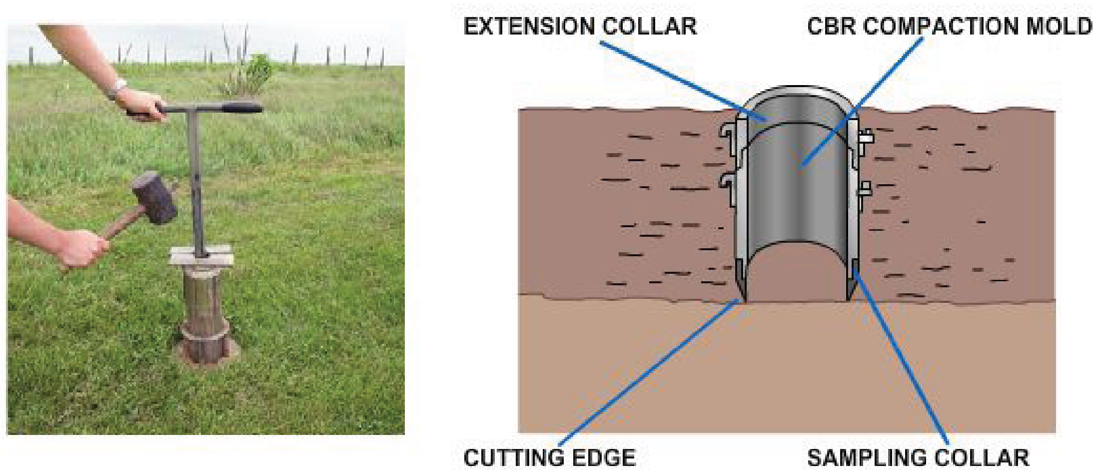


Figure 16-22 — Example of a cylinder CBR compaction mold.

Figure 16-23 demonstrates how to obtain a cylinder sample by using the CBR mold.

- Smooth the ground surface, and press the sampling collar and mold into the soil with moderate pressure.
- Excavate a trench around the cylinder and press the mold down over the soil again using a hand driver or loading bar if necessary. (Improvise a loading bar from any suitably sized piece of timber.)
- Carefully trim the soil away from the sampling collar with a knife, cutting downward and outward to avoid cutting into the sample. The sampling collar does the actual cutting to size. You can use the field CBR jack to force the sampler down, but it has only about 2 inches of travel, so if available, you would do better to use a truck jack. In either case, do not force the sampler down ahead of the trimming on the outside of the cylinder.
- Excavate the trench deeper and repeat the process until the soil penetrates well into the extension collar.
- Cut off the sample at the bottom of the mold with a shovel, knife, or wire, and remove the mold and sample from the hole.

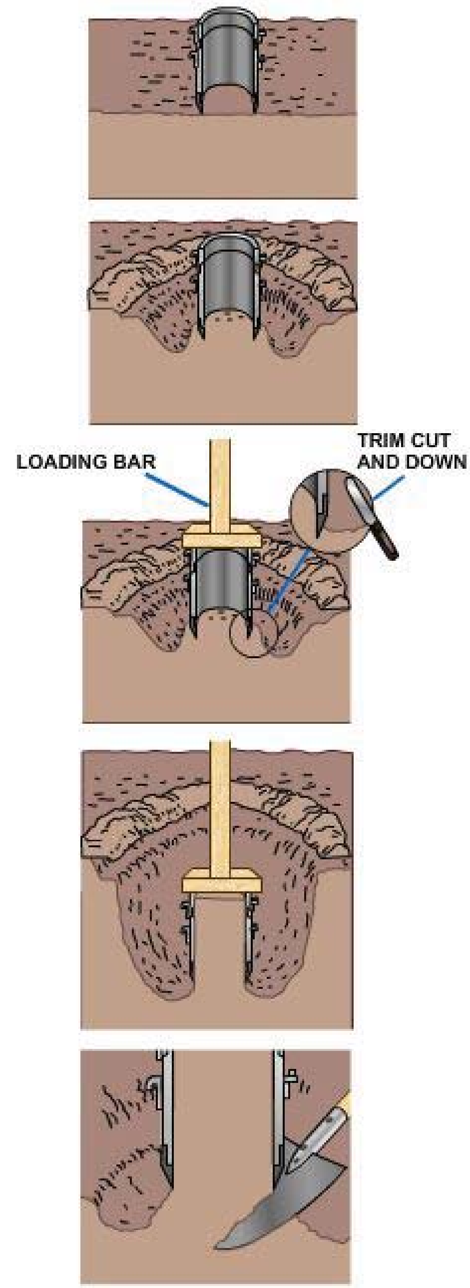
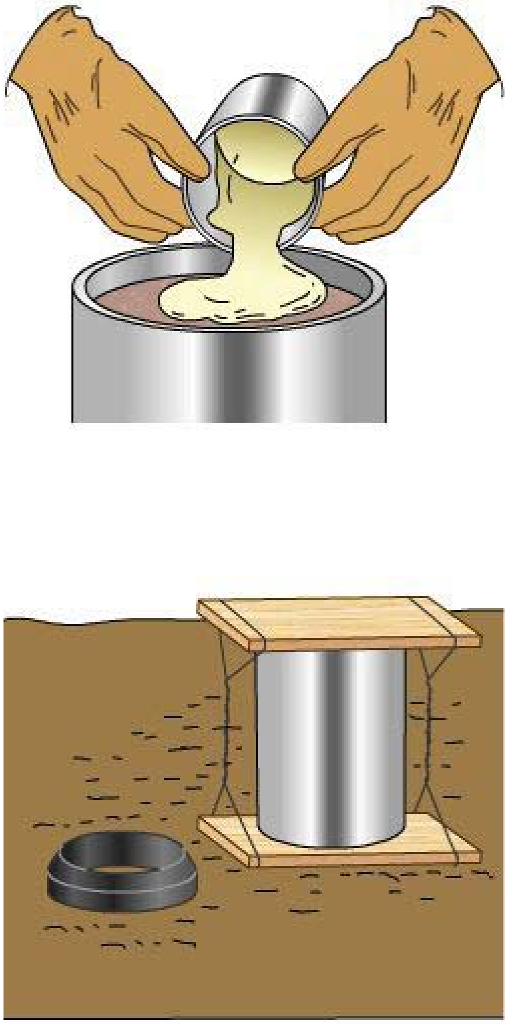


Figure 16-23 — Example of collecting an undisturbed cylinder sample by CBR compaction mold.

Undisturbed samples taken by cylinder method need to be protected similar to the chunk samples. (*Figure 16-24*)



- Remove the mold and sample from the hole.
- Remove the upper collar of the mold and trim the top surface of the sample down to approximately 1/2 inch from the top of the mold.
- Fill this recess with paraffin to seal the end of the sample.
- Turn the mold over and remove the cutting edge, creating a similar recess in the bottom of the sample.
- Fill this recess with paraffin. If the sample is to be handled a great deal, you should overfill the ends with paraffin and trim them exactly flush using a straightedge.
- Place boards over both ends and clamp in place, using bolts, string, or wire.

If the samples are to be transported some distance or handled quite a bit before testing, wrap the cylinders in cloth and soak them in paraffin layers.

Figure 16-24 — Example of sealing and protecting a CBR cylinder mold.

4.5.0 Quartering Samples

Quartering is the process of ensuring a soil sample's representation while reducing it to a convenient size or dividing it into two or more smaller samples for testing. The objectives are the same, but the procedures vary somewhat, depending upon the size of the sample.

4.5.1 Samples Weighing Over 100 Pounds

To quarter a sample of over 100 pounds, using a shovel, pile and thoroughly mix the sample on a canvas. (*Figure 16-25*)

- Place each new shovelful on the top-center of the preceding one so that the soil will be distributed evenly in all directions.
- Flatten the sample into a circular layer of approximately uniform thickness.
- Insert a stick or length of pipe under the canvas and then lift it at both ends to divide the sample into two equal parts.
- Remove the stick, leaving a fold in the canvas, and then reinsert it under the sample at right angles to the first division.
- Lift the stick again dividing the sample into four parts.
- Discard two diagonally opposite quarters taking care to clean the fines from the canvas.
- Remix the remaining material by taking an alternate shovelful from each quarter.
- Repeat the quartering process as necessary to reduce the sample to the desired size.

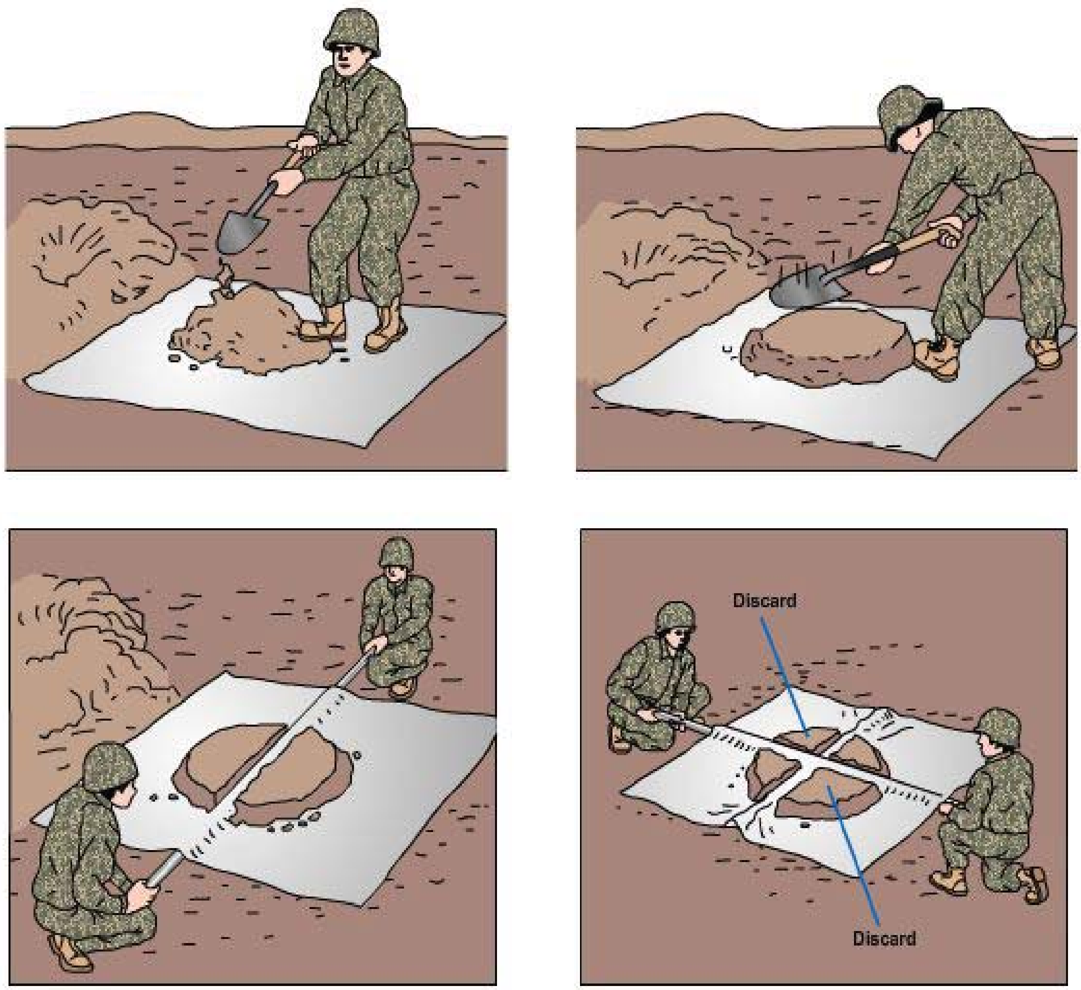


Figure 16-25 — Example of quartering and reducing a large sample to desired size.

4.5.2 Samples Weighing Between 25 and 100 Pounds

Figure 16-26 — Example of quartering a soil sample of 25-100 pounds.

In quartering a sample between 25 and 100 pounds, you can pile the soil on the canvas and mix it by alternately lifting the corners of the canvas and pulling the sample over as if preparing to fold the canvas diagonally. (*Figure 16-26*)

Flatten and quarter the sample as done with the larger, over 100-pound example.

Repeat until the sample is the desired size.

4.5.3 Samples Weighing Less Than 25 Pounds

For samples less than 25 pounds, the process is the same but on a smaller scale. (*Figure 16-27*)

Place the sample on canvas or a clean sheet of paper.

With a trowel, mix it thoroughly, form it into a conical shape, and flatten it.

Divide the sample into quarters, and discard two diagonally opposite quarters.

Remix the remaining material and repeat the process until the sample is the size needed for the test.

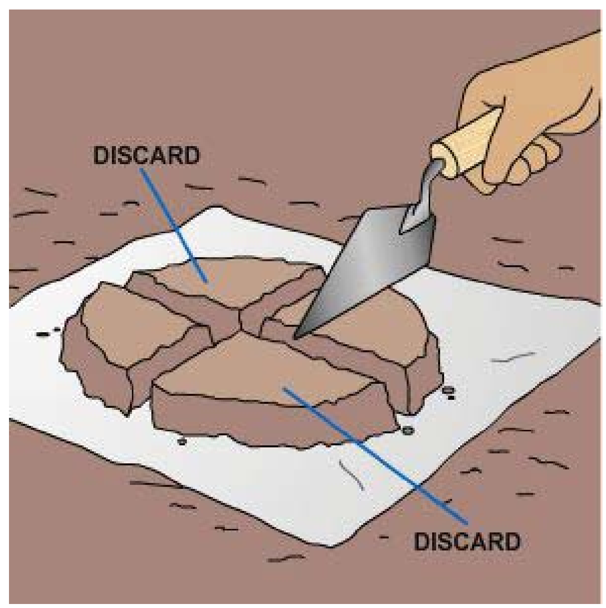


Figure 16-27 — Example of quartering a soil sample of less than 25 pounds.

Test your Knowledge (Select the Correct Response)

4. **(True or False)** Only soil samplings taken from test pits and holes are valid.

   A. True
   B. False

5.0.0 SOIL TESTING

To test the representative soil samples, disturbed or undisturbed, the Navy follows procedures laid down by the American Society for Testing Materials (ASTM). A complete soil test typically proceeds according to the following steps:

1. Determine moisture content.
2. Determine soil particle sizes (grains) and the percentage distribution of sizes with a mechanical analysis.
3. Determine specific gravity.
   - Specific gravity is expressed in terms of ratio: the weight of a given volume of substance relative to the weight of an equal volume of water. A cubic foot of water weighs 62.43 pounds.
     - For soil, determine the absolute specific gravity, that is, determine the ratio of the weight of a dense volume, which is a volume exclusive of air spaces.
     - For example, a cubic foot of dry sand weighs about 100 pounds, but with air exhausted, a cubic foot of sand weighs about 165.44 pounds. Therefore, the specific gravity of sand equals 165.44 divided by 62.43 (1 $ft.^3$ water), or about 2.65.
4. Determine Atterberg limits if the soil is clay or a similar fine-grained soil.
   - A fine-grained soil remains plastic over a certain range of moisture content. The upper moisture content is called the liquid limit; the lower is called the plastic limit. Above the range, the soil becomes fluid; below the range, the soil becomes semisolid.
5. Determine moisture-density relationship.
   - Compaction is used to determine the moisture-density relationship; in other words, with a given compaction energy, determining what moisture content will result in the maximum compaction. Compaction testing is not included in this course but will be discussed in EA Advanced.
6. Determine by field control testing:
   - the field moisture content (with an eye to reducing or increasing it to the optimum, if feasible).
   - the point at which the specified density has been obtained by compaction.

Field control testing is not included in this course but will be discussed in EA Advanced.

5.1.0 Determining Moisture Content

A soil's moisture content (also referred to as water content) is an indicator of the amount of water present. By definition, moisture content in a sample is the ratio of the weight of water to the weight of solids (oven-dried), expressed as a percentage (w).

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

Where:

$w =$ moisture content of the soil (expresses as a percentage)

$W_w =$ weight of water in the soil sample

$W_s =$ weight of oven-dried solids in the sample

With many soils, close control of moisture content during compaction is necessary to develop a required density and strength in the soil mass. The amount of compaction effort to obtain a specified density depends on having the moisture content at or very close to optimum.

Specified density is expressed in terms of dry unit weight, so moisture content must be determined with a wet unit weight to determine whether moisture must be added or removed from the soil mass at the construction site to achieve the optimum moisture content (OMC) for compaction.

There are several methods for determining moisture content of soil but the most accurate is the oven-drying method with an electric or portable gasoline oven to dry the samples.

The calcium carbide gas pressure method is a more expedient method, but it is less accurate and should always be approved by your supervisor.

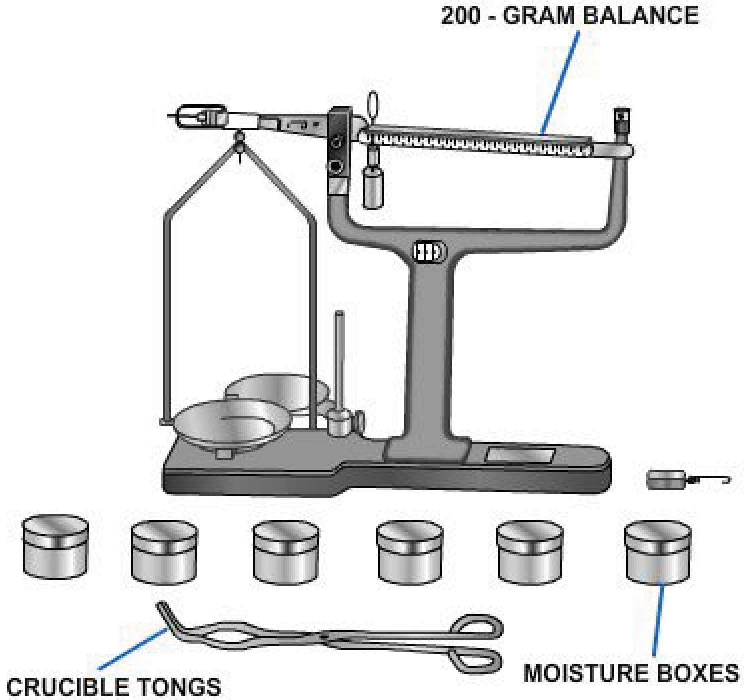
The Nuclear Moisture-Density Meter method is a third option, but it requires special training, along with operator certification, and will not be covered in this course.

5.1.1 Oven-drying Method

To use the oven-drying method (ASTM D 2216-05), again the most accurate method, use the following apparatus and procedures.

5.1.1.1 Apparatus

Figure 16-28 shows the laboratory apparatus needed for determining moisture content.



- A balance for weighing material to 0.01 grams (453.6 g = 1 pound)
- Several small circular moisture boxes (called cans) for placing samples in to weigh and dry
- An electric oven or a portable gasoline oven to dry samples
- Crucible tongs

Figure 16-28 — Apparatus for determining moisture content in the oven-drying method.

If an electric or gasoline oven is not available, the materials can be dried in a frying pan held over an ordinary stove or hot plate. However, the frying pan substitute has a disadvantage. Whereas the electric oven thermostat can be set to a desired temperature, with a frying pan, the temperature is hard to control and any organic material in the sample may be burned causing a slight to moderate inaccuracy in the result.

5.1.1.2 Procedure

Perform the following steps to determine the moisture content. Refer to *Figure 16-29* for entries on DD Form 1205.

- Record all identifying sample information (blocks 1 - 5).
- Label and weigh clean, dry, moisture boxes (cans); record as *Weight of Tare* (block d).
- Place required soil sample in can and cover with lid.
  - When conducting this test as part of another test method, use the specimen mass stated in that test method.
  - When conducting this test with no minimum specimen mass provided, use the values provided in *Table 16-5*, depending on the degree of accuracy of the reported water content.
- Weigh soil sample and tare to the nearest 0.01 gram; record as *Weight of Tare + Wet Soil* (block a).
- Oven-dry sample, with lid removed, at 110°C ± 5° until sample weight becomes constant.

- Oven-drying time will vary depending on the type of soil, the size of the sample, and other factors. For routine water-content determination, oven-dry a sample of clean sands and gravel for a minimum of 4 hours. For most other soils, a minimum drying time of 16 hours is adequate.

- Remove sample from oven; replace lid and allow to cool until it can be handled comfortably with bare hands.
- Weigh dried soil sample and tare; record as *Weight of Tare + Dry Soil* (block b).
- Determine weight of water (W_w) by subtracting *Weight of Tare + Dry Soil* (block b) from *Weight of Tare + Wet Soil* (block a); record as Weight of Water (W_w) (block c).
- Determine weight of dry soil (W_s) by subtracting *Weight of Tare* (block d) from *Weight of Tare + Dry Soil* (block b); record as *Weight of Dry Soil* (W_s) (block e).
- Determine water content (w), in percent, and record it using the formula:

$$w = \frac{W_w}{W_s} x\, 100$$

When determining the average water content, the individual tests must be within ± 1 percent. Any individual tests that do not meet this requirement will not be used. If none of the individual tests meet this requirement, then additional testing is required. Refer again to *Figure 16-29* to note an invalidated test.

SOIL MOISTURE-CONTENT DETERMINATION

1. PROJECT ENGINEER CENTER EXPANSION		2. DATE 1 Dec
3. JOB NUMBER 16-P-T	4. TEST SITE North Corner	5. SAMPLE NUMBER 5-C-1

TEST Bag 1 AVERAGE 3.6 %						
RUN NUMBER	1	2	3	4		
TARE NUMBER	1-1	1-2	1-3	1-4		
a. WEIGHT OF TARE + WET SOIL	33.92	37.82	32.46	32.26		2.6
b. WEIGHT OF TARE + DRY SOIL	33.31	37.18	31.84	31.68	MEAN=	3.6(+/-1)
c. WEIGHT OF WATER, W_w (a - b)	0.61	0.64	0.62	0.58		4.6
d. WEIGHT OF TARE	16.48	18.82	15.02	15.13		
e. WEIGHT OF DRY SOIL, W_s (b - d)	16.83	18.36	16.82	16.55		
WATER CONTENT, w (c/e x 100)	3.6 %	3.5 %	3.7 %	3.5 %	%	%

TEST Bag 2 AVERAGE 8.9 %						
RUN NUMBER	1	2	3	4		
TARE NUMBER	2-1	~~2-2~~	2-3	2-4		
a. WEIGHT OF TARE + WET SOIL	41.32	~~45.93~~	39.94	43.64		8.9
b. WEIGHT OF TARE + DRY SOIL	39.22	~~42.82~~	38.06	41.36	MEAN=	9.9(+/-1)
c. WEIGHT OF WATER, W_w (a - b)	2.10	~~3.11~~	1.88	2.28		10.9
d. WEIGHT OF TARE	16.31	~~18.56~~	15.93	15.81		
e. WEIGHT OF DRY SOIL, W_s (b - d)	22.91	~~24.26~~	22.13	25.55		
WATER CONTENT, w (c/e x 100)	9.2 %	~~12.8 %~~	8.5 %	8.9 %	%	%

TEST AVERAGE %						
RUN NUMBER						
TARE NUMBER						
a. WEIGHT OF TARE + WET SOIL						
b. WEIGHT OF TARE + DRY SOIL						
c. WEIGHT OF WATER, W_w (a - b)						
d. WEIGHT OF TARE						
e. WEIGHT OF DRY SOIL, W_s (b - d)						
WATER CONTENT, w (c/e x 100)	%	%	%	%	%	%

TEST AVERAGE %						
RUN NUMBER						
TARE NUMBER						
a. WEIGHT OF TARE + WET SOIL						
b. WEIGHT OF TARE + DRY SOIL						
d. WEIGHT OF WATER, W_w (a - b)						
d. WEIGHT OF TARE						
e. WEIGHT OF DRY SOIL, W_s (b - d)						
WATER CONTENT, w (c/e x 100)	%	%	%	%	%	%

6. REMARKS

WATER CONTENT $w = \frac{Ww}{Ws} \times 100$

Tare # 2-2 not used. Not within +/- 1% of MEAN
Probable error in recording weights of this sample

SAMPLE

7. TECHNICIAN *(Signature)* EA2 Johnson	8. COMPUTED BY *(Signature)* EA2 Johnson	9. CHECKED BY *(Signature)* EA1 Barnes

DD FORM 1205, DEC 1999 PREVIOUS EDITION IS OBSOLETE. Adobe Professional 7.0

Figure 16-29 — Example of data sheet for soil moisture content. DD Form 1205.

Table 16-5 — Recommended Minimum Test Specimen for Reporting Water Content.

Maximum Particle Size(100% Passing)	Standard Sieve Size	Minimum Moist Mass for Reporting to ± 0.1%	Minimum Moist Mass for Reporting to ± 1%
2.0 mm or less	No. 10	20.0 g	20 g*
4.75 mm	No. 4	100.0 g	20 g*
9.50 mm	3/8 in	500.0 g	50 g
19.00 mm	3/4 in	2.5 kg	250 g
37.50 mm	1 1/2 in	10.0 kg	1 kg
75.00 mm	3 in	50.0 kg	5 kg
*** To be representative, not less than 20 grams shall be used.**			

5.1.2 Calcium Carbide Gas Pressure Method (AASHTO T 217-1986)

CAUTION

The chemical reaction of calcium carbide with water produces acetylene gas, which is extremely flammable. Exercise extreme caution to avoid open flame when releasing the gas from the speedy moisture tester. Perform the test in a well-ventilated area, as asphyxiation could occur if performed in a confined area.

A typical Calcium Carbide Gas Pressure method uses a 26 gram, SPEEDY® moisture tester to determine the moisture content of soils, fine aggregates, sand, and clay.

Determination can be made in the laboratory or field to within ± 0.5 percent, in from 45 seconds to 3 minutes depending upon the material being tested. If another tester is to be used, consult the user's manual for the tester before conducting the moisture-content determination.

The tester operates on the principle of introducing a calcium carbide reagent (reactive agent) to the free moisture of the soil sample inside a sealed then shaken chamber. The resulting chemical reaction creates a gas that is contained in the sealed chamber. The resulting gas pressure is displayed on a built-in gas pressure gauge.

5.1.2.1 Apparatus

The SPEEDY® Moisture Tester set (*Figure 16-30*) includes:

Figure 16-30 — Example of a SPEEDY® Moisture Tester.

- SPEEDY® tester
- Balance
- Half-weight reagent
- Measuring scoop
- Brushes
- Cleaning cloth
- Two 1 1/4-in. steel balls

5.1.2.2 Procedure

- Weigh a specified gram sample of soil (26g on SPEEDY® Moisture Tester model).
- Place soil sample and two 1 1/4-inch steel balls in large chamber.
- Hold pressure vessel in a horizontal position to prevent soil from contacting reagent before tester is sealed.
- Place three scoops (24g) of reagent in cap. While still horizontal, insert cap into pressure vessel and tighten clamp to seal cap.
- Raise moisture tester to a vertical position so reagent falls into vessel.
- Return tester to horizontal and vigorously shake with a rotating motion for 10 seconds to put steel balls into orbit around inside circumference to break down soil.
  - Rest for 20 seconds; repeat shake-rest cycle for a total of 3 minutes.
  - Do not allow steel balls to fall against either cap or orifice leading to the dial; this may cause damage.
- Hold the tester horizontal at eye level, read and record dial reading as percent of moisture by wet mass.
- Point cap away and release gas pressure slowly.
- Empty pressure vessel and examine for lumps. If soil sample is not completely broken down, retest another sample and increase time limit (shaking unit) by 1 minute.

    - The limit of the tester is 12 percent moisture for aggregate, or 20 percent moisture for soil. If the limit is exceeded, then the test must be run again using a half-sized sample (13 grams) and the dial reading must be multiplied by 2.
- Determine percentage of moisture by dry mass (oven-dry moisture percentage), by converting direct wet mass reading into a calibration curve supplied with test set.

5.2.0 Mechanical Analysis

Determining grain sizes and the percentage distribution of each size is done with mechanical analysis. A complete mechanical analysis is accomplished in two parts: sieve analysis and ***hydrometer*** analysis.

5.2.1 Sieve Analysis

Sieve analysis applies to soils that are larger than the No. 200 sieve or contain small amounts of material passing the No. 200 sieve.

Sieve analysis can be done on the entire sample or on the sample after the fines are removed by prewashing. To conduct a mechanical analysis, use the following apparatus and procedures.

5.2.1.1 Apparatus

A typical sieve analysis apparatus includes:

- Gram weighing balance
- Sieves with apertures of varying sizes used to determine grain sizes (*Figure 16-31*)
- Sieves may be:
    - Circular sifter type (usually about 8 inches in diameter)
    - Rocker type, a rocker frame in which screens with apertures of various sizes can be placed

Figure 16-31 — Typical sieve set apparatus.

The sieve used for analysis is the so-called standard sieve. A standard sieve has a square aperture.

Sieve screen sizes have two types of identifying systems:

- A sieve with fewer than four apertures to the linear inch is designated by the size of an aperture, for example, a 1/4-inch, 1/2-inch, 3/4-inch, or 1-inch sieve.
- A sieve with four or more apertures to the linear inch is designated by a number representing the number of apertures per linear inch. A No. 4 sieve has four apertures to the linear inch; No. 6 has six apertures; and so on. The finest sieve used is a No. 200, which is slightly smaller than $\frac{1}{200^{th}}$ of an inch square.

To conduct a sieve analysis, you also need an electric or hand-operated sieve shaker. (*Figure 16-32*)

Shakers come in a variety of styles and functional operation.

Figure 16-32 — Example of types of sieve shakers.

5.2.1.2 Procedure-Sieve Analysis, Dry

To conduct a mechanical dry sieve analysis you must have a minimum amount of soil sample. (*Table 16-6*)

Table 16-6 — Minimum Amount of Soil Sample for Grain-Size Analysis.

Maximum particle size (sieve opening)	Minimum dry weight of test specimen	
3 in.	5,000 g	The minimum sample weight depends on the maximum particle size in the sample.
2 in.	4,000 g	
1 1/2 in.	3,000 g	
1 in.	2,000 g	
3/4 in.	1,000 g	
3/8 in. (No. 4)	500 g	

Samples are analyzed by the following procedure. Refer to *Figure 16-33* for entries on DD Form 1206.

Samples that contain cohesive soils such as clays or silts, which form hard lumps, must be prewashed. Look for the 4 additional operations.

GRAIN-SIZE ANALYSIS (SIEVE METHOD)

1. PROJECT ENGINEER CENTER EXPANSION		2. DATE 1 Dec
3. JOB NUMBER 16-P-T	4. EXCAVATION 5-C	5. DATE COMPLETED 5 Dec
6. NOTES ABOUT SAMPLE/DESCRIPTION Red in color, very fine sands		7. SAMPLE NUMBER 5-C-1
		8. ORIGINAL SAMPLE WEIGHT 4,405
9. PREWASHED ☒ YES ☐ NO	10. + #200 SAMPLE WEIGHT, WASHED 2,814	11. - #200 SAMPLE WEIGHT, WASHED 1,570

12. SIEVE SIZE	13. SIEVE WEIGHT	14. SIEVE-SAMPLE WEIGHT	15. WEIGHT RETAINED	16. CUMULATIVE WEIGHT RETAINED	17. PERCENT RETAINED	18. PERCENT PASSING
2"	585	585	0	0	0	100
1 1/2"	714	797	84	84	1.9	98.1
3/4"	577	738	161	245	3.7	94.4
1/4"	540	1,168	628	873	14.3	80.1
#4	507	625	118	991	2.7	77.4
#16	404	827	418	1,408	9.5	67.9
#30	596	820	224	1,633	5.1	62.7
#40	402	634	232	1,865	5.3	57.4
#60	534	966	433	2,298	9.9	47.6
#80	351	655	304	2,602	6.9	40.6
#100	265	329	64	2,665	1.5	39.2
#200	347	461	114	1,779	2.6	36.6

19. TOTAL WEIGHT RETAINED IN SIEVES *(Sum of column 15)*	2,779	24. ERROR *(8-23)* 23	25. ERROR IN PERCENTAGE $\left(\frac{24}{8}\right)$ X 100 = 0.5
20. WEIGHT SIEVED THROUGH #200 *(Weight in pan)*	33		
21. WASHING LOSS *(8 - [10+ 11])*	21		
22. TOTAL WEIGHT PASSING #200 SIEVE *(20+ 11)*	1,603		
23. TOTAL WEIGHT OF FRACTIONS *(19+ 22)*	4,381		

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

30. REMARKS
USCS SC W/GRAVEL

31. TECHNICIAN *(Signature)*	32. COMPUTED BY *(Signature)*	33. CHECKED BY *(Signature)*
EA2 Johnson	EA2 Johnson	EA1 Barnes

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Figure 16-33 — Example of grain-size analysis. DD Form 1206.

- Prepare sample.
  - Spread out and air dry.
  - Break up aggregate with fingers or mortar and pestle (usually a part of the laboratory apparatus). Take care not to crush individual grains. The object is to separate aggregations of clustering grains.
- Obtain representative size. (*Table 16-6*)
- Record identifying sample information on form (blocks 1 through 7).
- Oven-dry material at 110°C ± 5° until a constant weight is obtained; allow cooling.
- Weigh oven-dried sample to the nearest gram; record as original weight on form (block 8).
- If only a dry sieve is to be performed, check "No" in block 9 and enter 0 in blocks 10 and 11 and proceed with selecting sieves.
  - If sample will be prewashed, check "Yes" in block 9 and add the following 4 operations:
    1. Place sample in clean container; cover completely with water; allow soaking until any adhering and lumpy particles are completely disintegrated, 2 to 24 hours.
    2. Wash sample over a No. 200 sieve into a 2 x 2 foot concrete pan until all –200 materials have been washed through.
       a. If sample contains an appreciable amount of coarse particles, combine No. 4 and No. 200 sieves.
       b. Take care not to overload No. 200 sieve. If necessary, transfer sample in increments. (This process may take up to 6 different pans and as long as 8 hours.)
    3. Process +200 material.
       a. Oven-dry washed + 200 material at 110°C ± 5° until constant weight is obtained and allow cooling.
       b. Weigh to nearest tenth of a gram, record + *#200 Sample Weight, Washed* (block 10).
    4. Process –200 material.
       a. Allow the –200 material to settle in pan until surface water becomes clear (16 to 24 hours).
       b. Decant surface water (use siphon or syringe) ensuring settled material is not disturbed.
       c. Use a trowel to transfer as much material as possible from pan to pudding pans.
       d. Rinse remainder of material from 2 x 2 pans to pudding pans with as little water as possible.
       e. Oven-dry washed –200 material and determine weight to nearest tenth of a gram; record as — *#200 Sample Weight, Washed* (block 11).

- Retain material from these 4 additional steps for prewashed material for use in hydrometer analysis.

- Select a nest of sieves to accommodate largest particle size of soil; ensure all material will pass through largest sieve.
- Record weight of each selected sieve (to nearest tenth of a gram) on form (column 13).
    - Sieve selection varies according to type of soil being tested. The following is recommended as a minimum:

Stack (nest) sieves on top of each other with the largest sieve on top.

The coarsest sieve recorded is the sieve above the first one that retains any material.

The “retained” weight recorded for this sieve is 0 g.

The passing weight recorded through this sieve is the total weight of the sample.

2 inch
1 1/2 inch
1 inch
3/4 inch
3/8 inch
No. 4
No. 10
No. 16
No. 30
No. 40
No. 50
No. 100
No. 200

- Weigh and place a pan on bottom.
- Cover sample.
    - If sample was prewashed, place only +200 material onto top sieve of nest and cover.
    - If sample was not prewashed, place entire sample on top sieve of nest and cover.
- Place nest of sieves in sieve shaker and shake for 5 to 15 minutes.
    - Shaking interval depends on quantity of fine material.
        - Five minutes-for most coarse-grained soils.
        - Fifteen minutes-for most fine-grained soils.
- Remove cover and sieves from shaker in descending order.
- Weigh each sieve-sample and record on form (column 14).

- Determine weight of material retained on each sieve by subtracting weight of sieve (column 13) from weight of sieve and retained sample (column 14); record as weight retained (column 15).
- Add weights retained on all sieves and record as total weight retained in sieves (block 19).
- Weigh pan with material passing No. 200 sieve; subtract weight of pan; record as weight sieved through No. 200 (block 20).
- Complete form blocks 21 through 25 using formulas provided on sheet; if error percentage is 1 percent or greater, rerun test.
- Compute cumulative weight retained (column 16) for each sieve by adding weight retained (column 15) to the previous cumulative weight retained (column 16) with starting point being 0.
- Compute percent retained (column 17) for each sieve by dividing weight retained by total weight of fractions as follows:

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

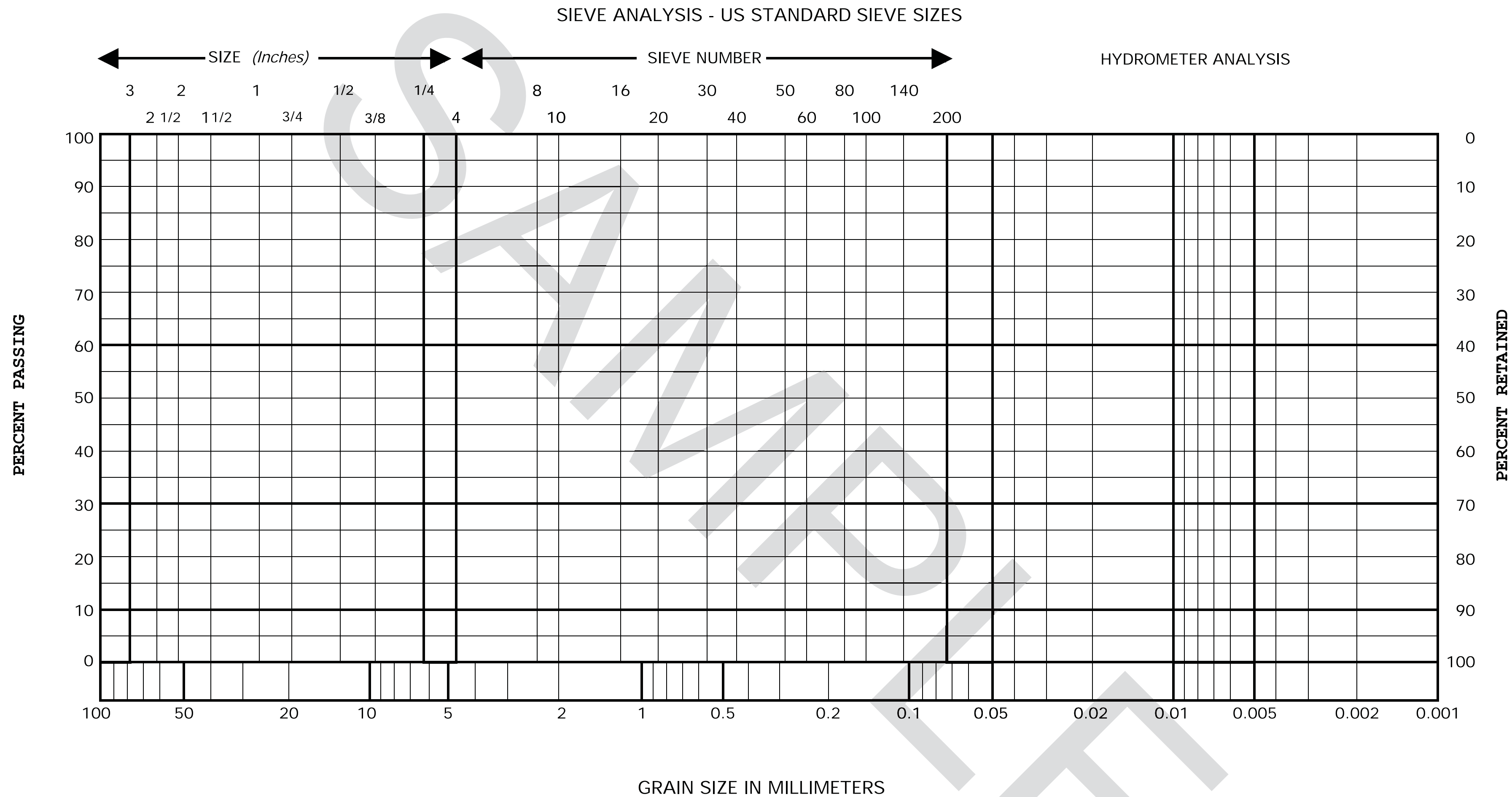
- Compute percent passing for each sieve size by subtracting cumulative weight retained (column 16) from total weight of fractions (block 23) and dividing by total weight of fractions as follows:

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

- Determine percentages for gravel, sand, and fines; record as:
  - Gravel is material retained on No. 4 sieve (block 26).
  - Sand is material passing No. 4 sieve, retained on No. 200 sieve (block 27).
  - Fines are material passing No. 200 sieve (block 28).
- Prepare Grain-Size Distribution graph, DD Form 1207. (*Figure 16-34*)
  - Record identifying sample information in remarks blocks.
  - Use sieve-analysis data to plot sieve size and percentage passing sieve.
  - Use a french curve to connect plotted points forming a smooth, free-flowing curve (grain-size distribution curve).

GRAIN SIZE DISTRIBUTION GRAPH - AGGREGATE GRADATION CHART

1. PROJECT	2. DATE
ENGINEER CENTER EXPANSION 16-P-T	6 Dec



EXCAVATION NUMBER	SAMPLE NUMBER	LL	PL	PI	Cu (D_{60}/D_{10})	Cc ($(D_{30})^2/(D_{60} \times D_{10})$)	SOIL DESCRIPTION/REMARKS	CLASSIFICATION (USCS)
5-c	5-C-1	20	10	10	N/A	N/A	Red in color, very fine sands	SC

3. TECHNICIAN *(Signature)*	4. PLOTTED BY *(Signature)*	5. CHECKED BY *(Signature)*
EA2 Johnson	EA2 Johnson	EA1 Barnes

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Figure 16-34 — Example of grain-size distribution graph. DD Form 1207.

16-45

5.2.1.3 Procedure-Sieve Analysis with Prewashing (recap)

If grain-size sample will be prewashed, and "Yes" in block 9 of DD Form 1206 (*Figure 16-33*) is checked, perform the following 4 operations:

- Place sample in clean container; cover completely with water; allow soaking until any adhering and lumpy particles are completely disintegrated, 2 to 24 hours.
- Wash sample over a No. 200 sieve into a 2 x 2 foot concrete pan until all –200 materials have been washed through.
    - If sample contains an appreciable amount of coarse particles, combine No. 4 and No. 200 sieves.
    - Take care not to overload No. 200 sieve. If necessary, transfer sample in increments. (This process may take up to 6 different pans and as long as 8 hours.)
- Process + 200 material.
    - Oven-dry washed + 200 material at 110°C ± 5° until constant weight is obtained and allow cooling.
    - Weigh to nearest tenth of a gram, record as + *#200 Sample Weight, Washed* (block 10).
- Process — 200 material.
    - Allow the — 200 material to settle in pan until surface water becomes clear (16 to 24 hours).
    - Decant surface water (use siphon or syringe) ensuring settled material is not disturbed.
    - Use a trowel to transfer as much material as possible from pan to pudding pans.
    - Rinse remainder of material from 2 x 2 pans to pudding pans with as little water as possible.
    - Oven-dry washed — 200 material and determine weight to nearest tenth of a gram; record as — *#200 Sample Weight, Washed* (block 11).
- Retain material from these 4 additional steps for prewashed material for use in hydrometer analysis.

5.2.2 Hydrometer Analysis

The determination of grain size distribution by sieve analysis is limited to materials larger than the No. 200 (0.074-mm) sieve. For soil classification, this is sufficient since grain size distribution is not used to classify fine-grained soils that pass through the No. 200 sieve. However, when appropriate to the geographical area, an analysis of the distribution of particles smaller than the No. 200 sieve is necessary for frost susceptibility. Frost susceptibility should always be considered in areas subject to substantially freezing temperatures, since repeated freezing and subsequent thawing of water in the soil can seriously affect the ability of the soil to support a structure. A soil is considered frost susceptible if it contains 3 percent or more by weight of particles smaller than 0.020 mm in diameter, and hydrometer analysis is the test used to determine the grain size distribution of soils passing the No. 200 sieve.

Figure 16-35 shows an example of a grain-size analysis using the hydrometer method.

GRAIN-SIZE ANALYSIS (HYDROMETER METHOD)

1. PROJECT	2. DATE
ENGINEER CENTER EXPANSION	6 Dec

3. BORING NUMBER	4. SAMPLE OR SPECIMEN NUMBER	5. CLASSIFICATION
5-C	5-C-1	SC
6. DISH NUMBER	**7. GRADUATE NUMBER**	**8. HYDROMETER NUMBER/TYPE** *(151H/152H)*
4-A	#3	359557

9. DISPERSING AGENT USED	10. QUANTITY
Sodium Hexametaphosphate	15 ML

11. COMPOSITE CORRECTION	12. DECIMAL FINES *(Block 29, DD Form 1206)*	13. SPECIFIC GRAVITY OF SOLIDS *(Block 6n, DD Form 1208)* G_s =
0.5	0.366	2.62

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

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

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

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

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

Hydrometer graduated in specific gravity (151H)

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

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

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Figure 16-35 — Grain-size analysis (Hydrometer Method). DD Form 1794.

Hydrometer analysis is based on Stokes' law, which relates the terminal velocity of a free-falling sphere in a liquid to its diameter.

The relation is expressed by the following equation:

$$V = \frac{G_s - G_w}{18n} x D^2$$

Where:

$V =$ terminal velocity

$G_s =$ specific gravity of solids

$G_w =$ specific gravity of the liquid in which the sphere is falling

$n =$ viscosity of the liquid

$D =$ diameter of the sphere

Larger particles settle more rapidly than smaller ones and it is assumed that Stokes' law can be applied to a mass of dispersed soil particles of various shapes and sizes.

The hydrometer analysis is an application of Stokes' law that permits the calculation of grain size distribution in silts and clays. For the analysis, the soil particles are given the sizes of equivalent spherical particles as in Stokes' Law.

The density of a soil-water suspension depends upon the concentration and specific gravity of the soil particles. If the suspension is allowed to stand, the particles will gradually settle out of the suspension, and the density will be decreased.

A hydrometer is an instrument used to measure the density of the suspension at a known depth below the surface. The density measurement, together with knowledge of the specific gravity of soil particles, determines the percentage of dispersed soil particles in suspension at the time and depth of measurement.

Stokes' law is used to calculate the maximum equivalent particle diameter for the material in suspension (at depth and elapsed time of settlement). A series of density measurements (at known depth of suspension and times of settlement) gives the percentages of particles finer than the diameters given by Stokes' law.

Thus, the series of readings will reflect the amount of different sizes of particles in the fine-grained soils. The particle diameter (D) is calculated from Stokes' equation using corrected hydrometer readings and a ***nomographic chart***. Hydrometer analysis procedures are not discussed in this course but are contained in ASTM D 422.

5.3.0 Specific Gravity Testing

Specific gravity is the ratio of the weight of a solid substance to the weight of an equal volume of water. In dealing with soils, determining specific gravity is necessary for certain tests, such as hydrometer analysis, and for computations involving volume and weight relationships.

The specific gravity of solids is normally applied only to soil that passes the No. 4 sieve. Generally, geotechnical engineers need a soil's specific gravity to perform additional testing of that particular soil.

In some cases though, there may be different soil fractions used when performing this test. For example, a –10 sample's resulting specific gravity is applicable to hydrometer analysis, while determining the zero-air-voids curve in soils-compaction testing (laboratory) uses the –4 sample's specific gravity.

A soil's specific gravity largely depends on the density of the minerals making up the individual soil particles. Some typical specific gravity values for specific soil types are:

- Solid substance of most inorganic soils — 2.60 to 2.80
- Tropical iron-rich laterite, as well as some lateritic soils — 2.75 to 3.0 +
- Sand particles composed of quartz — 2.65 to 2.67
- Inorganic clays — 2.70 to 2.80
- Soils with large amounts of organic matter or porous particles (such as diatomaceous earth) — 2.00 to 2.60

There are three different formats for expressing the specific gravity of a soil mass.

- Specific Gravity of Solids (G_s) — the ratio of the weight in air of a given volume of *soil particles* to the weight of an equal volume of distilled water, both at a stated temperature.
  - The specific gravity of solids is applied only to that fraction of a soil that passes a No. 4 sieve.
- Apparent Specific Gravity (G_a) — the ratio of the weight in air of a given volume of *the impermeable portion of soil particles* to the weight in air of an equal volume of distilled water, both at a stated temperature.
  - The impermeable portion of a porous material, such as most large soil grains, includes the solid material plus impermeable pores or voids within the particles.
- Bulk Specific Gravity (G_m) — the ratio of the weight in air of a given volume of *permeable material (including permeable and impermeable voids)* to the weight of an equal volume of distilled water, both at a stated temperature.

5.3.1 Sample Selection

For specific gravity tests, soil samples may be disturbed or undisturbed. However, take care to ensure that a sample is a representative sample.

When selecting a sample containing both large and small particles, separate it on a No. 4 sieve; discard any particles not passing.

It is easier to begin the test with an oven-dried sample. However, some soils, particularly those with high organic content, should be tested at their natural water content with the oven-dried weight determined at the end of the test.

5.3.2 Specific Gravity of Solids

As presented earlier, determining the specific gravity of solids applies only to soil that passes a No. 4 sieve. However, when used in conjunction with a hydrometer analysis, specific gravity is determined only on the fraction that passes a No. 200 sieve.

5.3.2.1 Apparatus

- 500-milliliter (ml) volumetric flask
  - For course discussion, assume the flask has been calibrated; the weight of the flask and water has been calibrated over a range of temperatures likely encountered in the laboratory. Calibration procedures are located in ASTM D 854.
- Balance, 2,000-gram capacity
- Balance, 200-gram capacity
- Cans, moisture content
- Dishes, evaporating
- Funnel
- Mortar and pestle
- Pump, vacuum (optional)
- Stirrer, soil dispersion (optional)
- Thermometer, general laboratory

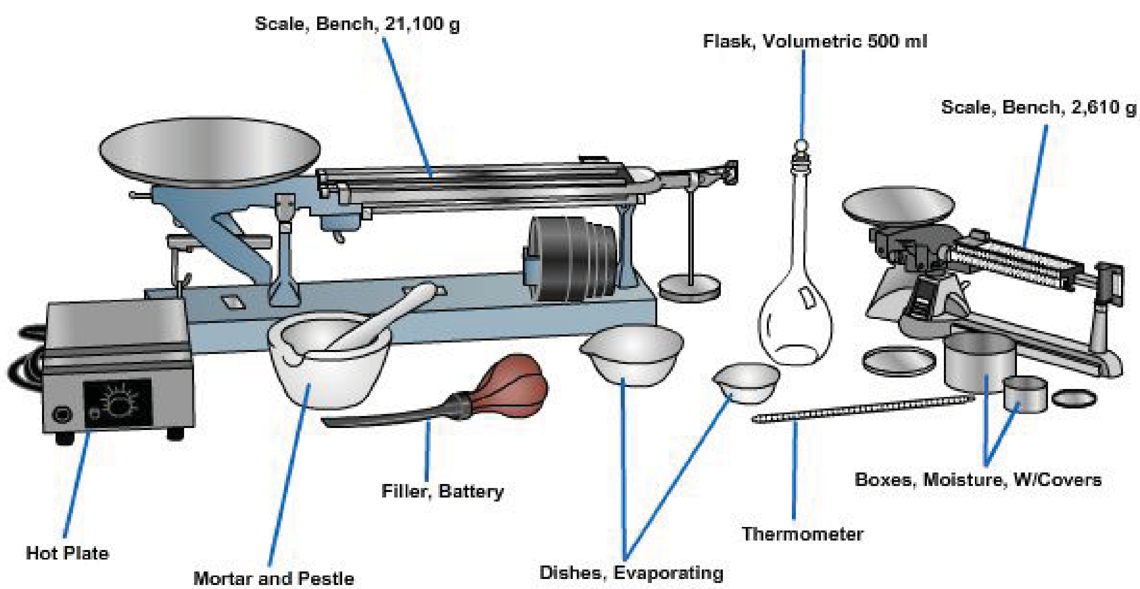

Figure 16-36 — Example of apparatus for determining specific gravity.

5.3.2.2 Procedure

To perform a specific gravity of solids test, use the following procedures. Refer to *Figure 16-37* for entries on DD Form 1208.

SPECIFIC-GRAVITY TESTS

1. PROJECT ENGINEERING CENTER EXPANSION		2. DATE 1 Dec
3. BORING NUMBER 5-C-1	4. JOB NUMBER 16-P-T	5. EXCAVATION NUMBER 5-C

6. SPECIFIC GRAVITY OF SOLIDS (G_s)

FLASK CALIBRATION DATA	a. FLASK NUMBER	b. CLEAN, DRY WEIGHT, W_b	c. FLASK + WATER WEIGHT, W_{bw}	d. OBSERVED TEMPERATURE, T_i
	#2A	171 Grams	668 Grams	25 °C

e. SAMPLE OR DETERMINATION NUMBER			5-C-1		
DETERMINATION DATA	f. DISH NUMBER		2A		
	g. WEIGHT OF DISH + DRY SOIL	Grams	308		
	h. WEIGHT OF DISH	Grams	270		
	i. WEIGHT OF DRY SOIL, W_s	Grams	38		
	j. WEIGHT OF FLASK + WATER + IMMERSED SOIL, W_{bws}	Grams	692		
	k. TEMPERATURE OF WATER, T_x	°C	23		
	l. CALCULATED WEIGHT OF FLASK + WATER AT T_x, W_{bw}	Grams	668		
	m. CORRECTION FACTOR FOR T_x, K		1		
n. SPECIFIC GRAVITY OF SOLIDS		$G_s = \frac{W_s K}{W_s + W_{bw} - W_{bws}}$	3		

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

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

8. REMARKS

9. TECHNICIAN *(Signature)* EACN Pineda, AP	10. COMPUTED BY *(Signature)* EACN Pineda, AP	11. CHECKED BY *(Signature)* EA 2 Johnson

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SAMPLE

Figure 16-37 — Example of data sheet for specific gravity. DD Form 1208.

- Calibrate volumetric flask (for course discussion, flask has been calibrated).
  - Record basic sample information and flask number (blocks 1-5; 6a).
  - Weigh clean, dry, flask to nearest 0.01 gram; record as Clean, Dry Weight W_b (block 6b).
  - Fill flask with room-temperature distilled water; ensure bottom of meniscus is even with calibration mark.
  - Weigh flask plus water; record as *Flask + Water Weight* W_{bw} (block 6c).
  - Determine water temperature to nearest whole degree, record as *Observed Temperature* T_i (block 6d).
  - Create graph or table for flask being used if additional specific-gravity determinations are to be made. (NAVFAC MO 330 provides additional guidance).
- Obtain soil sample for testing.
  - Separate sample over No. 4 sieve to obtain 100-gram sample passing sieve, or over No. 10 sieve to obtain 20-gram sample.
  - Discard material retained on sieve.
- Prepare sample for testing.
  - Record identifying sample information (blocks 6e, 6f).
  - Place – 4 or –10 sample into evaporating dish.
  - Perform following procedures for soil at natural water content or moisture; otherwise, go to next procedure for oven-dried sample:
    - Add distilled water to sample and mix to slurry.
    - Transfer slurry to flask and add distilled water until about three-fourths full.
  - Perform following procedures for oven-dried soil sample:
    - Oven-dry sample to a constant weight at temperature of 110°± 5°C.; allow cooling and weigh to nearest 0.01 gram; record as *Weight of Dish + Dry Soil* (block 6g).
    - Transfer dried sample to volumetric flask; avoid any particle loss.

      Fill flask three-fourths full with distilled water and allow to soak for 12 hours.
    - Weigh empty, dry evaporating dish; record as *Weight of Dish* (block 6h).
- Process sample through test method.
  - Remove entrapped air by bringing solution to a slow, rolling boil for 10 minutes, occasionally rolling flask to assist in air removal (ensure no loss of material occurs while boiling); cool to room temperature.
  - Fill flask with distilled water until bottom of meniscus is level with calibration mark.
  - Dry outside; thoroughly remove any moisture adhering to neck.

- Weigh flask and contents to nearest 0.01 gram; record as *Weight of Flask + Water + Immersed Soil* (W_{bws}) (block 6j).
- Shake flask immediately after weighing (put contents in suspension); determine water temperature at mid-depth to nearest degree; record as *Temperature of Water* (T_x) (block 6k).
- Determine dry unit weight for soil processed at natural moisture content:
  - Transfer soil solution from flask to pre-weighed pudding pan; record as *Weight of Dish* (block 6h). Use care when transferring all grains.
  - Oven-dry to constant weight at temperature of 110° ± 5°C; allow cooling; record as *Weight of Dish + Dry Soil* (block 6g).

- Compute results on DD Form 1208.(*Figure 16-37*)
  - Compute weight of dry soil (W_s) by subtracting weight of dish (block 6h) from weight of dish + dry soil (block 6g); record as *Weight Of Dry Soil* W_s (block 6i).
  - Determine weight of flask and water (W_{bw}) by plotting temperature of water (T_x) (block 6k) on calibration curve; record as *Calculated Weight of Flask + Water at* T_x, W_{bw} (block 6L). (If the calibration curve and graph were not produced, use the formula as indicated and record the result on the form.)

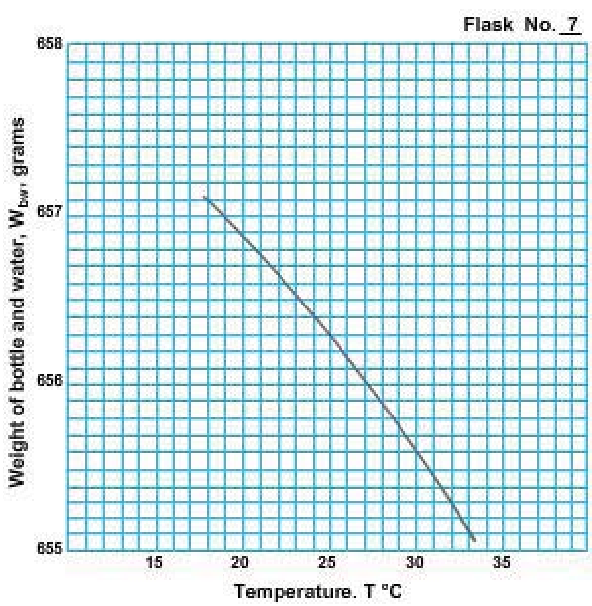


Figure 16-38 — Example of calibration curve for a volumetric flask.

$$W_{bw} = \left[\frac{P_w(T_x)}{P_w(T_i)} \, x \, \left[(W_{bw} \ at \ T_i) - W_b \right] \right] + W_b$$

Where:

$P_w(T_x)$ = density of water identified by temperature (T_x)

$P_w(T_i)$ = density of water identified by temperature (T_i)

W_{bw} = weight of flask and water in grams

W_b = weight of flask in grams

T_i = observed/recorded temperature of water in ºC

T_x = any other desired temperature, in ºC

  - Determine correction factor (K).
    - Locate temperature of water (T_x) (block 6k) in *Table 16-7*.
    - Read across to correction factor column; record as *Correction Factor for* T_x, K (block 6m).

Table 16-7 — Relative Density of Water and Correction Factor (K) at Various Temperatures.

TEMP ºC	RELATIVE DENSITY	CORRECTION FACTOR, K	TEMP ºC	RELATIVE DENSITY	CORRECTION FACTOR, K	TEMP ºC	RELATIVE DENSITY	CORRECTION FACTOR, K
18.0	0.99862	1.0004	23.0	0.99756	0.9993	28.0	0.99626	0.9980
18.5	0.99852	1.0003	23.5	0.99744	0.9992	28.5	0.99611	0.9979
19.0	0.99843	1.0002	24.0	0.99732	0.9991	29.0	0.99597	0.9977
19.5	0.99833	1.0001	24.5	0.99720	0.9990	29.5	0.99582	0.9976
20.0	0.99823	1.0000	25.0	0.99707	0.9988	30.0	0.99567	0.9974
20.5	0.99813	0.9999	25.5	0.99694	0.9987	30.5	0.99552	0.9973
21.0	0.99802	0.9998	26.0	0.99681	0.9986	31.0	0.99537	0.9971
21.5	0.99791	0.9997	26.5	0.99668	0.9984	31.5	0.99521	0.9970
22.0	0.99780	0.9996	27.0	0.99654	0.9983	32.0	0.99505	0.9968
22.5	0.99768	0.9995	27.5	0.99640	0.9982	32.5	0.99490	0.9967

- Compute specific gravity of solids to two decimal places using the following formula; record as *Specific Gravity of Solids* G_s (block 6n).

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

Where:

$W_s =$ dry weight of the sample

$K =$ correction factor based on the density of water at 20ºC Obtain the factor by selecting the correction factor corresponding the recorded temperature. (*Table 16-6*)

$W_{bw} =$ weight of the flask filled with water only at test temperature

Obtain this value from a calibration curve, or table, previously prepared for the flask used.

$W_{bws} =$ weight of the flask, water, and sample at test temperature

5.3.3 Bulk and Apparent Specific Gravity

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

To recap the definitions of Apparent Specific Gravity (G_a) and Bulk Specific Gravity (G_m):

Apparent Specific Gravity (G_a) — the ratio of the weight in air of a given volume of *the impermeable portion of soil particles* to the weight in air of an equal volume of distilled water, both at a stated temperature.

- The impermeable portion of a porous material, such as most large soil grains, includes the solid material plus impermeable pores or voids within the particles.

Bulk Specific Gravity (G_m) — the ratio of the weight in air of a given volume of *permeable material (including permeable and impermeable voids)* to the weight of an equal volume of distilled water, both at a stated temperature.

The following applies to the determination of both bulk and apparent specific gravity. Bulk specific gravity is usually determined for the coarser materials retained on a No. 4 sieve. Large stones may be determined individually.

For aggregates used in Portland-cement concrete, measure to determine the bulk specific gravity of the aggregates in a saturated, surface dry (SSD) condition. This is the condition in which the pores in each aggregate particle are filled with water and no excess water is on the particle surface.

This test method covers the specific gravity and absorption of coarse aggregate. The specific gravity may be expressed as apparent specific gravity, bulk specific gravity, bulk specific gravity SSD.

5.3.3.1 Sample Preparation

Prepare a representative sample by washing the material over the No. 4 sieve to remove dust and coatings and obtain a sample size; approximately 2 kilograms are required. Ensure the sample is representative.

5.3.3.2 Apparatus

- Balance, sensitive to 0.5 gram, capable of suspending the sample container in water from the center of the weighing platform or pan of the weighing device
- Wire sample basket or a bucket with a 4- to 7-liter capacity for 1 1/2-inch or smaller aggregate and a larger basket or bucket for larger aggregate sizes.
- Water tank large enough to hold the basket
- Volumetric Flask, 2 to 3 cubic feet
- Heat source (oven or hot plate)
- Metal sample container
- Metal spatula
- Absorbent towel

5.3.3.3 Procedure

Perform the test in the following order, recording weights to the nearest 0.5 gram. Refer to *Figure 16-37* again.

- Obtain representative sample.
- Record basic sample information (block 7a).
- Dry the sample to a constant weight at 110°C + 5°.
- Weigh container and record as *Tare* (block 7j).
- Weigh container and dry sample; record as *Tare and Dry Soil* (block 7i).

- Determine weight of dry soil by subtracting *Tare* (block 7j) from *Tare and Dry Soil* (block 7i); record as Dry Soil (A) (block 7k).
- Allow cooling to 50°C; immerse in water; soak at room temperature for 24 hours.
- Remove sample from water and roll in a large, absorbent cloth until all visible films of water are removed.
    - The surfaces of the particles will still appear to be slightly damp. The larger fragments may be wiped individually. When saturated surface is dry, the surface may still appear damp but take care to avoid excessive evaporation during the surface drying.
    - The aggregate sample is now in an SSD condition.
- Weigh saturated surface dry container and record as *Tare* (block 7d).
- Weigh container with saturated surface dry sample; record as *Tare + Saturated Surface Dry Soil* (block 7c).
- Determine weight of saturated surface dry sample by subtracting *Tare* (block 7d) from *Tare + Saturated Surface-Dry Soil* (block 7c); record as *Saturated Surface-Dry Soil (B)* (block 7e).
- Weigh wire basket in water; record as Wire Basket In Water (block 7g).
- Place sample in basket and immerse in water; hang basket and sample from balance and support so it hangs freely in water; record as *(Wire Basket + Soil) in Water* (block 7f).
- Determine weight of saturated soil sample by subtracting Wire Basket In Water (block 7g) from *(Wire Basket + Soil) in Water* (block 7f); record as *Saturated Soil in Water (C)* (block 7h).
- Measure temperature of water and soil; record in (block 7b).
- Compute Apparent Specific Gravity using following formula; record as *Apparent Specific Gravity* G_a (block 7l). $G_a = \frac{A}{A - C}$
- Compute Bulk Specific Gravity using following formula; record as *Bulk Specific Gravity* G_m (block 7m). $G_m = \frac{A}{B - C}$
- Compute Bulk Specific Gravity (SSD) using following formula; record as *Bulk Specific Gravity, Saturated Surface Dry (SSD)* G_m (block 7n). $G_m = \frac{B}{B - C}$
- Where : $A = weight\ of\ dry\ soil\ in\ air$
  $B = weight\ of\ SSD\ sample\ in\ air$
  $C = weight\ of\ SSD\ sample\ in\ water$

5.3.4 Specific Gravity of Composite Sample

After determining the specific gravity of solids (G_s) and the apparent specific gravity (G_a), the specific gravity of an entire soil sample (both larger and smaller than a No. 4 sieve) can be calculated with the following formula:

$$G = \frac{100}{\frac{\% \text{Passing No.4 sieve}}{G_s} + \frac{\% \text{Retained on No.4 sieve}}{G_a}}$$

Enter this composite specific gravity, along with the percent of materials retained on, or passed through the No. 4 sieve, in the remarks block of the data sheet.

5.3.5 Comment Regarding Correction Factor (K)

Refer again to *Figure 16-37*. There you will see the (K) value used *(0.9993)* from *Table 16-6* and the results obtained by using the correction factor in calculating G_s (block 6n). Carried to four decimal places, $G_s = 2.6256$.

If you were to disregard (K) and recalculate, you would obtain $G_s = 2.6238$.

The value obtained without the correction factor is hardly different from the value obtained with the correction factor. Therefore, unless unusually accurate precision is required, you may disregard the correction factor.

5.4.0 (Atterberg Limits) Liquid Limit, Plastic Limit, Plasticity Index Determination (ASTM 4318-95A)

If the proper amount of water is present, clays and some other fine-grained soils exhibit plasticity. A plastic soil can be deformed beyond the point of recovery without cracking or exhibiting a change in volume and be remolded.

The liquid limit (LL) is that point at which the material contains the greatest water content and remains plastic; additional water causes it to become a thick liquid.

The plastic limit (PL) is that point at which the material contains the lowest water content and remains plastic; less water causes it to become brittle and break into fragments if remolding is attempted.

The plasticity index (PI) is the numerical difference between the LL and the PL, expresses as:

$$PI = LL - PL$$

A large PI indicates a very plastic soil; a small PI denotes a soil with little plasticity.

As water content decreases below the PL, the soil mass shrinks and becomes stiffer. The shrinkage limit (SL) is that point at which, with further drying, shrinkage stops.

No sharp distinction identifies the liquid, plastic, and solid brittle states of consistency, so standardized procedures have been established for determining the LL and PL. These consistency limits, as well as the shrinkage limit, are called the Atterberg limits, named for Albert Atterberg, a Swedish chemist who did the initial work on soil plasticity.

However, since tests in this course determine only the LLs and PLs and not the SLs, they are not identified as the Atterberg limits.

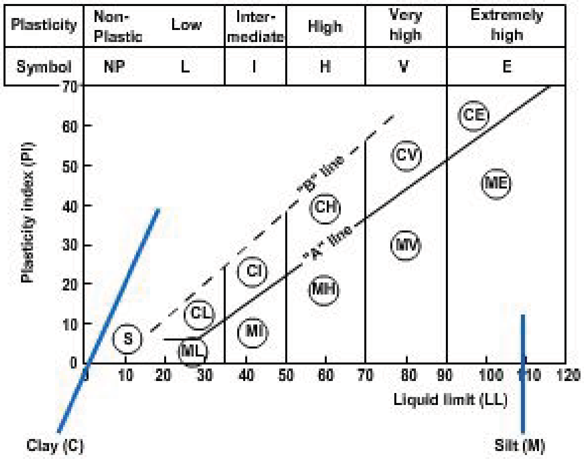


Figure 16-39 — Example of a plasticity chart.

Research with large numbers of clay soils established the soil plasticity chart for laboratory classification of fine-grained soils, an example of which is shown in *Figure 16-39*.

The LL and PI values are coordinates that locate a particular soil sample on the chart.

The region on the chart in which the sample falls gives the classification based on the behavioral characteristics of the particular soil.

Take particular care when performing tests. Some soils, particularly those with a high organic content, can provide inconsistent readings or drastic differences between an oven-dried sample and a sample at natural moisture content.

Conduct the following tests on samples of natural moisture content. Determine the moisture content at the end of the test.

5.4.1 Apparatus-Test Equipment

A Liquid Limit testing device consists of a brass bowl mounted on a box type apparatus with a crank. (*Figure 16-40*) When the crank is turned, the device elevates and drops the bowl (containing a sample) a specific distance onto a hard rubber anvil centered under the bowl. Each drop is called a "blow."

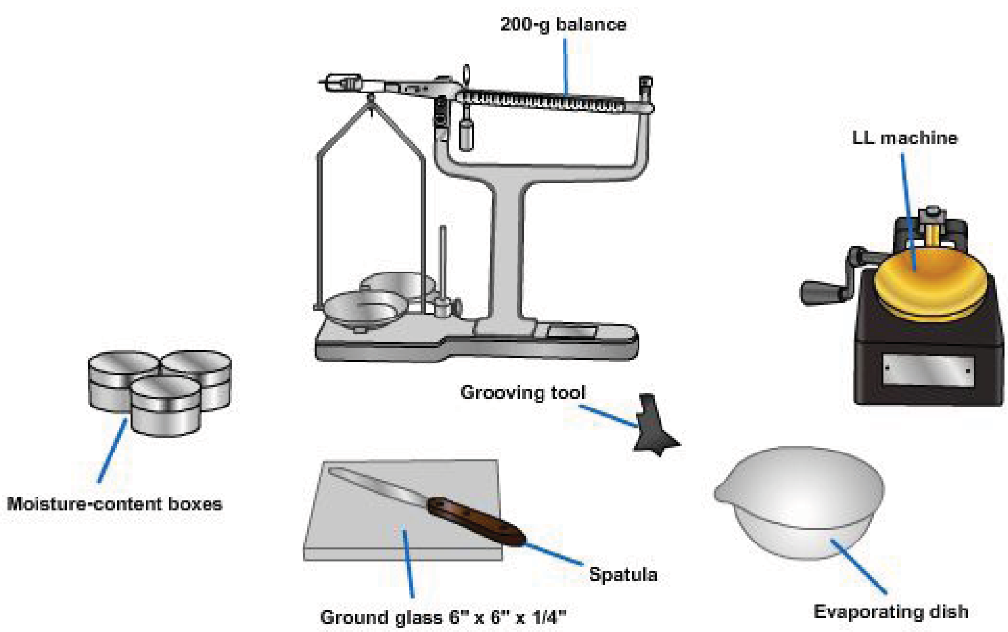


Figure 16-40 — Example of apparatus for LL & PL testing.

The test requires the standard support equipment of scale, moisture-content (tare) cans, and evaporating dish, as well as the LL device. *Figure 16-41* provides a more detailed description of an LL device.

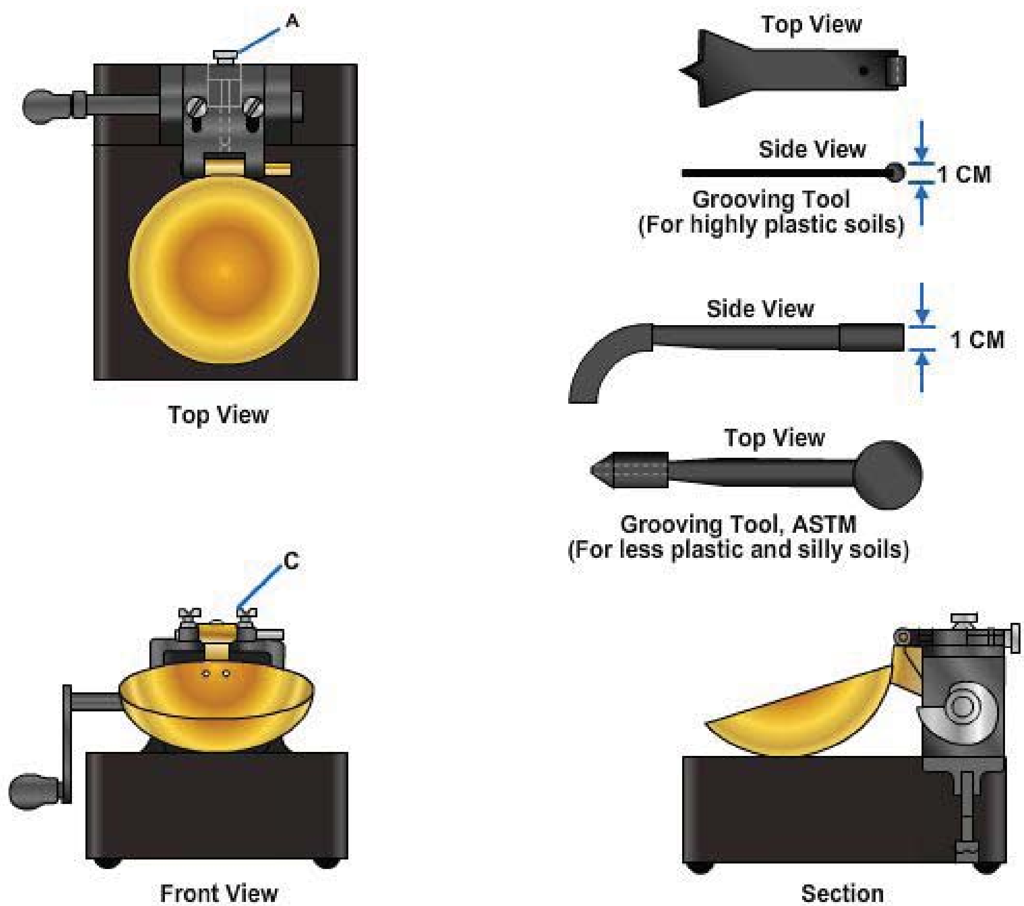


Figure 16-41 — Example of Liquid Limit device with grooving tools.

5.4.2 Procedure (Liquid Limit LL)

- Prepare soil sample.
  - Sieve soil sample (at natural moisture content) over No. 40 sieve; obtain at least 250 grams.
  - If little or no material is retained on No. 40 sieve:
    - Collect 200 to 250 grams of –40 material for testing.
    - Mix material with distilled water until water content is slightly below LL, about peanut butter consistency. (The goal is to have the material fall in the 25- to 35-blow range for the first test.)
    - Place mixture in airtight plastic bag for at least 16 hours (overnight) so moisture content can become consistent throughout; remix material thoroughly before testing.
  - If material is retained on No. 40 sieve:
    - Place –40 material in airtight plastic bag to maintain natural moisture content.

- Soak coarse material retained on No. 40 sieve. (Soaking time is variable.)
- Rub ***colloidal*** [k*uh*-**loid**-l] material from surfaces of large particles until clean, placing fines in suspension.
- Pour off suspended fines slowly into another pan; be careful not to pour off coarse material.
- Add clean water to coarse material and repeat wash process until poured off water is sufficiently clear to indicate majority of fines in suspension have been poured off.
- Remove excess water from pan containing suspended fines after fines have settled by decantation and evaporation. (Do not oven-dry or add chemical substances to speed dry or hasten the settlement.)
- Oven-dry coarse material that was soaked and washed.
- Sieve oven-dried coarse material over No. 40 sieve.
- Combine –40 material obtained from plastic bag, decanted and evaporated fines, oven dried material sieved over No. 40.
  - If combined material is too moist, air-dry until water content is slightly below LL.
  - If combined material is too dry, add small quantities of water until water content is slightly below LL (peanut butter consistency).
- Place combined mixture in airtight plastic bag for at least 16 hours (overnight) so the moisture content can become consistent throughout; remix material thoroughly before testing.

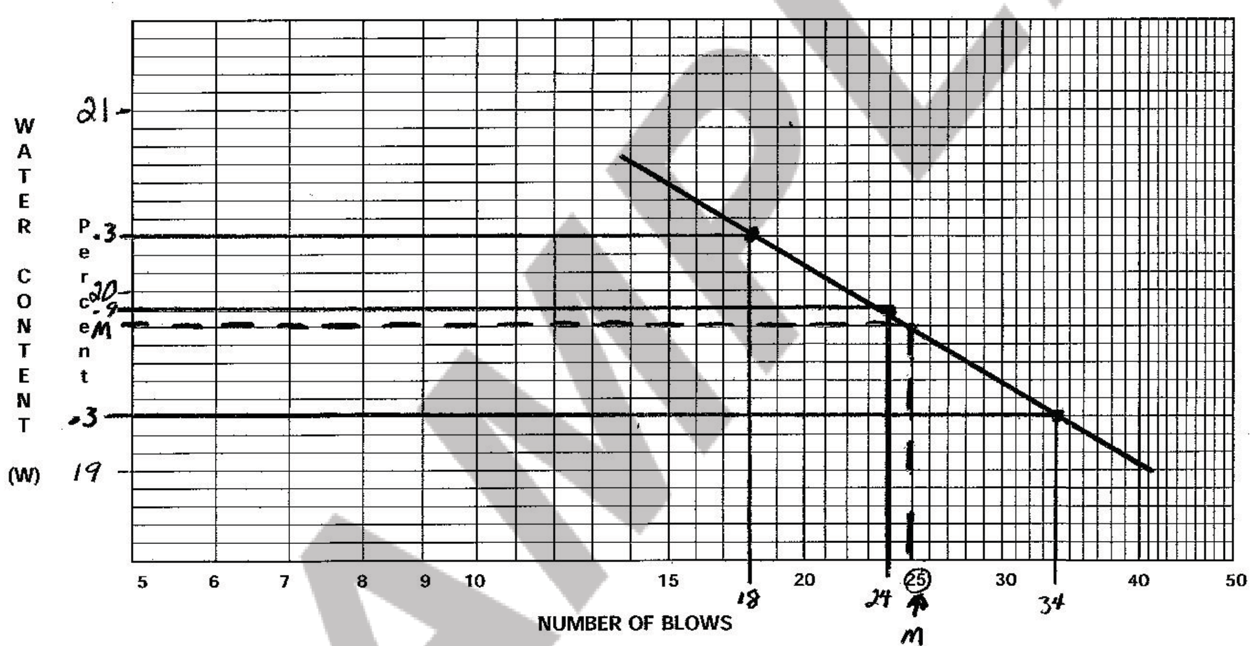
- Inspect LL device.
  - Ensure pin connecting cup is not worn permitting side play.
  - Ensure screws connecting cup to hanger arm are tight.
  - Check cup for wear; if grooved from use, replace it.
  - Check contact between cup and base; if flat on cup or dent in base can be felt, replace or repair.
  - Check grooving tool for wear.
  - Check cup drop height so point on cup meeting base (not lowest point of the cup) rises to a height of 1 centimeter; use gauge on handle of grooving tool to assist. (The height of the drop must be 1 centimeter. Use the thumbscrew at the rear of the device to make an adjustment.)
- Perform LL test. Refer to *Figure 16-42* DD Form 1209.
  - Obtain about 50 grams of 200- to 250-gram prepared sample; place in airtight container for use in PL test.
  - Record all identifying sample information on DD Form 1209 (blocks 1-5).

LIQUID- AND PLASTIC-LIMITS DETERMINATION

1. PROJECT ENGINEER CENTER EXPANSION		2. DATE 3 Dec
3. EXCAVATION NUMBER 5-C	4. JOB NUMBER 16-P-T	5. SAMPLE NUMBER 5-C-1

6. LIQUID LIMIT, LL

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



7. PLASTIC LIMIT, PL

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

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

9. TECHNICIAN (Signature)	10. COMPUTED BY (Signature)	11. CHECKED BY (Signature)
EA2 Billings	EA2 Billings	EA1 Barnes

DD FORM 1209, DEC 1999 PREVIOUS EDITION IS OBSOLETE. Adobe Professional 7.0

Figure 16-42 — Example of data sheet for LL & PL determinations. DD Form 1209.

- Label and pre-weigh three empty moisture-determination tares (boxes); record as *Weight of Tare* (block 6d).

- Place 20 to 25 grams of thoroughly mixed sample into brass cup, and level it off with a maximum depth of 1 centimeter. *(Figure 16-43*)

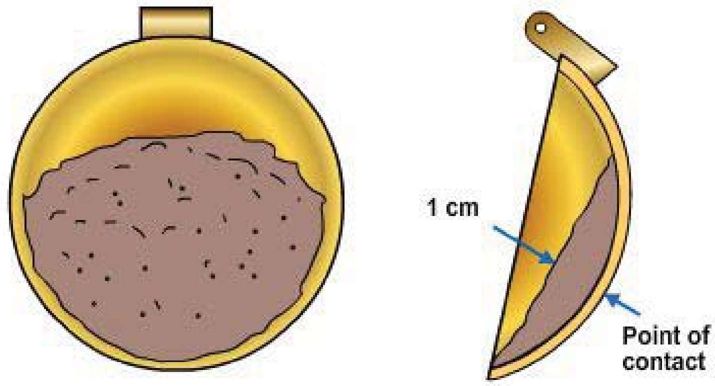


Figure 16-43 — Example of leveling LL sample into cup.

- Divide sample in cup with grooving tool so a clean, sharp groove is formed. *(Figure 16-44*)

Hold cup with cam follower upward and draw grooving tool (beveled edge forward) through specimen downward away from cam follower.

Use more than one stroke but no more than six; clean grooving tool's cutting edge after each stroke.

Avoid tearing side of groove; replace sample and regroove if side tears.

Figure 16-44 — Example of cup and grooving tool.

With some sandy and highly organic soils, it is impossible to draw the grooving tool through the specimen without tearing the sides of the groove. In such cases, the groove should be made with a spatula, using the grooving tool only for a final check of the groove). (*Figure 16-45)*

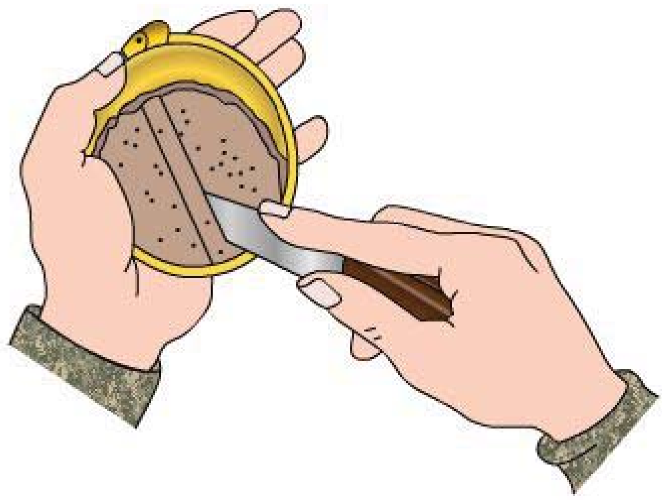


Figure 16-45 — Example of cutting groove with spatula in sandy soil.

- Attach cup to device; ensure height of drop is 1 centimeter.
- Turn crank of LL device at two revolutions per second; count blows until sample's halves make contact at bottom of groove along a distance of 13 millimeters (1/2 inch.) *(Figure 16-46)*

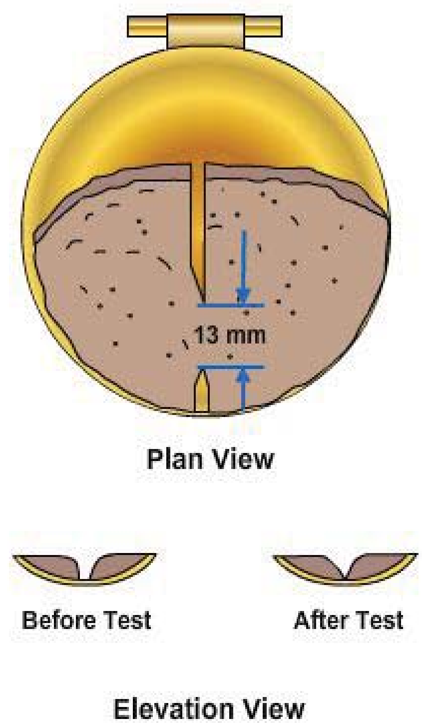


Figure 16-46 — Example of sample contact.

- Record number of blows to close groove 13 millimeters.

- Obtain 5 to 10 grams from cup to determine moisture content; take sample perpendicular to groove from edge of cup through portion that has closed in bottom of groove, as shown in *Figure 16-47*. Place in pre-weighed box; cover with lid; weigh and record as *Weight of Wet Soil + Tare* (block 6a).

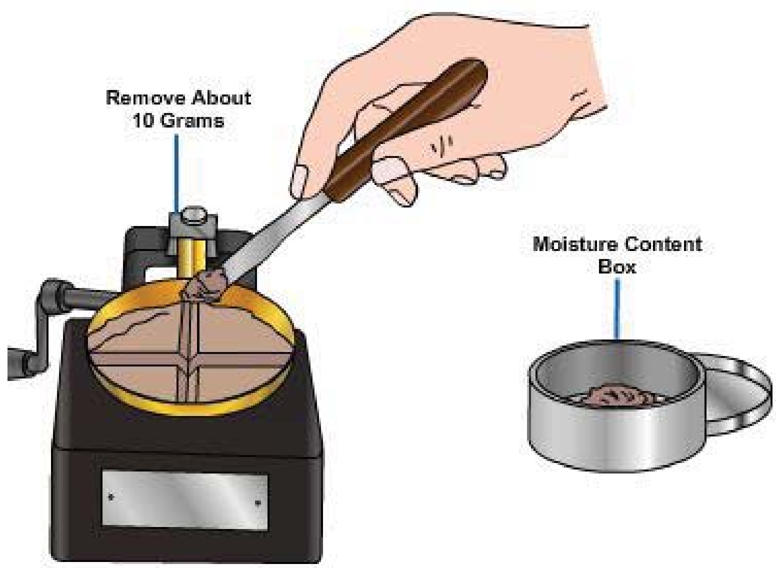


Figure 16-47 — Example of removing sample for moisture determination.

- Transfer remaining cup soil to mixing dish; wash and dry cup and grooving tool.
- Remix entire soil specimen; add a little water to increase water content of sample and decrease number of blows required to close groove. Repeat steps for at least two additional trials, producing successively lower number of blows to close groove.
- Oven-dry moisture-determination samples (3 minimum); allow to cool, reweigh and record as *Weight of Dry Soil + Tare* (block 6b).
- Determine weight of water (W_w) by subtracting *Weight of Dry Soil + Tare* (block 6b) from *Weight of Wet Soil + Tare* (block 6a); record as *Weight of Water* $W_w = a - b$ (block 6c).
- Determine weight of dry soil (W_s) by subtracting *Weight of Tare* (block 6d) from *Weight of Dry Soil + Tare* (block 6b); record as *Weight of Dry Soil* $W_s = b - d$ (block 6e).
- Determine and record water content for each specimen by computing following formula:

$$W = \frac{W_w}{W_s} x100$$

- Plot water-content points on Form 1209 semilog graph (water versus number of blows); draw a straight line (flow line) representative of sample (3 minimum) points.

- Determine LL by interpreting the graph where the flow line intersects the 25-blow line. Record LL to nearest whole number (block 8 LL).

5.4.3 Procedure (Plastic Limit PL)

The PL of a soil is the water content, expressed as a percentage of weight of oven-dried soil, at which the soil begins to crumble when rolled into a thread millimeters in diameter. About 50 grams of material are required for the PL test.

Perform the following steps to determine the PL. Refer again to *Figure 16-42* DD Form 1209

- Label and pre-weigh two empty moisture-determination tares (boxes); record as *Weight of Tare* (block 7d).
- Obtain 50-gram sample set aside during LL test; reduce water content (if required) to obtain consistency whereby the sample can be rolled without sticking to hands while spreading or mixing continuously on glass plate. Drying process may be accelerated by air-drying only.
- Select about 2 grams (marble size) from 50-gram mass; form test specimen into ellipsoidal mass; roll on a finely ground glass plate with fingers or palm of hand to a uniform thread diameter of 3.2 millimeters (1/8 inch), taking no more than 2 minutes. *(Figure 16-48)*
  - Rolling rate should be 80 to 90 strokes per minute; count a stroke as one complete motion forward and back to starting position; rate may have to decrease for very fragile soil.

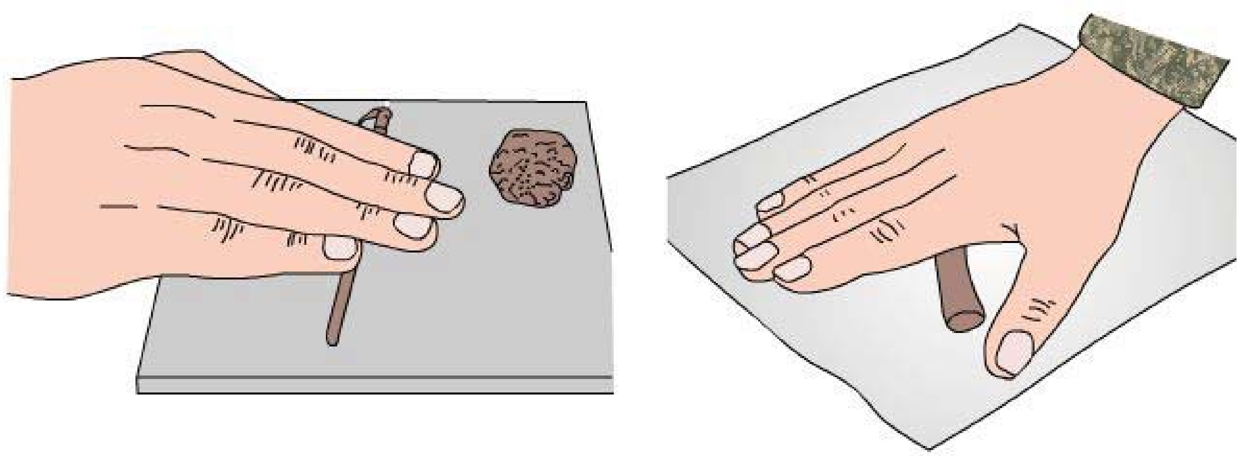


Figure 16-48 — Example of rolling Plastic Limit (PL) sample by fingers or palm.

- Remold and roll again to 3.2 millimeters diameter; repeat until total sample crumbles before reaching the 3.2-millimeters-diameter thread. *(Figure 16-49*)
    - Rolled sample may not crumble at same time; if thread breaks into smaller lengths, roll each length to 3.2 millimeters; continue until sample can no longer be remolded and rolled to 3.2-millimeter thread without total break-up.

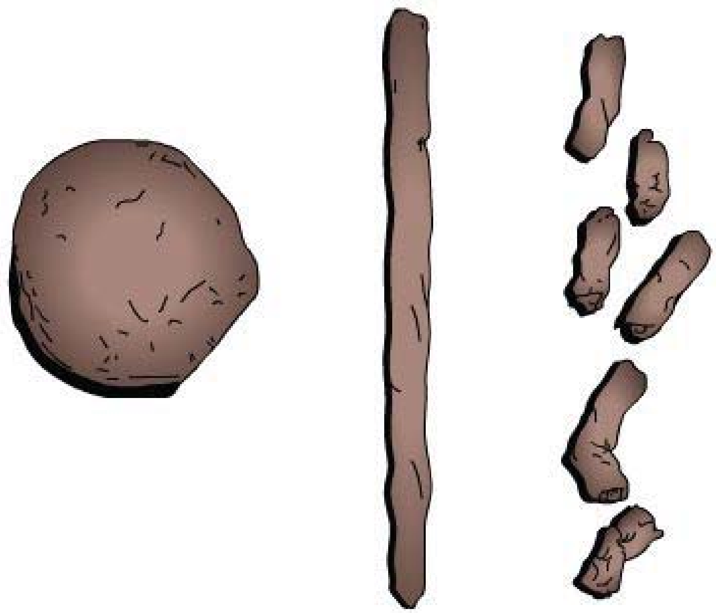


Figure 16-49 — Example of PL sample roll/thread test before and after crumbling.

- Collect and place crumbled portions into pre-weighed moisture-determination box and cover with lid.
- Repeat until crumbled threads in box weigh at least 6 grams.
- Repeat steps to obtain a second box of at least 6 grams of material.
- Weigh boxes with crumbled threads; record as *Weight of Wet Soil* + *Tare* (block 7a).
- Determine water content by following steps of LL test.
    - Oven-dry moisture-determination samples (2 minimum); allow to cool, reweigh and record as *Weight of Dry Soil* + *Tare* (block 7b).
    - Determine weight of water (W_w) by subtracting *Weight of Dry Soil* + *Tare* (block 7b) from *Weight of Wet Soil* + *Tare* (block 7a); record as *Weight Of Water* $W_w = a - b$ (block 7c).
    - Determine weight of dry soil (W_s) by subtracting *Weight of Tare* (block 7d) from *Weight of Dry Soil* + *Tare* (block 7b); record as *Weight of Dry Soil* $W_s = b - d$ (block 7e).
    - Determine and record water content for each specimen by computing following formula:

$$W = \frac{W_w}{W_s} x100$$

- Determine average water content of samples and record to nearest tenth as PL.

- When determining average water content, individual tests must be within ± 1 percent of mean; any individual test not meeting this requirement will not be used (*Figure 16-42 Tare Number 5-P*); if no individual test meets this requirement, additional testing is required

5.4.4 Plasticity Index (PI) Determination

- Compute plasticity index using following formula:

$$PI = LL - PL$$

  - Record as $(LL - PL) \quad PI =$ (block 8 PI)
- Classify soil by plotting LL versus PI on plasticity chart as follows, referring to *Figure 16-50*.
  - Material plotted on or above A line is classified as clay; material plotted below A line is classified as silt.
  - Material plotted on or right of 50 percent line has a high LL (H); material plotted left of 50 percent line has a low LL (L).
  - Upper, or U, line is an approximate upper boundary; although not impossible, any results plotted above U line should be considered suspect and tests rechecked.

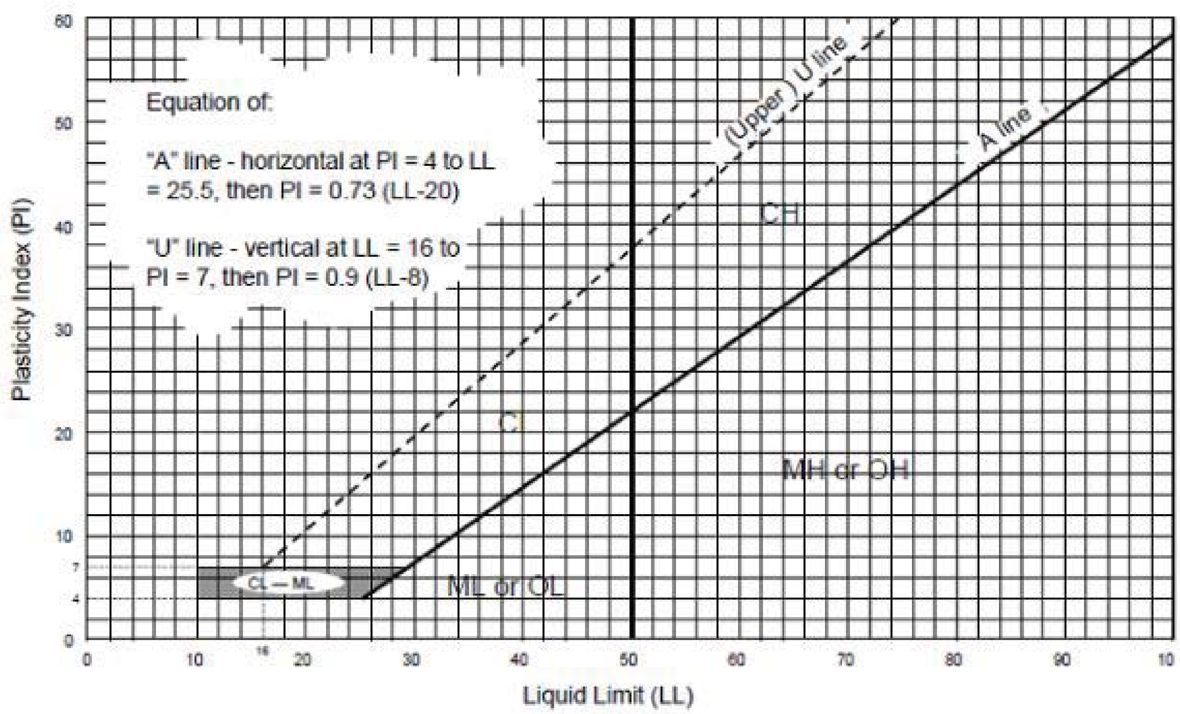


Figure 16-50 — Example of USCS Plasticity Index chart for soil classification.

Test your Knowledge (Select the Correct Response)

5. The Navy follows _____ procedures to test representative soil samples.

   A. American National Standards Institute (ANSI)
   B. National Institute for Standards and Technology (NIST)
   C. National Standards Body (NSB)
   D. American Society for Testing Materials (ASTM)

6.0.0 CONCRETE TESTING

Chapter 8 of this course provides information about concrete and its use in the construction industry. You may recall that concrete is one of the most economical, versatile, and universally used construction materials, as well as one of the few building materials that a user can produce directly on the job to meet the specific requirements.

To combine the ingredients correctly (on the job site or nearby), you must know the required physical properties of both the plastic and the hardened concrete. The hardened concrete must have the following:

- Strength
- Workability
- Uniformity
- Durability
- Watertightness
- Consistency

The quality and character of the hardened concrete is greatly influenced by the properties of the mix when it is plastic. To attain optimum quality, the plastic mix must be uniform, consistent, and workable while meeting the specified requirements.

Concrete testing is directed toward those properties and specified requirements.

6.1.0 Concrete Tests

In concrete testing, as in soils testing, no single test can provide all of the required information. Therefore, an array of tests must be performed to gather specific data.

The following describes common tests that you may perform as an Engineering Aid.

6.1.1 Aggregate Tests

An aggregate must provide maximum strength and durability in a concrete mixture. Fineness, coarseness, and aggregate gradation are factors considered when deriving the correct concrete mix for a specific construction purpose. Specific gravity, absorption, and moisture also affect the aggregate's ability to bind well with cement and water in a concrete mix.

The components of the final mix (cement, water, and aggregate) must bond adequately for structural strength and must resist weather and loads.

Correct aggregate selection also reduces the project's cost. An engineering analysis determines the aggregate best suited for a particular purpose. *(Table 16-8)*

Table 16-8 — Example of Maximum Recommended Sizes of Coarse Aggregate.

Structure	Minimum Dimension (Inches)			
	2 1/2 to 5	6 to 11	12 to 29	30 or More
Reinforced walls, beams, and columns	1/2 to 3/4	3/4 to 1 1/2	1 1/2 to 3	1 1/2 to 3
Unreinforced walls	3/4	1 1/2	3	6
Slabs, heavily reinforced	3/4 to 1	1 1/2	1 1/2 to 3	1 1/2 to 3
Slabs, lightly reinforced	3/4 to 1 1/2	1 1/2 to 3	3	3 to 6
NOTE: Maximum size not to exceed 1/5 of minimum dimension of a wall or similar structure, 1/3 of slab thickness for horizontal slab, or 3/4 of minimum clear spacing between reinforcing bars.				

In order to provide the strongest and most durable concrete, the aggregate contained in the mixture must be the best possible in terms of gradation, shape, strength, and cleanliness. Testing allows the best selection.

These include tests for stockpile sampling, gradation, specific gravity, absorption, and surface moisture. These tests are not included in this course, but you can learn more about aggregate testing in NAVFAC MO-330 *Materials Testing.*

6.1.2 Slump Tests

"Workability" describes the relative ease or difficulty of placing and consolidating concrete. During placing, concrete should be as stiff as possible as a homogeneous, voidless mass. However, too much stiffness makes it too difficult or impossible to work into forms and around reinforcing steel. Too fluid a mixture is also detrimental.

The measure of concrete's workability is its slump, which is a design consideration inversely proportional to the stiffness of the mix.

As shown in *Table 16-9*, recommended values for slump vary for different types of construction.

Table 16-9 — Recommended Slumps for Various Types of Construction.

Types of construction	Slump, inches*	
	Maximum	Minimum
Reinforced foundation walls and footings	5	2
Plain footings, caissons, and substructure walls	**4**	**1**
Reinforced slabs, beams, and walls	**6**	**3**
Building columns	**6**	**3**
Pavements	**3**	**2**
Heavy mass construction	**3**	**2**
Bridge decks	**4**	**3**
Sidewalks, driveways, and slabs on ground	**6**	**3**
*When high-frequency vibrators are used, the values may be decreased approximately one-third; in no case should the slump exceed 6 inches.		

To measure this designed inverse proportion between stiffness and workability, testers typically perform slump tests during project preparation as concrete mix trial batches and as quality control during construction. Procedures for performing slump tests will be explained later in this chapter.

6.1.3 Strength Tests

Engineers, by a combination of concrete design mix and reinforcing (if necessary), must balance the strength of concrete (compressibility) with its weakness (flexibility). A project's design mix must meet the structure's intended force loading on a given element.

Often, trial batches are prepared for a mix design test and as the project progresses, for a quality control (QC) measure to ensure that concrete mixed on site or delivered to the field satisfies those specified strengths. These mix design and QC trial batches are then subjected to the following tests.

6.1.3.1 Compression Test (ASTM C39 / C39M)

Compression tests are conducted to determine a mix design's ability to resist a crushing force.

In a standard compression test, a load is applied *parallel to the longitudinal axis* of a pre-molded and properly cured concrete cylinder of a specified standard size. (*Figure 16-51*)

A properly conducted test calculates the maximum compression load in pounds per square inch (psi) that the mix design, or QC sample, can obtain at the point the cylinder ruptures.

Figure 16-51 — Example of concrete cylinder compression test.

The test procedures themselves will be covered in EA Advanced, but the procedures for preparing the cylinders for testing will be discussed later in this chapter.

6.1.3.2 Flexural Strength Test (ASTM C 78)

Flexural strength (modulus of rupture) tests are conducted to determine a concrete's ability to resist a breaking force.

In a standard flexural test, a load is applied *perpendicular to the longitudinal axis* of a standard size, pre-molded, and properly cured concrete beam. (*Figure 16-52*)

From this test, the flexural strength, expressed in terms of modulus of rupture and given in psi, can be readily calculated.

Figure 16-52 — Example of flexural strength test.

As with the compression test, only the procedures to prepare the test beams will be discussed in this course.

6.2.0 Slump Tests

The slump test is performed on newly mixed concrete.

To perform the test, you need a slump cone and a tamping rod. *(Figure 16-53*)

The slump cone should be galvanized steel, 12 inches in height, with a base opening 8 inches in diameter and top opening 4 inches in diameter.

The top and bottom openings are perpendicular to the vertical axis of the cone.

The tamping rod is a straight steel rod 5/8 inches in diameter and approximately 24 inches in length.

One end of the rod is rounded to a diameter of 5/8 inches. (Do not substitute a piece of rebar.)

Figure 16-53 — Example of sump test equipment.

6.2.1 Sampling Procedures (ASTM C172)

Obtaining a concrete sample for a slump test should be accomplished according to ASTM C172 *Standard Practice for Sampling Freshly Mixed Concrete*.

This course will present only the procedure for sampling from a revolving drum transit mixer (TM) or agitator. If you ever need to obtain a sample from a paving mixer, open-top truck mixer, or other type of equipment, refer to the most recent ASTM C 172.

Samples taken for the test specimens must be representative of the entire batch. Accomplish this by taking partial samples at two or more regularly spaced intervals during discharge of the middle portion of the batch.

Pass a scoop or pail repeatedly through the entire discharge stream and combine the partials into one sample for testing purposes.

Be sure the first and last portions of the combined samples are taken as quickly as possible while still representing the entire batch, but never exceeding 15 minutes to gather the combined samples.

If it is necessary to transport samples away from the mixer to another location where the slump test is to be performed, combine the samples and remix them with a shovel to ensure uniformity.

6.2.2 Testing Procedures (ASTM C 143)

Perform slump tests according to ASTM C143 / C143M *Standard Test Method for Slump of Hydraulic-Cement Concrete.* Be sure to start the test within 5 minutes after obtaining the final portion of the composite sample.

Perform the following steps to determine the slump:

- Moisten inside of slump cone and place it on a flat, moist, nonabsorbent (rigid) surface. Hold in place during filling by standing on two foot pieces.

NOTE: Complete the following steps in an elapsed time of no more than 2 1/2 minutes.

- Fill slump cone to one-third volume (2 5/8 inches high) with plastic concrete.
- Rod concrete by applying 25 evenly distributed strokes; penetrate full depth of first layer.
- Add second layer until two-thirds volume filled (about 6 1/8 inches high).
- Rod second layer as first with rod just penetrating underlying first layer.
- Add third and last layer; overfill if possible.
- Rod third layer as second with rod just penetrating underlying second layer; if height subsides below top of cone, add concrete to keep above top of mold.
- Strike off excess concrete with tamping rod in screeding and rolling motion so cone is completely filled.
- Remove slump cone from concrete.
    - Place hands on handles and press downward.
    - Step off footholds.
    - Raise cone carefully and quickly in vertical direction.
        - Raise cone a distance of 12 inches within 5 to 7 seconds by a steady upward lift with no lateral or twisting motion.

- Place cone directly beside slumped concrete.
    - At this point, about 2 1/2 minutes should have elapsed since start of filling.

- Measure and record slump immediately, as shown in *Figures 16-54 and 16-55*.
    - Place tamping rod along top of cone so it projects over concrete.
    - Measure slump from bottom of rod to top center of concrete with a ruler.
    - Record slump to nearest ¼ inch.

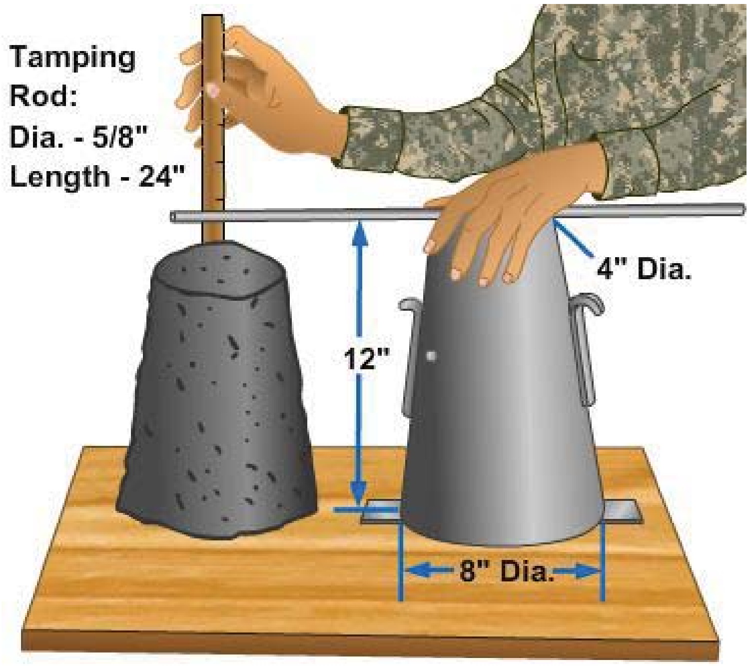


Figure 16-54 — Example of measuring slump.

Figure 16-55 — Seabee performing slump test.

If a decided falling away or shearing off occurs from one side or portion of the specimen mass, disregard the measurement and make a new test on another portion of the sample.

If two consecutive tests show falling away or shearing off, the concrete probably lacks the necessary plasticity and cohesiveness for the slump test to be applicable.

After measuring and recording to the nearest ¼ inch, the slump test is complete. However, as a supplementary procedure, tap the sides of the specimen gently with the tamping rod. The reaction of the concrete will indicate its cohesiveness and workability.

A well-proportioned, workable mix gradually slumps to lower elevations and retains its original identity. A poor mix crumbles, segregates, and falls apart.

If a slump test is for a mix design's trial batch, then too little or too much slump indicates the need for a new trial batch with revised mix proportions.

When the test is for a quality control measure, the slump obtained by testing will be compared to the slump specified for that particular project or element of that project. If QC testing reveals too little or too much slump, the quality control inspector or other appropriate authority will need to determine whether to accept or reject the concrete.

6.3.0 Preparation of Concrete Specimens

Concrete specimens representative of a distinct batch of concrete must be sampled and analyzed for quality control. The number of specimens tested depends on the job specifications. If no requirement is listed in the specifications, a minimum of 2 will be molded for each test age for each 100 cubic yards, or fraction thereof, of each class of concrete placed in any one day.

A third specimen may be taken to assist in determining when forms may be removed. The test specimens must remain on site and undisturbed for an initial curing period (the first 16 to 48 hours after molding). Normally the test ages are 7 and 28 days for compressive strength tests.

6.3.1 Cylinder Specimens

Concrete cylinder specimens are taken to perform tests evaluating the compressive strength of the concrete. (*Figure 16-56*)

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.

At least two cylinders are required to constitute a test. Therefore, a minimum of four specimens are required if tests are to be made at 7 and 28 days.

The test results will be the average of the strengths of the two specimens tested at 28 days.

The standard cylindrical specimen is 6 inches in diameter by 12 inches long.

Figure 16-56 — Typical concrete cylinder mold.

6.3.1.1 Standards for Cylinder Molds

Figure 16-57 — Seabee making typical concrete cylinder molds.

Cylinder molds should be made of steel, cast iron, or other nonabsorbent material that does not react with concrete containing Portland cement or other hydraulic cements.

Molds should hold their dimensions and shapes under severe use.

They should hold water poured into them without leakage. (*Figure 16-57*)

6.3.1.2 Filling Cylinder Molds

Place the molds on a level, rigid surface, free of vibration or other disturbances, at a place as near as possible to the location where they are to be stored for the first 24 hours.

Perform the following steps to produce and label a concrete cylinder for testing:

- Prepare mold.
  - Clean and dry.
  - Oil lightly.
  - Assemble.
- Make cylinder.
  - Fill mold one-third full with fresh concrete.
  - Consolidate concrete by applying 25 evenly distributed strokes over mold's surface area with tamping rod; rod must totally penetrate layer.
  - Tap side of mold 8 to 10 times with tamping rod.
  - Add concrete to two-thirds full.
  - Apply 25 evenly distributed strokes to mold's surface area using rounded end of tamping rod; rod must pass through second layer and 1 inch into first layer.
  - Tap side of mold 8 to 10 times with tamping rod.
  - Add concrete to slightly overfill.

- Apply 25 strokes; rod must pass entirely through and 1 inch into second layer.
- Tap side of mold 8 to 10 times with tamping rod.
- Trowel off concrete so it is flush with top of mold and smoothly finished.

- Label mold; as a minimum, label should include:
  - Specimen number.
  - Date cylinder was made.
  - Project or placement concrete came from.
    - The system of labeling is optional. The information should be recorded on a paper tag or gummed label and attached to the mold.
- Cover cylinder with plastic or wet burlap to maintain moisture; covering should be tight around cylinder but not make contact with fresh concrete.
- Allow cylinder to cure undisturbed for 24 hours.
- Remove covering and mold from cylinder after 24 ($\pm$ 8) hours.
- Transfer label from mold to concrete cylinder; label may be transferred or information recorded directly on cylinder with grease pencil.
- Cure cylinder.

6.3.1.3 Curing and Storing Cylinders

During the initial curing period of test specimens, be sure to take precautions to prevent the evaporation and loss of water in the specimens. After an initial curing period of16 to 48 hours, remove specimens from the job site that are intended for checking the strength of trial design mixtures or QC of field concrete.

Take them to the testing laboratory, moist-cure them at 73.4°F, and store them in moist rooms, damp sand or sawdust, or limewater to maintain free water on all surfaces of the specimen at all times.

Occasionally, some test specimens are made in the field to determine when forms may be removed. These specimens are in addition to the required number of specimens formed for strength determination. Give these specimens (as much as possible) the same protection as the specimens for compression testing. Store them in or on the structure as near as possible to the point of use. Test them in the moist condition resulting from the specified curing treatment.

Specimens intended for testing to determine when a structure may be put into use are removed from the molds at the same time the forms are removed from the structure.

To ship specimens to a laboratory, pack them in a sturdy wooden box or other suitable container surrounded by wet sawdust or wet sand. Provide protection from freezing during storage or shipment. Moist curing is continued when the specimens are received in the laboratory.

6.3.1.4 Capping Cylinders

To prepare cylinders for testing, plane the ends of compression-test specimens within 0.002 inch and within 0.5 degree of being perpendicular to the axis of the cylinder.

- 2 to 4 hours after molding, cap specimens formed in strong metal molds having accurately flat baseplates.

- Make a stiff paste of Portland cement and water at time cylinder is molded so capping mixture will shrink before application.
- Remove any free water or laitance (layer of fine particles on surface) from end of specimen.
- Apply paste to top of concrete and work with a flat plate until smooth and level with top of mold.

Grind hardened concrete specimens to smooth the ends or cap them with a material having greater compressive strength than the concrete.

- Prepared mixtures of sulfur and granular materials, special high-strength gypsum plasters, and neat high-early strength cement are satisfactory capping materials.
- Ordinary low-strength plaster of paris, compressible rubber, or fibrous materials are not suitable for caps.
- Apply selected material in a plastic state and finish to desired plane surface by applying glass or metal plates and squeezing out excess material to provide a cap that is as thin as possible.

Apply sulfur caps in time to harden at least 2 hours before testing. Plaster caps cannot be stored over 4 hours in the moist room. Age neat cement caps 6 days or more in the moist room (2 days when Type II cement is used).

During capping, protect moist-cured specimens against drying by covering them with wet burlap.

There are numerous alternatives to sulfur caps listed in ASTM C 617 *Standard Practice for Capping Cylindrical Concrete Specimens*. If you must use sulfur caps, ensure that sulfur vapors are not inhaled while heating the capping compound. Ensure there is adequate ventilation and respiratory protection is used. Used sulfur capping compound is a hazardous material and must be properly disposed of.

6.3.2 Beam Specimens

The flexural strength of hardened concrete is measured by using a simple concrete beam and third-point loading mechanism. The flexural strength is determined by calculating measured breaks of the beam and is expressed as a modulus of rupture in psi.

The standard beam specimen is 6 x 6 x 21 inch (152 x 152 x 532 mm.) for concrete in which the maximum size of the coarse aggregate is 2 in. (50 mm). When the maximum size of the coarse aggregate exceeds 2 in. (50 mm), the smaller cross-sectional dimension is to be increased to at least three times the nominal maximum size of the coarse aggregate.

All beam specimens prepared in the field are to be the standard beam size (6 in. wide by 6 in. deep by 21 in. long) unless required otherwise by project specifications.

6.3.2.1 Standards for Beam Molds

Beam molds are to be smooth on all interior surfaces and free from warpage. The molds are to produce specimens that do not exceed the required cross-sectional dimensions by 1/8 inches. The length of a specimen is not to be more than 1/16 inches shorter than the specified length, but may exceed that length.

6.3.2.2 Rodding

Assemble a standard 6- x 6- x 21-inch concrete-beam mold and lightly oil the inside. Fill the mold with two layers of concrete from the production batches, each about 3 inches deep. Consolidate each layer by rodding, using one stroke per 2 square inches (63 per layer), evenly distributed over the layer's surface.

Tap the sides lightly 10 to 15 times with a rubber mallet to close the voids left by rodding. Lightly spade the concrete along the mold's sides with a trowel to help remove surface voids. When rodding the second layer, penetrate the first layer about 1/2 inch. Strike off the top surface with a straightedge, finish it with a wood or magnesium float.

6.3.2.3 Curing

Place a suitable identifying label on the finished surface of the specimens. Cover the entire specimens—still in the mold—with a double thickness of wet burlap. Ensure that the specimens remain on site and are undisturbed for an initial curing period (the first 16 to 48 hours after molding).

After this curing period, move them to the testing laboratory and remove them from the molds for further curing. The most satisfactory curing range for concrete is 68° to 86°F, with 73.4°F being the most favorable temperature. Moist-cure the beams in saturated lime water, totally submerged in a wet-tank humidity room, or keep them wet until they are tested.

When transporting specimens from the field to the laboratory, be sure they are sufficiently cushioned to protect them from damage by jarring. Additional measures are required to prevent damage by freezing temperatures and moisture loss. You can prevent moisture loss by covering the specimens with plastic or surrounding them by wet sand or wet sawdust.

Summary

Engineering Aids are part of a project from its initial stages. (*Figure 16-58*) Proper testing and analysis of local soil and available aggregate can determine the feasibility of a project at a proposed site. As an EA, the data and information you garner will allow design engineers to make decisions about the foundation (earth) under a foundation, and determine the viability of aggregate use in a concrete mix design. Each decision has its associated cost impact, so your accurate calculations are important in multiple ways.

Figure 16-58 — Materials testing applies to soils, aggregate, and concrete.

Review Questions (Select the Correct Response)

1. Soil is a mixture of mineral grains enclosing various sizes of voids that contain _____.

   A. air (or other gases)
   B. water
   C. organic matter
   D. air (or other gases), water, and organic matter

2. Into how many groups do geologists classify rock?

   A. Two
   B. Three
   C. Four
   D. Five

3. What classification of rock is formed by cooling from a molten state?

   A. Igneous
   B. Sedimentary
   C. Metamorphic
   D. Organic

4. What classification of rock is formed by accumulation of particles and remains of plants and animals?

   A. Igneous
   B. Sedimentary
   C. Metamorphic
   D. Organic

5. What classification of rock is formed by pressure and heat applied to existing rock?

   A. Igneous
   B. Sedimentary
   C. Metamorphic
   D. Organic

6. What is the term for the physical and chemical process that transforms rock into a loose, incoherent mixture?

   A. Atmospheric exposure
   B. Decomposition
   C. Disintegration
   D. Weathering

7. **(True or False)** Transported soil will reflect the characteristics of the underlying parent rock from which it was derived.

   A. True
   B. False

8. Examples of alluvial soil can be found in _____.

   A. mouths of river deltas
   B. freshwater lakes and rivers
   C. dunes
   D. eskers, kames, and moraines

9. Examples of lacustrine soil can be found in _____.

   A. mouths of river deltas
   B. freshwater lakes and rivers
   C. dunes
   D. eskers, kames, and moraines

10. Examples of aeolian soil can be found in _____.

   A. mouths of river deltas
   B. freshwater lakes and rivers
   C. dunes
   D. eskers, kames, and moraines

11. Examples of glacial soil can be found in _____.

   A. mouths of river deltas
   B. freshwater lakes and rivers
   C. dunes
   D. eskers, kames, and moraines

12. What is the term for fine particles that pass the No. 200 sieve and exhibit plasticity and strength?

   A. Marine soil
   B. Clay
   C. Silt
   D. Colluvial soil

13. What is the term for fine particles that pass the No. 200 sieve and exhibit little plasticity and strength?

   A. Marine soil
   B. Clay
   C. Silt
   D. Colluvial soil

14. According to the Unified Soil Classification System, materials retained on a 3-inch sieve are classified as _____.

    A. sands
    B. fines
    C. gravels
    D. cobbles

15. Which bulky particle shape is considered the most desirable for construction purposes?

    A. Angular
    B. Subangular
    C. Rounded
    D. Subrounded

16. Well-graded soils consist of _____ particle sizes.

    A. uniformly graded large
    B. uniformly graded small
    C. uniformly graded intermediate
    D. a good representation of all

17. In a dense structure with a high degree of compactness, _____.

    A. closely packed soil particles interlock with smaller grains
    B. uniformly graded large particles compact together
    C. uniformly graded small particles compact together
    D. uniformly graded intermediate particles compact together

18. What is the minimum-maximum specific gravity range of most inorganic soils?

    A. 2.60 -- 2.65
    B. 2.60 -- 2.80
    C. 2.65 – 3.00
    D. 3.00 -- 3.50

19. Which soil property has the greatest effect on soil when subject to loading?

    A. Specific gravity
    B. Gradation
    C. Moisture Content
    D. Plasticity

20. Which of the following best describes the term “hydroscopic moisture”?

    A. Soil water absorbed by the atmosphere
    B. Absorbed moisture in soil at any time
    C. Absorbed moisture in air-dried soil
    D. Thin films of water surrounding soil particles

21. Which of the following factors does the term “moisture content” (symbol W) refer to?

A. The amount of free water in a soil sample
B. The proportion of the weight of water to the weight of wet soil expressed as a percentage
C. The amount of hydroscopic moisture in a soil sample
D. The proportion of the weight of water to the weight of dry soil expressed as a percentage

22. Which of the following properties of fine-grained soil permits clay to be rolled into thin threads at certain moisture contents without crumbling?

A. Liquidity
B. Consistency
C. Plasticity
D. Cohesiveness

23. Which of the following terms is used to describe the boundary where further loss of moisture does not change a soil’s volume?

A. Liquid Limit
B. Plastic Limit
C. Plasticity Index
D. Shrinkage Limit

24. Which of the following terms is used to describe the moisture content corresponding to the arbitrary limit between the liquid and plastic state of a soil?

A. Liquid Limit
B. Plastic Limit
C. Plasticity Index
D. Shrinkage Limit

25. Which of the following terms is used to describe the moisture content corresponding to the arbitrary limit between the plastic and semisolid state?

A. Liquid Limit
B. Plastic Limit
C. Plasticity Index
D. Shrinkage Limit

26. Which of the following constructions would be least affected by soil moisture?

A. An asphaltic-cement road laid on a sand-clay admixture
B. A concrete building foundation laid on a base of fine-grained soil
C. A concrete building foundation laid on a gravel base
D. An asphaltic-cement runway laid on a gravel-clay admixture

27. What soil classification often undergoes large volume changes with variations in moisture content?

   A. Gravel
   B. Sand
   C. Silt
   D. Clay

28. According to the United Soil Classification System, what are the three major divisions of soil classifications?

   A. Course-grained, Fine-grained, Organic
   B. Course-grained, Fine-grained, Sand
   C. Course-grained, Peat, Organic
   D. Cobble, Fine-grained, Organic

29. What is the soil classification when less than half of the coarse-grained portion of a soil sample is retained on a No. 4 sieve?

   A. Gravel
   B. Sand
   C. Clay
   D. Silt

30. When samples are taken by test holes with the hand auger, the samples may be completely disturbed, but they are satisfactory for determining which of the following information?

   A. Compaction capabilities
   B. Moisture content
   C. Soil profile
   D. All of the above

31. From which of the following locations was a soil sample tagged CB-P3-1 taken?

   A. Project CB, bag No. P3, pit No. 1
   B. Project CB, pit No. 3, location No. 1
   C. Construction battalion pit No. 3, area No. 1
   D. Construction borrow pit No. P3, bag No. 1

32. For which of the following tests are disturbed samples satisfactory for use?

   A. Mechanical analysis
   B. Frost susceptibility
   C. Specific gravity
   D. All of the above

33. How large a sample is enough to determine the moisture content of fine-grained soils?

    A. 50 grams
    B. 75 grams
    C. 100 grams
    D. 200 grams

34. A moisture content sample taken at 0730 will not be tested until 1430. At a minimum, what action, if any, should be taken to prevent the evaporation of moisture from the soil?

    A. Seal the canister with friction tape.
    B. Dip the canister in paraffin.
    C. Wrap the canister with a paraffin-coated cloth.
    D. None, since the test will be performed within 1 day.

35. For which of the following soil properties are undisturbed soil samples tested?

    A. In-place density
    B. Shear strength
    C. Compressive strength
    D. All of the above

36. For which of the following soil types would an undisturbed chunk sample be best suited for sampling?

    A. Highly plastic
    B. Cohesionless
    C. Slightly plastic
    D. Moderately cohesive

37. Which of the following steps should be taken next after removing a CBR mold and undisturbed sample from a hole?

    A. Remove the cutting edge.
    B. Coat the top of the sample with paraffin.
    C. Remove the upper collar and trim a ½-inch recess in the top of the mold.
    D. Place boards over both ends.

38. Which of the following methods is one way to be certain that a soil sample is representative of the whole sample?

    A. Soaking
    B. Straining
    C. Quartering
    D. Halving

39. What quarter(s) should you discard when quartering a sample?

A. Any single quarter
B. Two adjacent quarters
C. Two diagonally opposite quarters
D. Any three quarters

40. What is the identified sequence of a complete soil test as laid down by the American Society for Testing Materials (ASTM)?

A	Determine specific gravity
B	Determine moisture content
C	Determine moisture-density relationship
D	Determine grain size and distribution
E	Determine the field moisture content
F	Determine Atterberg limits

A. A, B, F, C, E, D
B. B, C, A, D, F, E
C. B, D, A, F, C, E
D. B, D, C, A, E, F

Refer to Figure PC 16-1 for questions 41-44
Table of Values from DD Form 1205
Compute water content for each run.

Test	**Natural Soil Moisture Content**					
Run Number	1	2	3			
Tare Weight	6	7	9			
A. Weight of Tare + Wet Soil	196.4	187.3	209.6			grams
B. Weight of Tare + Dry Soil	176.8	169.9	190.2			grams
C. Weight of Water, $W_w = (A - B)$						grams
D. Weight of Tare	43.6	44.0	46.4			grams
E. Weight of Dry Soil, $W_s = (B - D)$						grams
Water Content, $w = \frac{W_w}{W_s} x100$	%	%	%			

Figure PC 16-1

41. What is the dry weight in grams of the soil in run number 1?

A. 176.8
B. 152.8
C. 143.6
D. 133.2

42. What is the weight of water in grams in run number 2?

A. 17.4
B. 17.6
C. 18.4
D. 18.6

43. What is the water content of run number 3?

A. 13.0%
B. 13.2%
C. 13.5%
D. 17.4%

44. What is the average moisture content of the three runs?

A. 13.4%
B. 14.0%
C. 31.1%
D. 41.9%

45. Sieve analysis applies to soils that are larger than the _____ sieve.

A. ½ inch
B. No.4
C. No.40
D. No. 200

46. When is it necessary to prewash a sample before proceeding with a normal dry sieve analysis?

A. When the sample is too dry
B. When the sample has an undesirable water content
C. When the sample contains too little superfine materials
D. When the sample contains cohesive soil forming hard lumps

47. _____ retain on a No. 4 sieve.

A. Sands
B. Fines
C. Gravels

48. _____ pass a No. 4 sieve and retain on a No. 200 sieve.

A. Sands
B. Fines
C. Gravels

49. _____ pass a No. 200 sieve.

A. Sands
B. Fines
C. Gravels

50. During a sieve analysis, 2% of the material passed the No. 200 sieve. What subsequent test should you perform on the sample to determine this soil's susceptibility to frost?

A. Hydroscopic moisture content
B. Hydrometer analysis
C. Specific gravity
D. Moisture-density relationship

51. Which of the following materials should you test for specific gravity of solids after a sieve analysis has been performed?

A. Only those larger than the No. 40 sieve
B. Only those retained on the No. 4 sieve
C. Only those passing the No. 4 sieve
D. Materials passing the No. 200 sieve

52. Which factor in the calculation for Specific Gravity of Solids has the least impact on the outcome? $G_s = \frac{W_s K}{W_s + W_{bw} - W_{bws}}$

A. $W_s =$ dry weight of the sample
B. $K =$ correction factor based on the density of water at 20ºC
C. $W_{bw} =$ weight of the flask filled with water only
D. $W_{bws} =$ weight of the flask, water, and sample

53. How should the surface of a saturated-surface-dry (SSD) sample appear?

A. Very wet
B. Very dry
C. Damp
D. Pitted

54. The _____ is the point at which the material contains the greatest water content and remains plastic.

A. plasticity index (PI)
B. plastic limit (PL)
C. liquid limit (LL)
D. shrinkage limit (SL)

55. The _____ is the point at which the material contains the lowest water content and remains plastic.

A. plasticity index (PI)
B. plastic limit (PL)
C. liquid limit (LL)
D. shrinkage limit (SL)

56. The _____ is the point at which, with further drying, shrinkage stops.

A. plasticity index (PI)
B. plastic limit (PL)
C. liquid limit (LL)
D. shrinkage limit (SL)

57. Beyond what limit should you consider results suspect when entering data on a USCS Plasticity Chart?

A. Below 50 LL
B. Above 51 LL
C. Below A line
D. Above U line

58. What property of concrete does the slump test measure?

A. Compressibility
B. Workability
C. Durability
D. Strength

59. From which portion of a batch should a slump test be taken at 2 or more regularly spaced intervals?

A. First and middle
B. Middle only
C. First and last
D. Middle and last

60. How many times is each layer of a slump test rodded?

A. 10
B. 15
C. 25
D. 30

61. For a slump test, what should the elapsed time be from beginning of fill to lifting the cone?

A. 2 ½ minutes
B. 5 minutes
C. 7 ½ minutes
D. 10 minutes

62. What are the dimensions of a standard concrete cylinder specimen?

A. 6 in. diameter by 6 in. long
B. 6 in. diameter by 12 in. long
C. 8 in. diameter by 6 in. long
D. 8 in. diameter by 12 in. long

63. A standard size cylinder specimen should be filled in _____ layers and rodded _____ times at each layer.

A. 2, 25
B. 2, 50
C. 3, 25
D. 3, 50

Trade Terms Introduced in this Chapter

Atterberg	Albert Mauritz Atterberg (1846–1916). Swedish chemist and agricultural scientist who created the Atterberg limits commonly referred to by geotechnical engineers and engineering geologists.
California Bearing Ratio (CBR)	A penetration test for evaluation of the mechanical strength of road subgrades and basecourses.
Colloidal	Of a mixture in which very small particles of one substance are distributed evenly throughout another substance. The particles are generally larger than those in a solution and smaller than those in a suspension.
Hydrometer	An instrument used to measure the specific gravity (or relative density) of liquids, that is, the ratio of the density of the liquid to the density of water.
Laterite	A red, porous, claylike soil formed by the leaching of silica-rich components and enrichment of aluminum and iron hydroxides.
Nomographic chart	A chart representing numerical relationships.
Weathering	The physical disintegration and chemical decomposition of earth materials at or near the earth's surface.

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.

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

Standard Method for Particle-Size Analysis of Soils, ASTM D422-63, American Society for Testing and Materials, Philadelphia, Pa., 2007.

Standard Practice for Capping Cylindrical Concrete Specimens, ASTM C617 - 98(2003), American Society for Testing and Materials, Philadelphia, Pa., 2003.

Standard Practice for Making and Curing Concrete Test Specimens in the Field, ASTM C31 / C31-8b, American Society for Testing and Materials, Philadelphia, Pa, 2008.

Standard Practice for Sampling Freshly Mixed Concrete, ASTM C172-08, American Society for Testing and Materials, Philadelphia, Pa., 2008.

Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System), ASTM D2487 - 06e1, American Society for Testing and Materials, Philadelphia, Pa., 2006.

Standard Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass ASTM D2216 – 05, American Society for Testing and Materials, Philadelphia, Pa., 2005.

Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils, ASTM D4318 – 05, American Society for Testing and Materials, Philadelphia, Pa, 2005.

Standard Test Method for Slump of Hydraulic Cement Concrete, ASTM C143 / 143M - 08, American Society for Testing and Materials, Philadelphia, Pa, 2008.

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