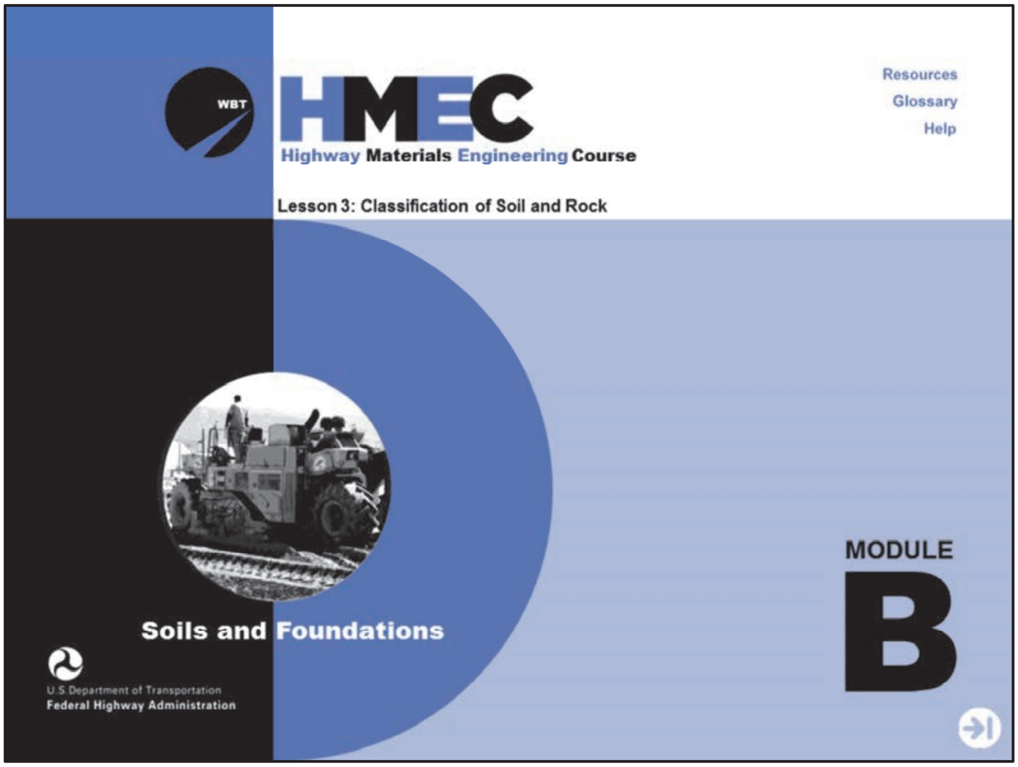
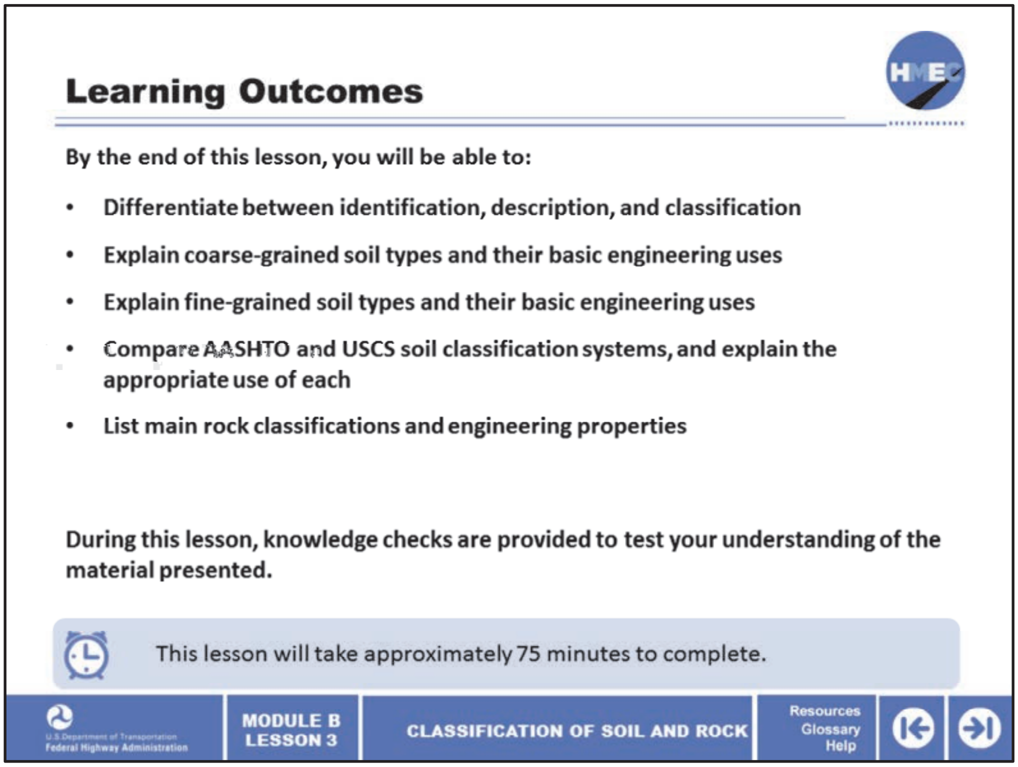


Welcome to the Highway Materials Engineering Course Module B, Lesson 3: Classification of Soil and Rock. This lesson is designed to focus on the group process required for geotechnical issues in the real world, with an emphasis on the role of the materials engineer. Materials engineers should be asking questions, collaborating, and viewing other perspectives in all aspects of geotechnical work. They should know when to ask for help and ask for it when needed.

A printer-friendly version of the lesson materials can be downloaded by selecting the paperclip icon. Only the slides for the this lesson are available.

If you need technical assistance during the training, please select the Help link in the upper right-hand corner of the screen.

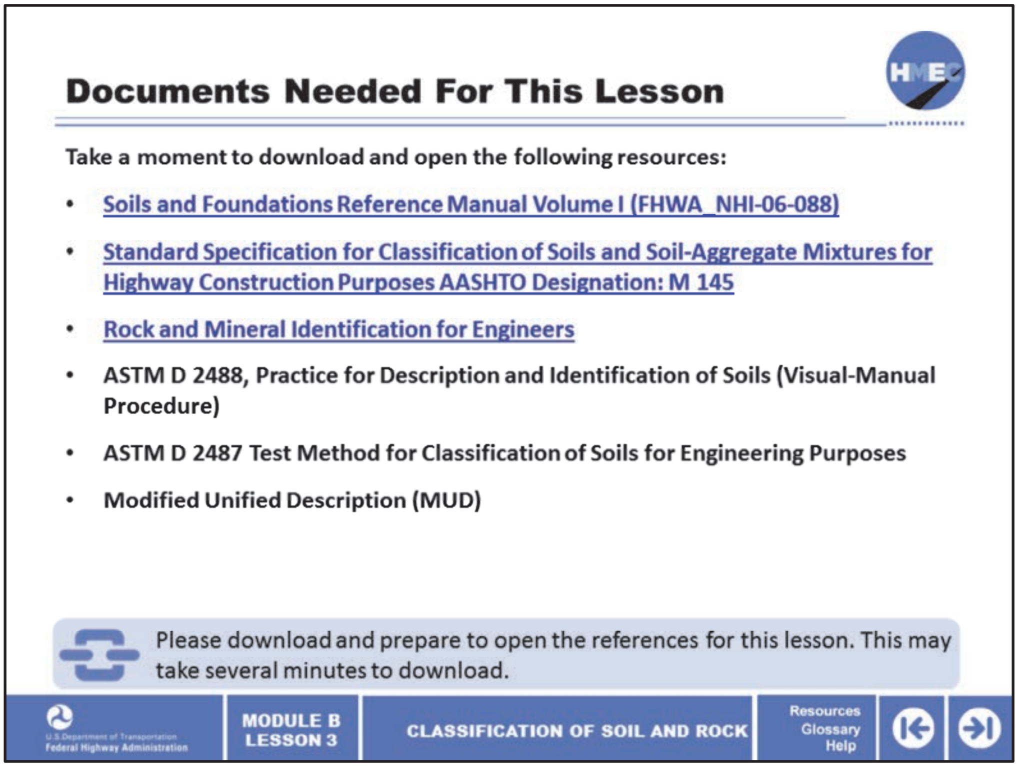


Welcome to Module B, Lesson 3: Classification of Soil and Rock. By the end of this lesson, you will be able to:

- Differentiate between identification, description, and classification;
- Explain coarse-grained soil types and their basic engineering uses;
- Explain fine-grained soil types and their basic engineering uses;
- Compare AASHTO and USCS soil classification systems, and explain the appropriate use of each; and
- List main rock classifications and engineering properties.

During this lesson, knowledge checks are provided to test your understanding of the material presented.

This lesson will take approximately 75 minutes to complete.



In addition to this course material, there are excellent resources available. You are being provided two PDFs of the two-volume set of the Soils and Foundations Reference Manual (FHWA_NHI-06-088 and 089).

The following documents are referenced during this lesson and are provided through the URL links. Please take a moment to download and open the documents. Note that these documents are quite large and depending on your Internet speed this may take several minutes to download.

Soils and Foundations Reference Manual Volume I ➔
http://harpersenterprise.adobeconnect.com/soils_and_foundations_volume1/

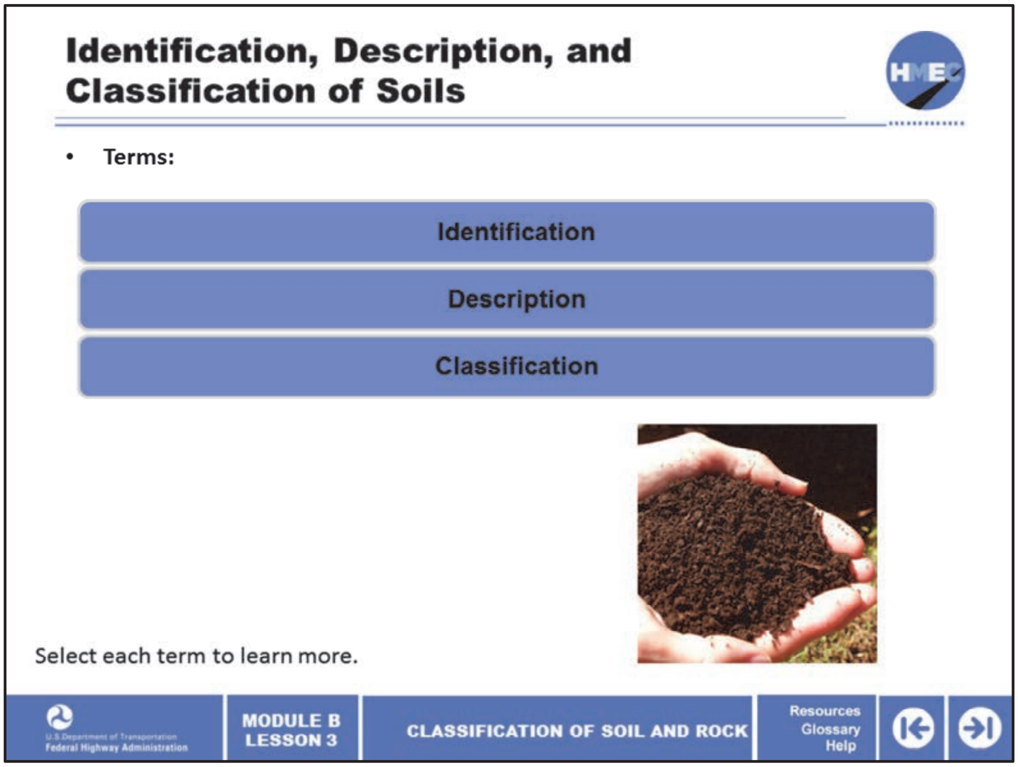
AASHTO Designation M 145 ➔
http://harpersenterprise.adobeconnect.com/hmec_resource_m145/

Rock and Mineral Identification for Engineers (FHWA) ➔
http://www.fhwa.dot.gov/pavement/pccp/fhwahi91205.pdf

ASTM D 2488, Practice for Description and Identification of Soils (Visual-Manual Procedure)

ASTM D 2487 Test Method for Classification of Soils for Engineering Purposes

Modified Unified Description (MUD)

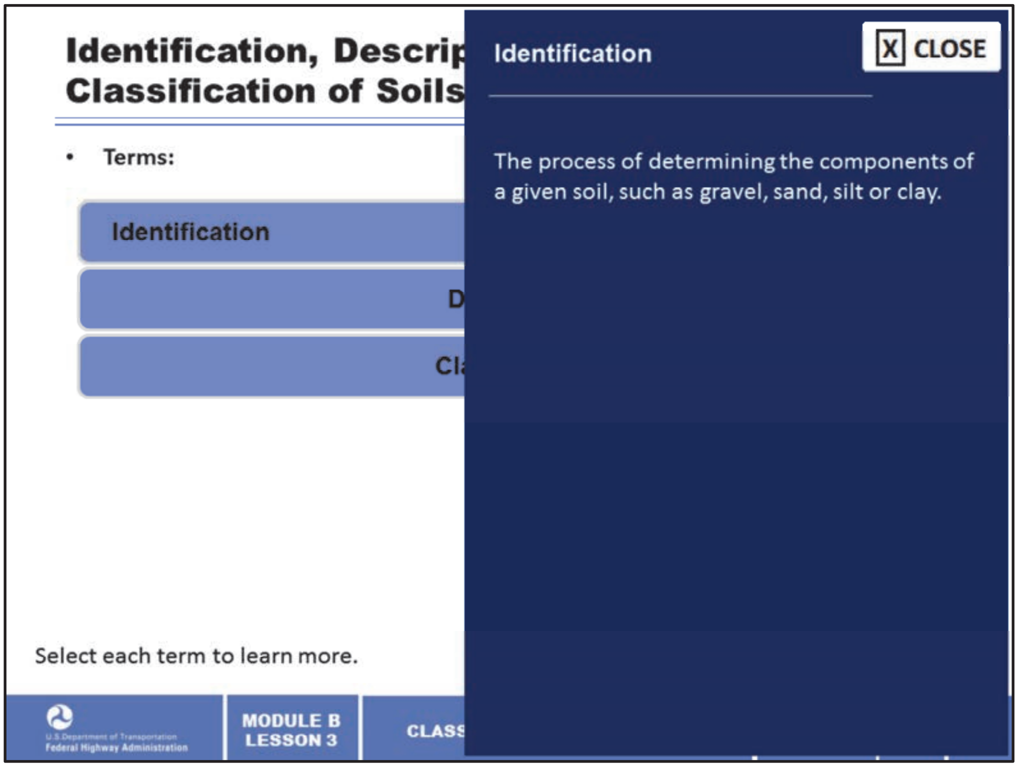


Let’s define identification, description, and classification and discuss what they are used for and how they differ.

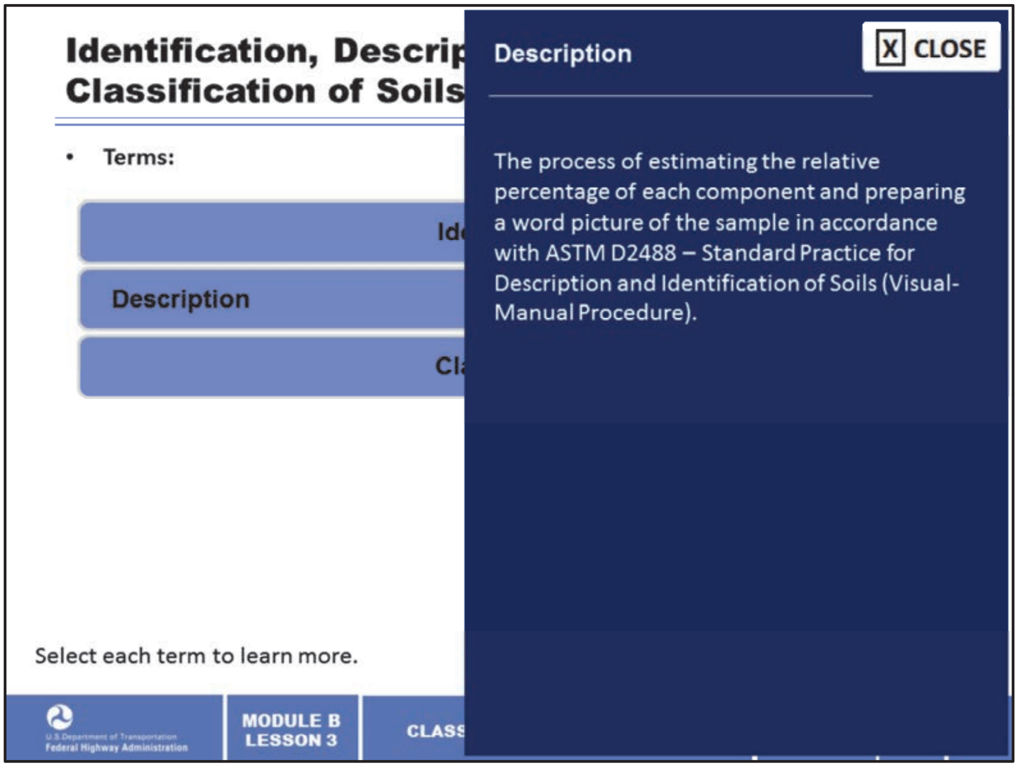
The important distinction between classification and both identification and description is that standard AASHTO or ASTM tests must be performed to determine a soil's classification. The field personnel should only identify and describe the soils encountered. Group symbols associated with classification should not be used in the field. It is important to send the soil samples to a laboratory for accurate visual identification classification by a technician experienced in soils work, as this single operation will provide the basis for later testing and soil profile development.

Select each term to learn more.

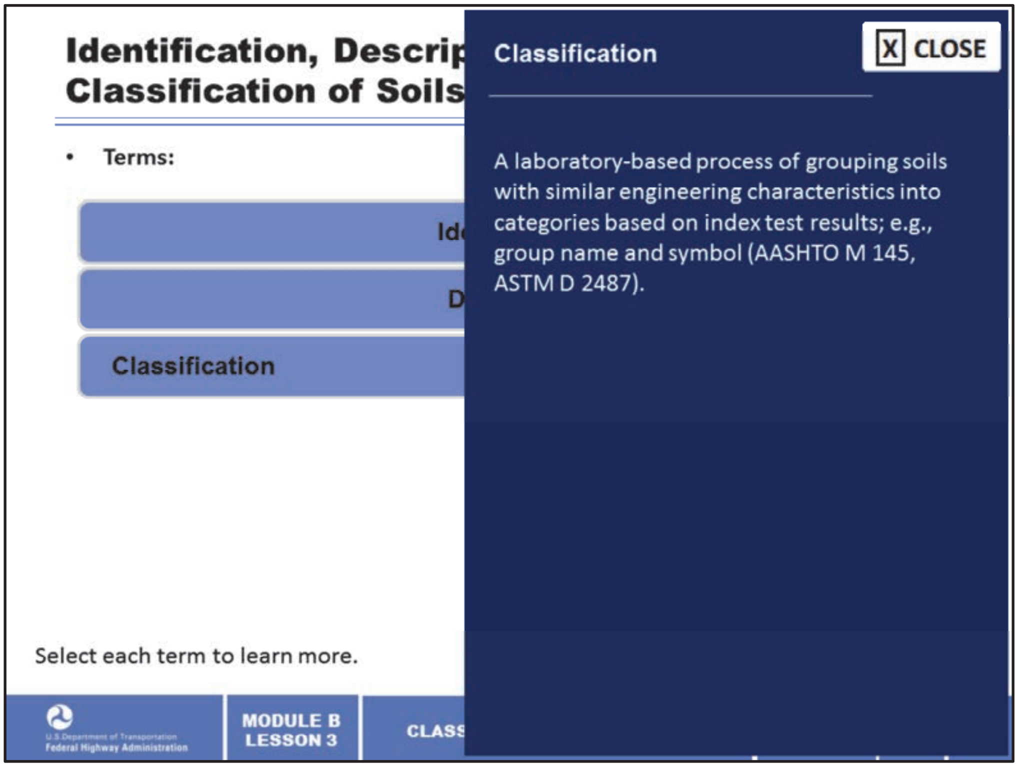
Image description: Photo of hands filled with soil.



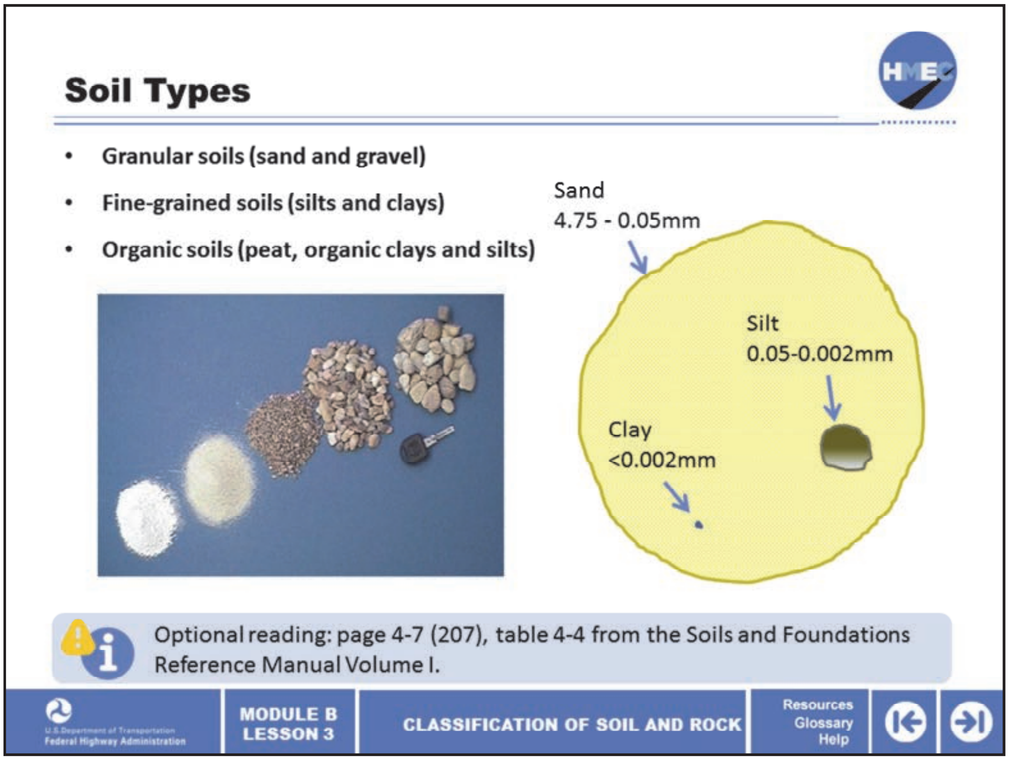
Identification is the process of determining the components of a given soil, such as gravel, sand, silt or clay.



Description is the process of estimating the relative percentage of each component and preparing a word picture of the sample in accordance with ASTM D2488 – Standard Practice for Description and Identification of Soils (Visual-Manual Procedure).



Classification is a laboratory-based process of grouping soils with similar engineering characteristics into categories based on index test results; e.g., group name and symbol (AASHTO M 145, ASTM D 2487).



Let’s discuss how we can identify soils in the field. Initially we will identify soils by their principal size components. Granular soil types are identified by their grain size. The smallest sand particle is just within the range of vision for the average person.

The slide graphic provides an indication of the relative sizes of silt and clay. Silt and clay are fine-grained components (too small to visually distinguish individual grains). Therefore, they are identified by their physical behavior, which is controlled by mineralogy more than grain size. Organic soils, which are also fine grained will be identified by the vegetative matter component and smell.

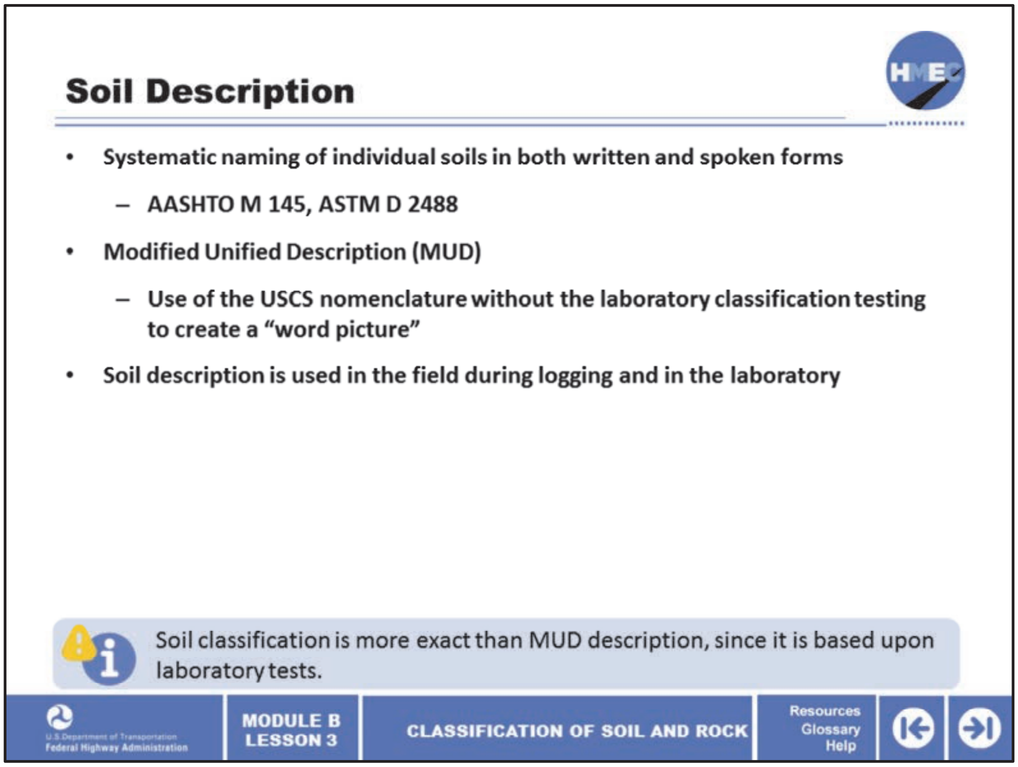
The photo on the left shows soil particle sizes including (right to left): medium gravel, fine gravel, medium-coarse sand, silt, and dry clay (kaolin).

The illustration on the right gives an indication of the relative size of clay, silt and sand particles. Silt is about 25 times the size of the largest clay particle, while sand is about 1000 times the size of clay.

For optional reading, refer to page 4-7 (207 in the PDF) to view table 4-4 from the Soils and Foundations Reference Manual Volume I.

Image description: Photo of soil particle sizes including, medium gravel, fine gravel, medium-coarse sand, silt, and dry clay (kaolin).

Image description: Illustration giving an indication of the relative size of clay, silt and sand particles.



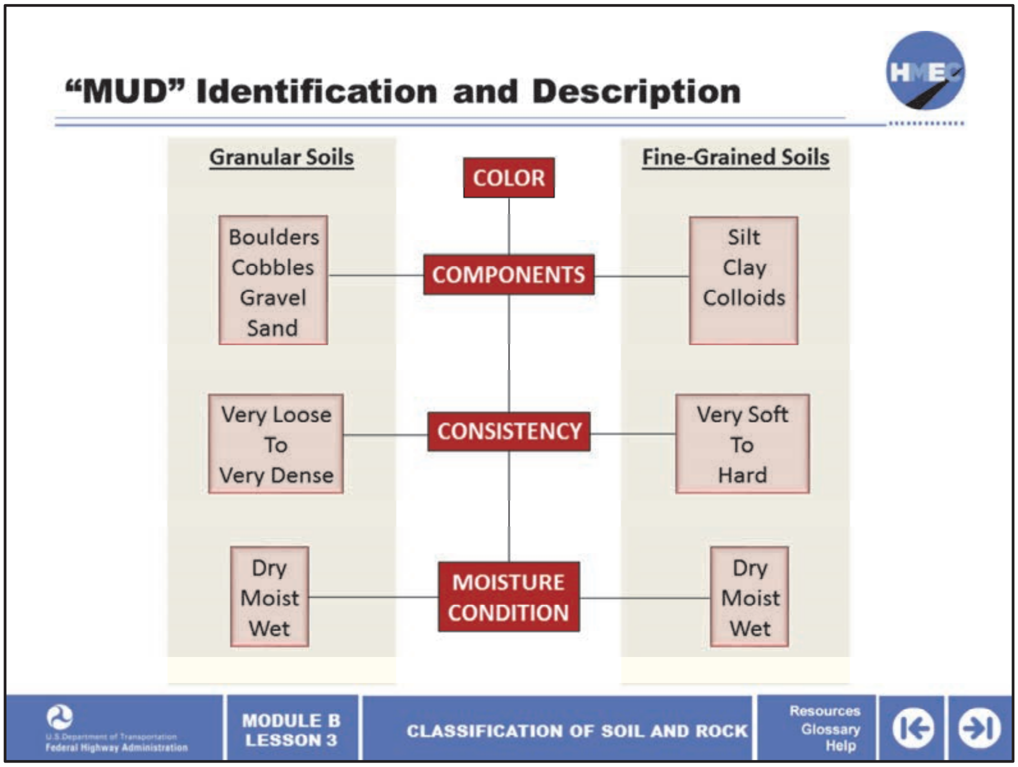
Let's discuss soil description in more detail. Soil description is the systematic naming of individual soils. It is used in the field to describe on the boring log what was found during the soil borings. Typically the process outlined in ASTM D 2488 is followed to develop a word picture for the soil.

The Modified Unified Description (MUD) system is the use of the Unified Soil Classification System (USCS) nomenclature without the laboratory classification testing. The procedure involves visually and manually examining soil samples with respect to texture, plasticity, and color and developing a "word picture" of a sample for entering on a subsurface exploration log or other appropriate data sheet. The description system is intended to provide the best word description of the sample to those involved in the planning, design, construction, and maintenance processes. This procedure applies to soil description made in the field and laboratory.

Detailed soil and rock descriptions and classifications are an essential part of the information developed to support design and construction processes. Subsurface information for any given area is, and can be, generated and accumulated over a prolonged period of time by various geotechnical specialists for different projects and purposes. It is critical that geotechnical specialists working on projects use standardized terminology and procedures to maintain consistency in borehole logging and reporting practices.

As we will discuss later in this lesson, the Unified Soil Classification System and the AASHTO Soil Classification System are, for the most part, based upon the results of laboratory tests.

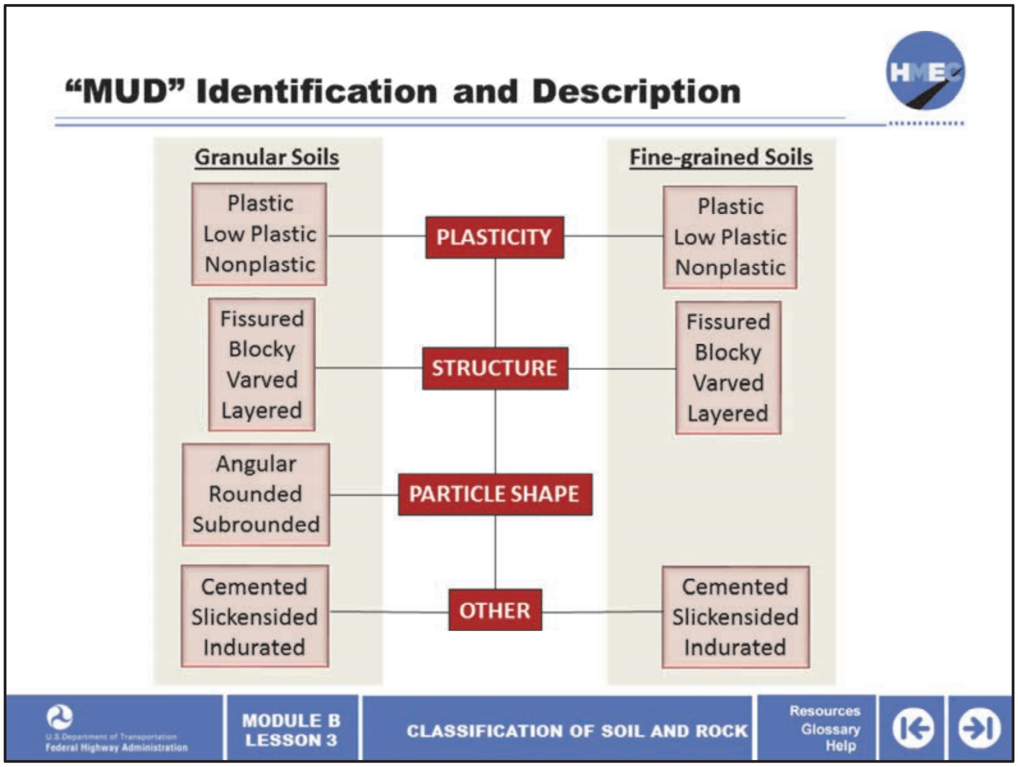
Soil classification is more exact than MUD description, since it is based upon laboratory tests.



Let's discuss the MUD process in more detail. Someone on the drill crew will be responsible for describing soils in the field, building a word picture. That person, whether a geotechnical specialist, the crew chief, or the driller should be knowledgeable of the MUD process. That will ensure consistent soil descriptions for use by the project team.

As the material engineer, you need to be knowledgeable of the MUD process so you can properly understand and interpret the boring logs. The MUD process starts with the main categories shown above, which are color, components, consistency, and moisture condition.

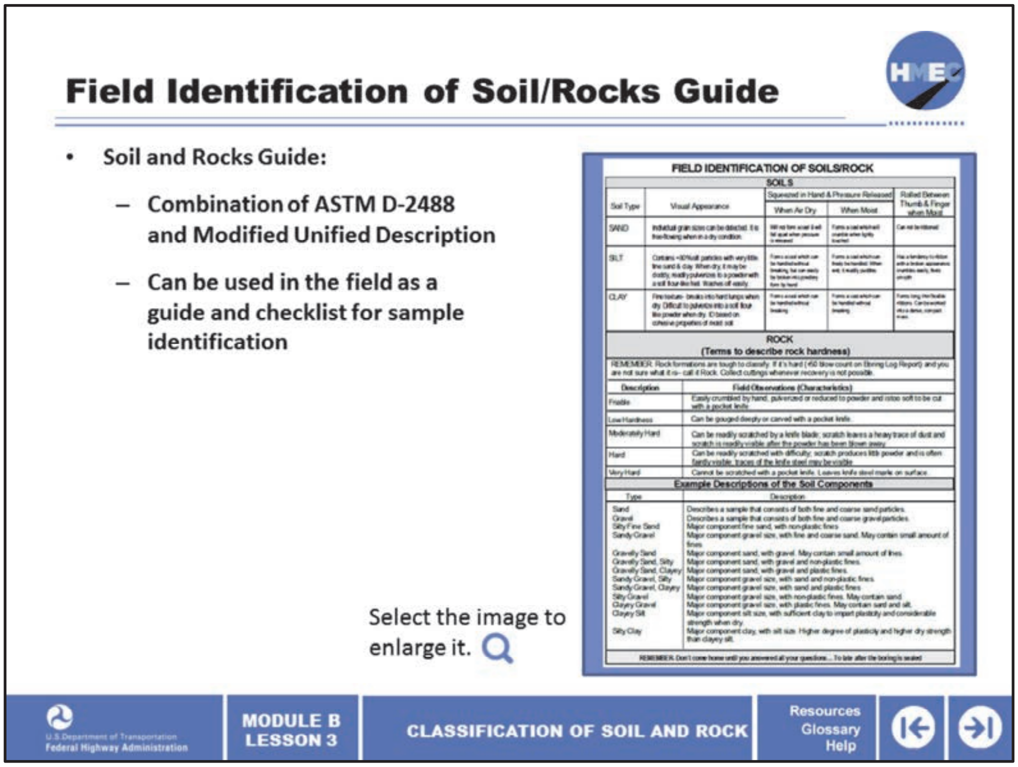
- Color is based upon the locally utilized color scheme;
- Components are the material that makes up the sample;
- Consistency is the samples relative consistency based upon standard penetration "N" values; and
- Moisture condition is the description of the sample's moisture condition.



The MUD process of identification and description has other items that can be added to the description (word picture), including:

- Plasticity is based on an estimate of the percentage of fine-grained soils in the sample;
- Structure is the depositional or physical features in which the soil particles are arranged;
- Particle shape is based upon the apparent shape of the particles; and
- Other – additional descriptive terms used to describe soils.

Please note that there are several terms related to this screen that may be unfamiliar. They are structure, varved, layered, fissured, blocky, slickensided, and indurated. If you are not familiar with these terms, we recommend referencing the Glossary for further definitions.



This field identification of the Soil and Rocks Guide is a combination of ASTM D 2488 and Modified Unified Description, and it can be used in the field as a guide and checklist for sample identification.

Image description: Field identification of the Soil and Rocks Guide form.

FIELD IDENTIFICATION OF SOILS/ROCK

SOILS

Soil Type	Visual Appearance	Squeezed in Hand & Pressure Released: When Air Dry	Squeezed in Hand & Pressure Released: When Moist	Rolled Between Thumb & Finger when Moist
SAND	Individual grain sizes can be detected. It is free-flowing when in a dry condition.	Will not form a cast & will fall apart when pressure is released	Forms a cast which will crumble when lightly touched	Can not be ribboned
SILT	Contains +80%silt particles with very little fine sand & clay. When dry, it may be cloddy, readily pulverizes to a powder with a soft flour-like feel. Washes off easily.	Forms a cast which can be handled without breaking, but can easily be broken into powdery form by hand	Forms a cast which can freely be handled. When wet, it readily puddles.	Has a tendency to ribbon with a broken appearance, crumbles easily, feels smooth
CLAY	Fine texture- breaks into hard lumps when dry. Difficult to pulverize into a soft flour-like powder when dry. ID based on cohesive properties of moist soil.	Forms a cast which can be handled without breaking	Forms a cast which can be handled without breaking	Forms long, thin flexible ribbons. Can be worked into a dense, compact mass.

ROCK
(Terms to describe rock hardness)

REMEMBER: Rock formations are tough to classify. If it's hard (+60 blow count on Boring Log Report) and you are not sure what it is-- call it Rock. Collect cuttings whenever recovery is not possible.

Description	Field Observations (Characteristics)
Friable	Easily crumbled by hand, pulverized or reduced to powder and istoo soft to be cut with a pocket knife.
Low Hardness	Can be gouged deeply or carved with a pocket knife.
Moderately Hard	Can be readily scratched by a knife blade; scratch leaves a heavy trace of dust and scratch is readily visible after the powder has been blown away.
Hard	Can be readily scratched with difficulty; scratch produces little powder and is often faintly visible; traces of the knife steel may be visible.
Very Hard	Cannot be scratched with a pocket knife. Leaves knife steel marks on surface.

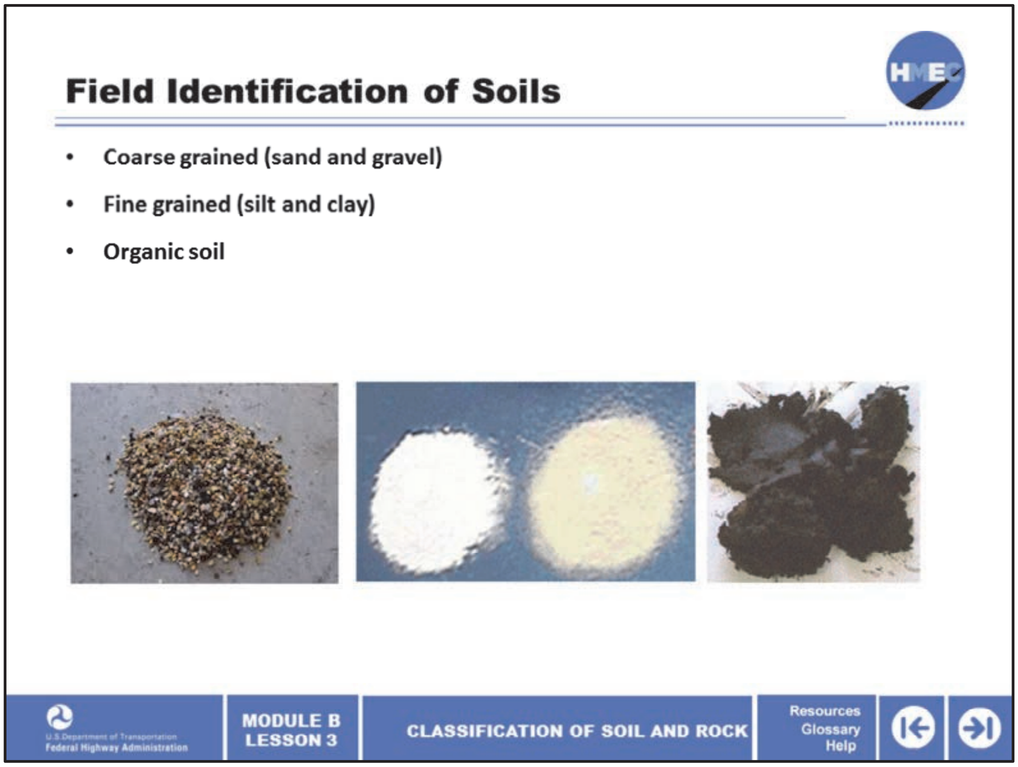
Example Descriptions of the Soil Components

Type	Description
Sand	Describes a sample that consists of both fine and coarse sand particles.
Gravel	Describes a sample that consists of both fine and coarse gravel particles.
Silty Fine Sand	Major component fine sand, with non-plastic fines
Sandy Gravel	Major component gravel size, with fine and coarse sand. May contain small amount of fines
Gravelly Sand	Major component sand, with gravel. May contain small amount of fines.
Gravelly Sand, Silty	Major component sand, with gravel and non-plastic fines.
Gravelly Sand, Clayey	Major component sand, with gravel and plastic fines.
Sandy Gravel, Silty	Major component gravel size, with sand and non-plastic fines.
Sandy Gravel, Clayey	Major component gravel size, with sand and plastic fines
Silty Gravel	Major component gravel size, with non-plastic fines. May contain sand.
Clayey Gravel	Major component gravel size, with plastic fines. May contain sand and silt.
Clayey Silt	Major component silt size, with sufficient clay to impart plasticity and considerable strength when dry.
Silty Clay	Major component clay, with silt size. Higher degree of plasticiy and higher dry strength than clayey silt.

REMEMBER: Don't come home until you answered all your questions... To late after the boring is sealed

This chart is a combination of ASTM D 2488 and Modified Unified Description, and it can be used in the field as a guide and checklist for sample identification.

Image description: Field identification of the Soil and Rocks Guide form.

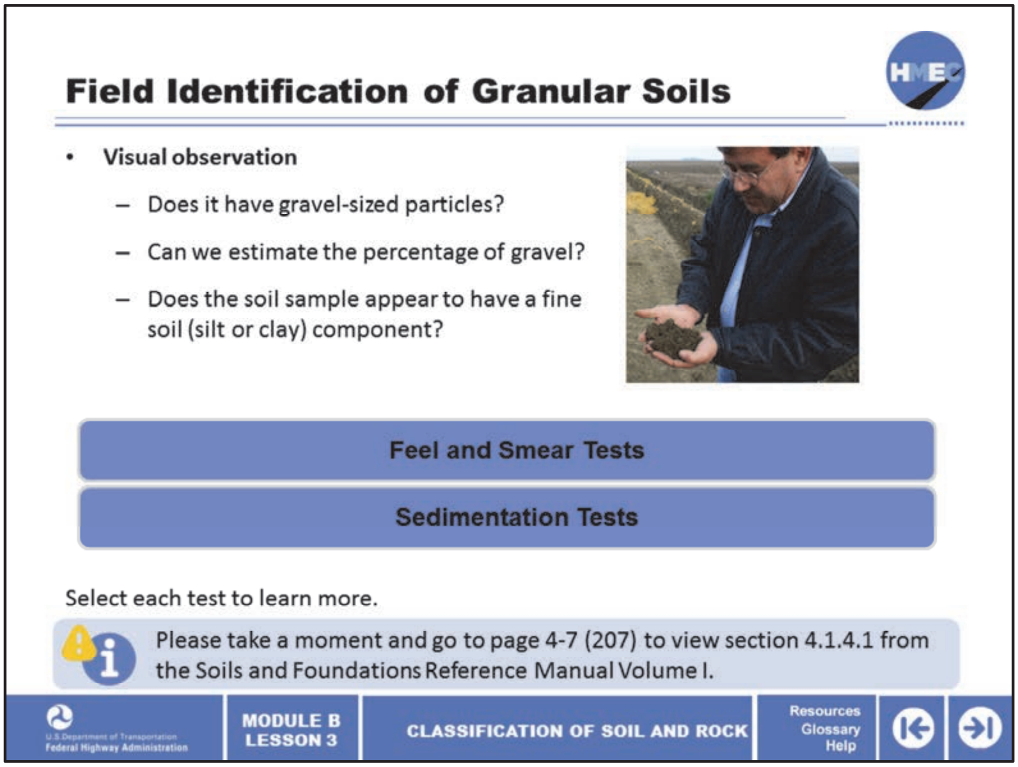


In the following slides we will discuss techniques and procedures we might use to identify soils in the field such as coarse grained (sand and gravel), fine grained (silt and clay), and organic soil.

Image description: Photo of coarse grained sand and gravel.

Image description: Photo of fine grained silt and clay.

Image description: Photo of organic soil.

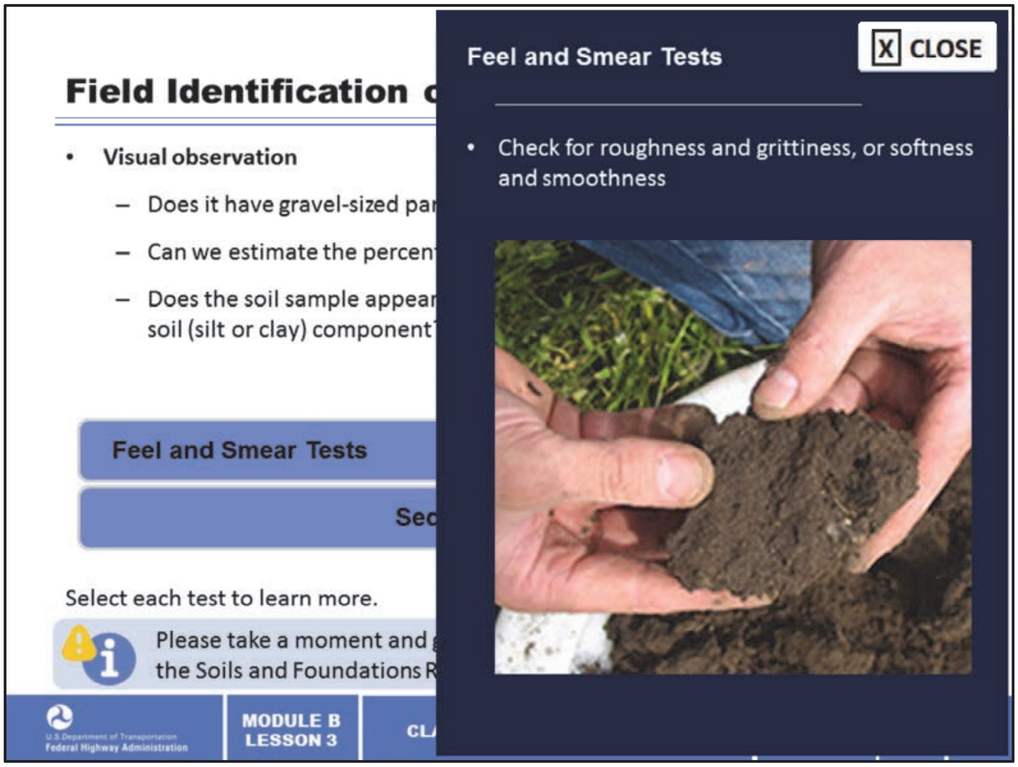


To identify granular soils in the field, first we visually observe the soil sample. Since we can see the soil particles down to individual grains of sand, we can tell a lot about the sample by visually observing the material. For instance, does it have gravel-sized particles? If so, are they coarse or fine? Can we estimate the percentage of gravel? Does the soil sample appear to have a fine soil (silt or clay) component?

Once we have visually inspected the sample, there are a couple of field tests we can use to evaluate the grain size of the sand portion of the sample. Select each test to learn more.

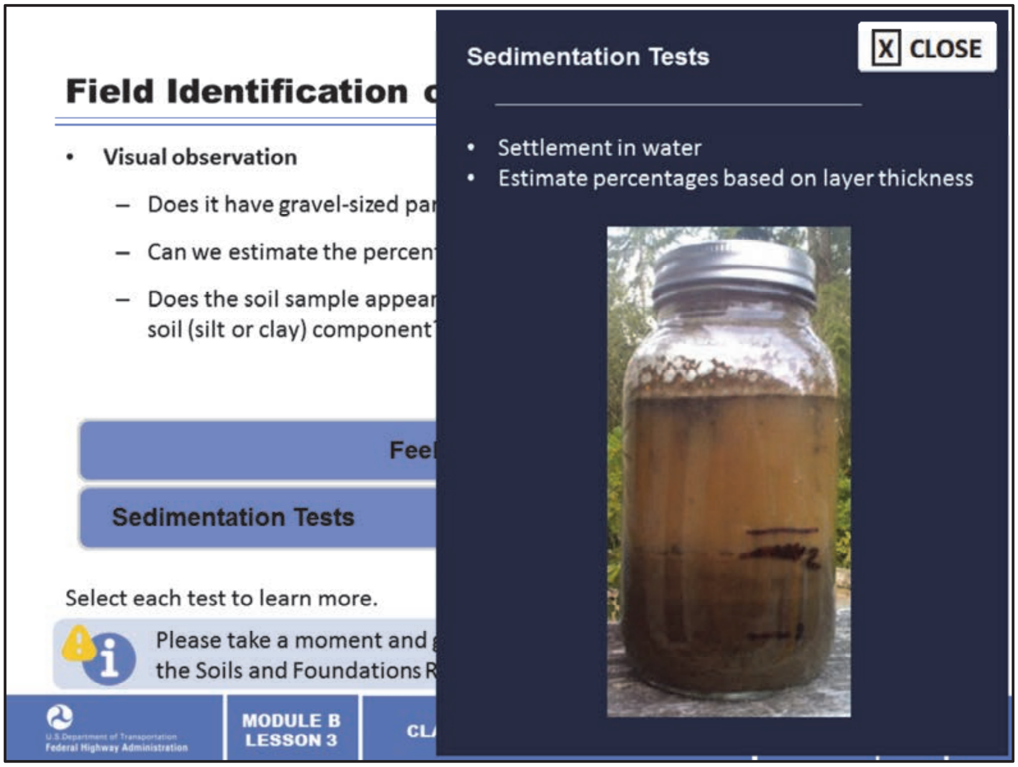
Please take a moment and go to page 4-7 (207) to view section 4.1.4.1 from the Soils and Foundations Reference Manual Volume I. This section will provide a more detailed discussion on these tests.

Image description: Photo of a man looking at his hands, which are full of soil.



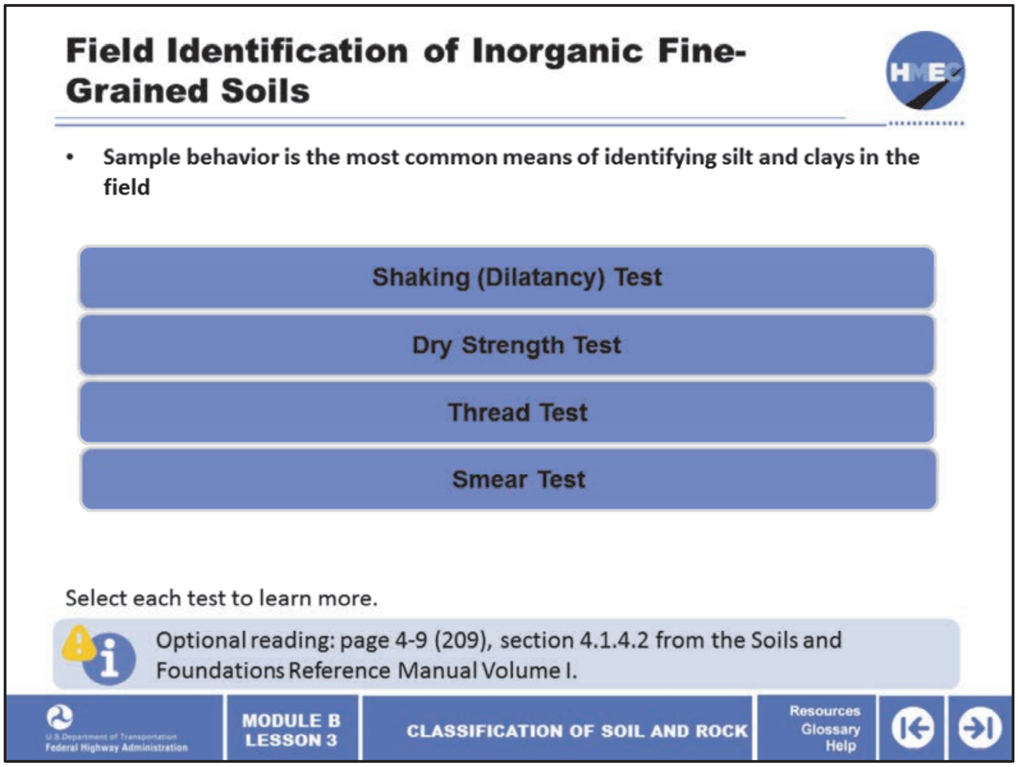
Feel and Smear Tests*:* A pinch of soil is handled lightly between the thumb and fingers to obtain an impression of the grittiness or of the softness of the constituent particles. Thereafter, a pinch of soil is smeared with considerable pressure between the thumb and forefinger to determine the degrees of roughness and grittiness, or the softness and smoothness of the soil. Based on the feel, we can determine how coarse the sand is.

Image description: Photo of two hands pinching a clump of soil.



Sedimentation Test: A small sample of the soil is shaken in a clear container (or often a sample jar) filled with water and allowed to settle. The sample will deposit in the bottom of the container in layers. The coarse components (sand) will be on the bottom with progressively finer material (silt and then clay) in layers toward the top. You can estimate percentages based on layer thickness.

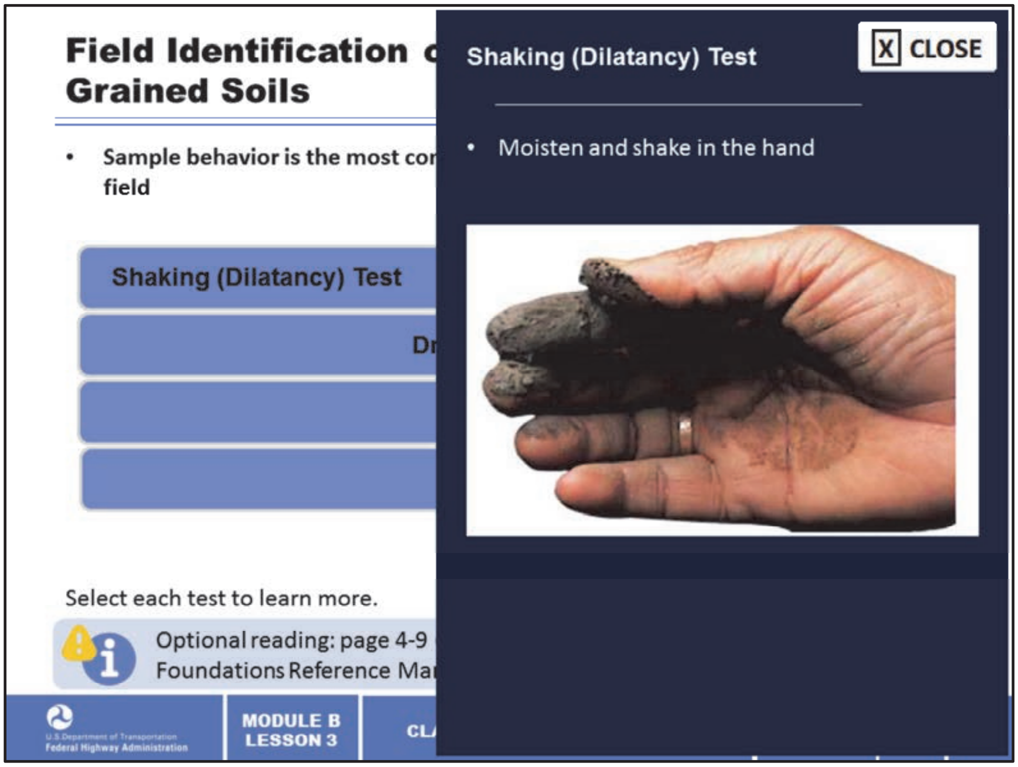
Image description: Photo of a jar filled with water and soil.



Sample behavior is the most common means of identifying silt and clays in the field. There are a few simple field tests we can perform to help identify the type of soil in the sample. These tests can be performed on a fine soil sample or on the fine soil portion of a sand/gravel sample.

Select each test to learn more.

For optional reading, refer to page 4-9 (209) to view section 4.1.4.2 from the Soils and Foundations Reference Manual Volume I. This section will provide a more detailed discussion on these tests.

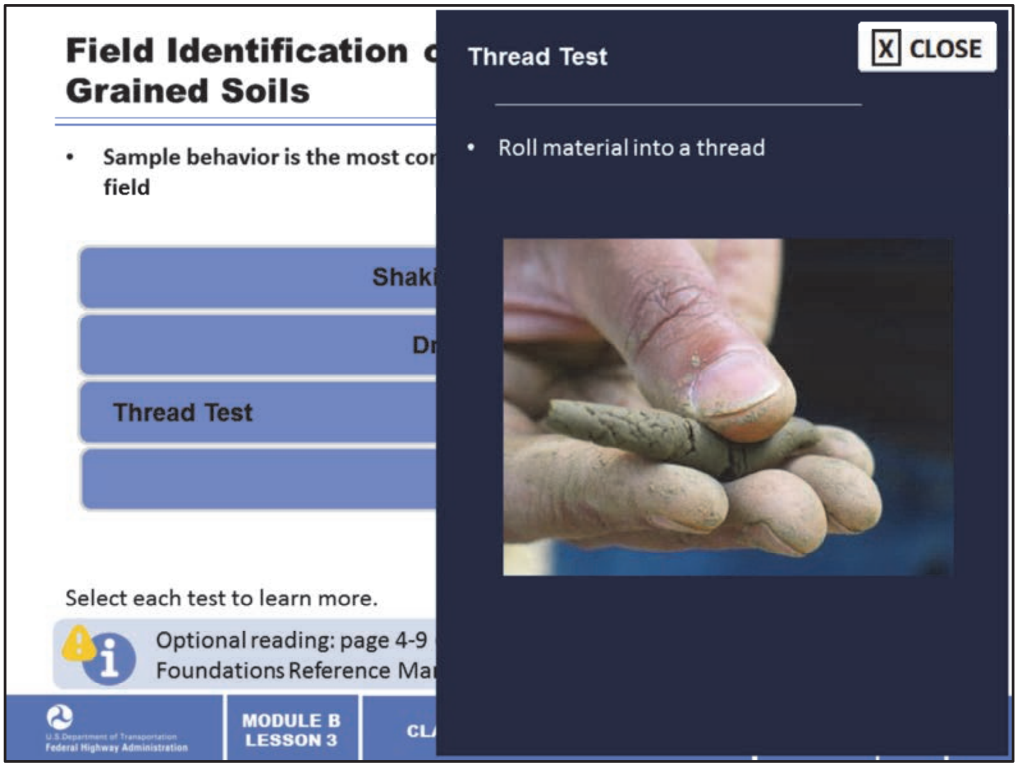


Shaking (Dilatancy) Test: The test involves lightly squeezing a wetted soil pat between the thumb and forefinger and releasing it alternatively to observe its reaction and the speed of the response. Soils that are predominantly silty (nonplastic to low plasticity) will show a dull dry surface upon squeezing and a glassy wet surface immediately upon releasing of the pressure. Highly plastic clays do not exhibit this reaction.

Image description: Photo of a hand with wet mud covering the thumb and forefinger.

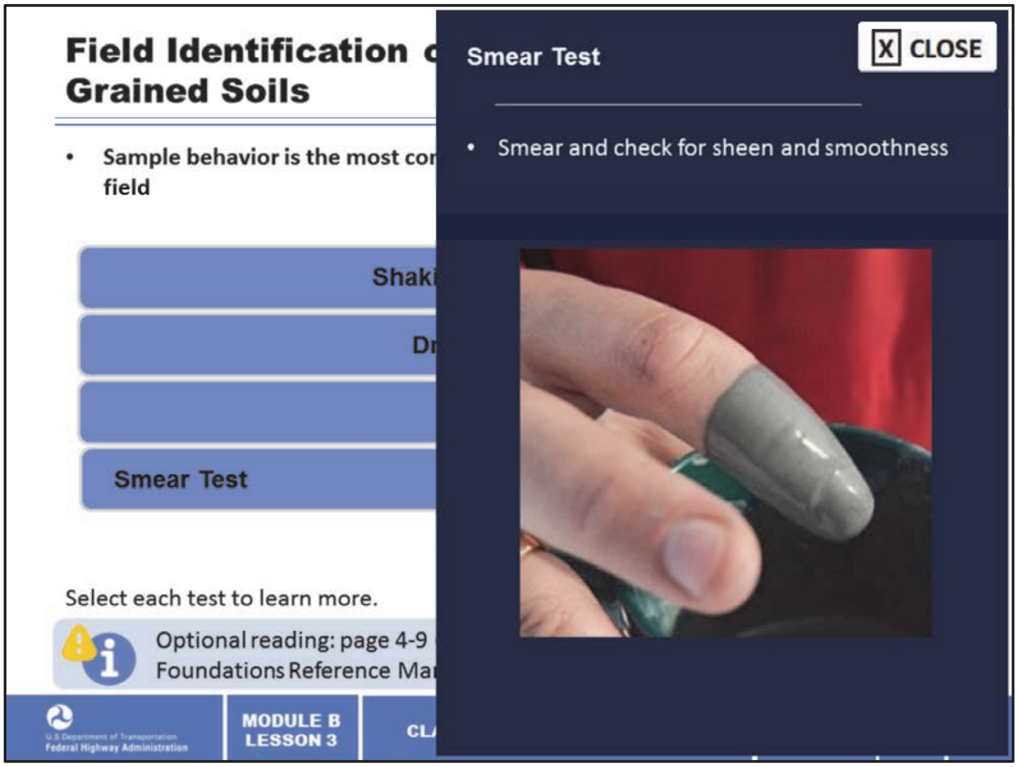
Dry Strength Test: A portion of the sample is allowed to dry out and a fragment of the dried soil is pressed between the fingers. Fragments which cannot be crumbled or broken are characteristic of clays with high plasticity. Fragments which can be disintegrated with gentle finger pressure are characteristic of silty materials of low plasticity. A small cube of soil can be molded and dried on the dashboard of a vehicle to create a test sample.

Image description: Photo of a man holding dried soil clumps in his hands.



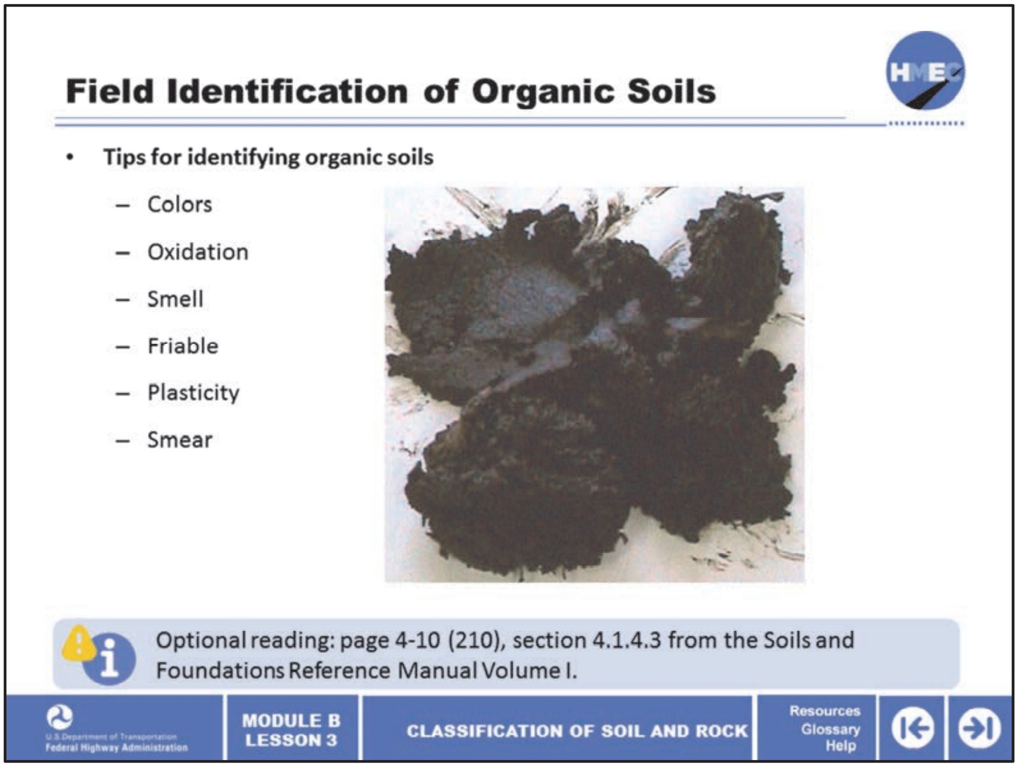
Thread Test: (After Burmister, 1970) A thread is rolled out to the smallest diameter possible before disintegration. The smaller the thread achieved, the higher the plasticity of the soil.

Image description: Photo of a hand rolling a soil thread.



Smear Test: A fragment of soil smeared between the thumb and forefinger or drawn across the thumbnail will, by the smoothness and sheen of the smear surface, indicate the plasticity of the soil.

Image description: Photo of an index finger covered in a smooth, shiny mud.



Organic soils may contain a significant amount of fine-grained inorganic soils or almost none. Fine-grained soil with less than 50% (by volume) of organic matter are described as either organic silts or organic clays. If the percent of organic matter exceeds 50%, they are described as peat. The behavior of these two materials is entirely different. Every effort should be made in the field to identify organic soils, however, to be sure that they are correctly classified they must be sampled and tested in the laboratory (AASHTO T 267 or ASTM D 2974).

The picture shown here is muck with a small trace of vegetative matter.

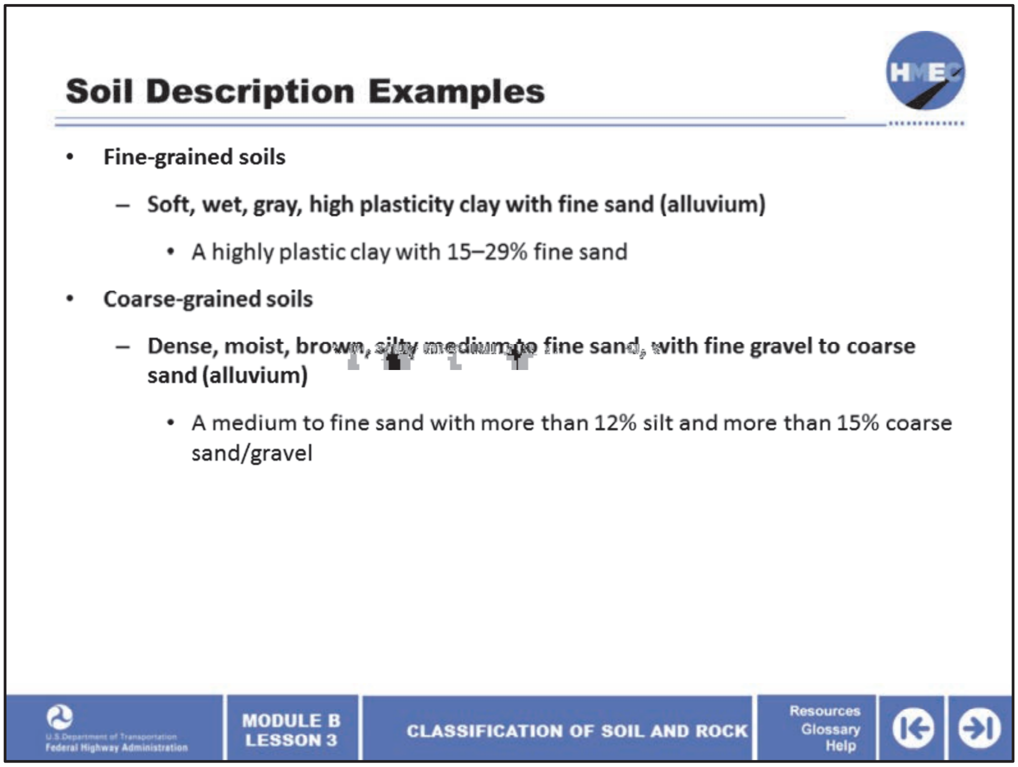
Let's discuss some tips for identifying organic soils:

• Colors: Dark gray and black and sometimes dark brown colors, although not all dark colored soils are organic;
• Oxidation: Most organic soils will oxidize when exposed to air and change from a dark gray/black color to a lighter brown; i.e., the exposed surface is brownish, but when the sample is pulled apart the freshly exposed surface is dark gray/black;
• Smell: Fresh organic soils usually have a characteristic odor which can be recognized, particularly when the soil is heated;
• Friable: Compared to non-organic soils, less effort is typically required to pull the material apart and a friable break is usually formed with a fine granular or silty texture and appearance;
• Plasticity: Their workability at the plastic limit is weaker and spongier than an equivalent

non-organic soil; and
• Smear: Although generally smooth, is usually duller and appears more silty.

For optional reading, refer to page 4-10 (210) to view section 4.1.4.3 from the Soils and Foundations Reference Manual Volume I. This section will provide a more detailed discussion on indicators.

Image description: Photo of organic soil.

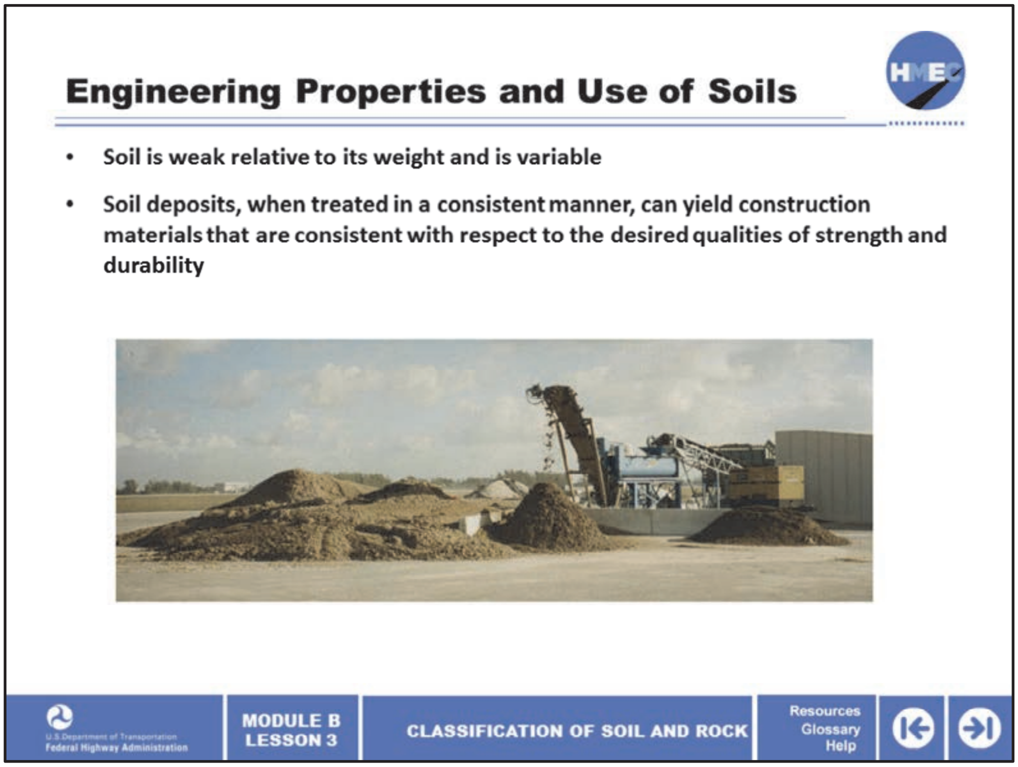


Let's look at a couple of examples of how we might describe two soils we identified in the field.

Fine-grained soils: Soft, wet, gray highly plastic clay with fine sand (alluvium). A properly trained individual reading this description would know that this is a highly plastic clay with 15–29% fine sand that was deposited by water. It has a soft consistency, wet to the touch, and gray in color.

Coarse-grained soils: Dense, moist, brown, silty medium to fine sand with fine gravel to coarse sand (alluvium). A properly trained individual reading this description would know that this is a medium to fine sand with more than 12% silt and more than 15% coarse sand/gravel that was deposited by water. Its apparent density is dense, it has signs of water but is relatively dry to the touch, and is brown in color.

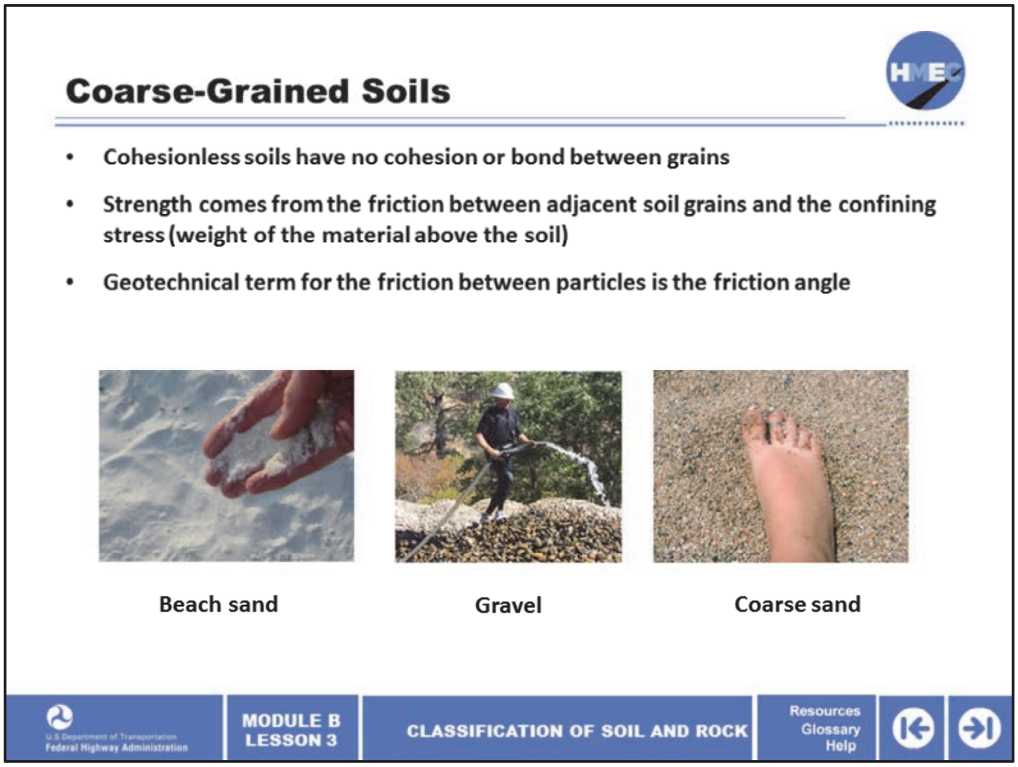
Now that we have learned how to identify and describe soils, let's discuss their engineering properties and uses.



Over the next several slides, we will discuss the engineering properties and uses of soils on our transportation projects. In general, and as compared to other construction materials, soil is weak relative to its weight and is variable.

In spite of those properties, experience has shown that soil deposits, when treated in a consistent manner, can yield construction materials that are consistent with respect to the desired qualities of strength and durability. However, where highway structures must interface directly with the earth in an “as is” condition, such as structure foundations, embankments, or highway subgrades, the geotechnical designs must take into consideration the engineering properties of the soil.

Image description: Photo of an engineering facility.



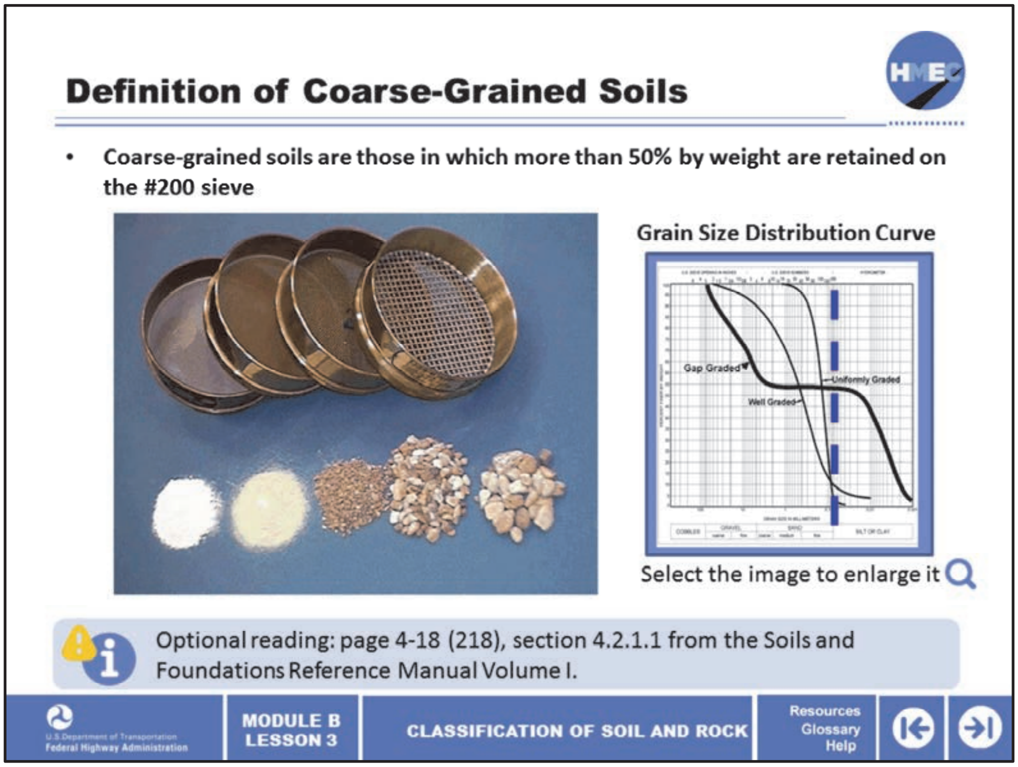
First let's discuss coarse-grained soil and their engineering uses. If the soil does not contain significant amounts of fines, they are also known as cohesionless soils, since they have no cohesion or bond between grains. The strength of cohesionless soils comes from the friction between adjacent soil grains and the confining stress (weight of the material above the soil).

The geotechnical term for the friction between particles is the friction angle, which is dependent on several factors, including density or void ratio, gradation, grain size, and particle shape. We will discuss these factors and their influence later.

Image description: Photo of a hand holding beach sand.

Image description: Photo of a man holding a hose watering down gravel.

Image description: Photo of a foot in coarse sand.

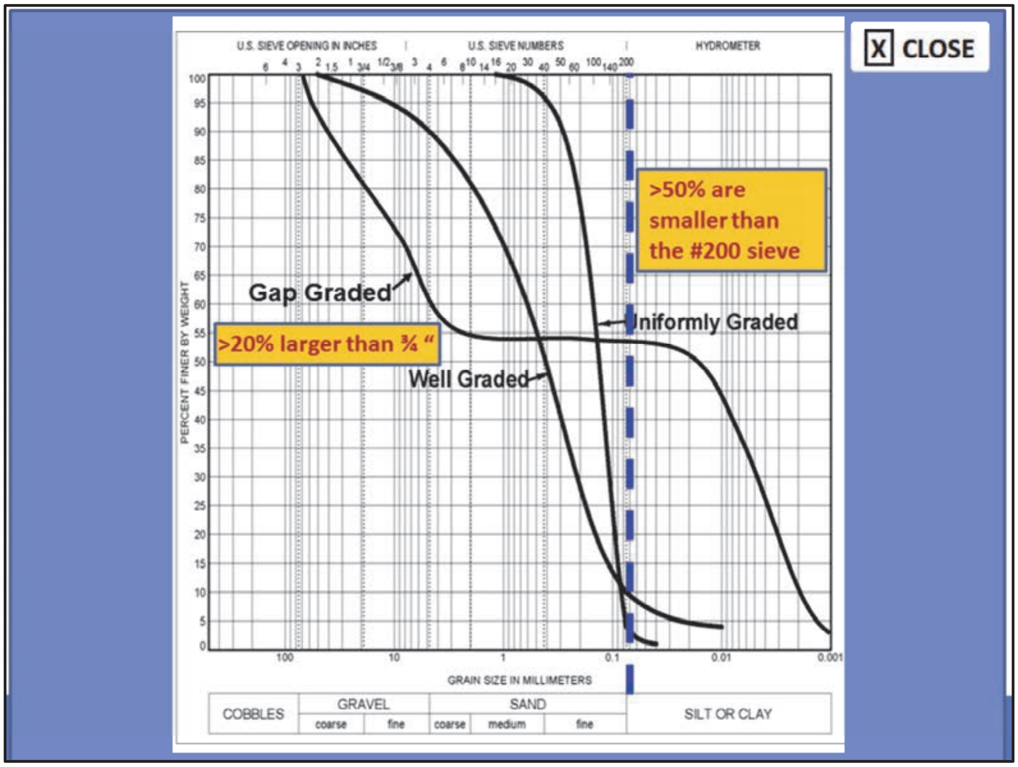


Coarse-grained soil are those that have more than 50% retained on the #200 sieve. The engineering uses and characteristics will be dependent on the distribution of the grain sizes in the material. The grain size distribution (GSD) curve, which is developed based on laboratory sieve analysis, is an excellent tool to help evaluate a coarse-grained material. Select the link to read more about coarse-grained soils.

For optional reading, refer to page 4-18 (218) to view section 4.2.1.1 Classification of Coarse Grained Soils from the Soils and Foundations Reference Manual Volume I.

Image description: Photo of four different sized sieves and five different soil samples.

Image description: Graph of a grain size distribution curve.

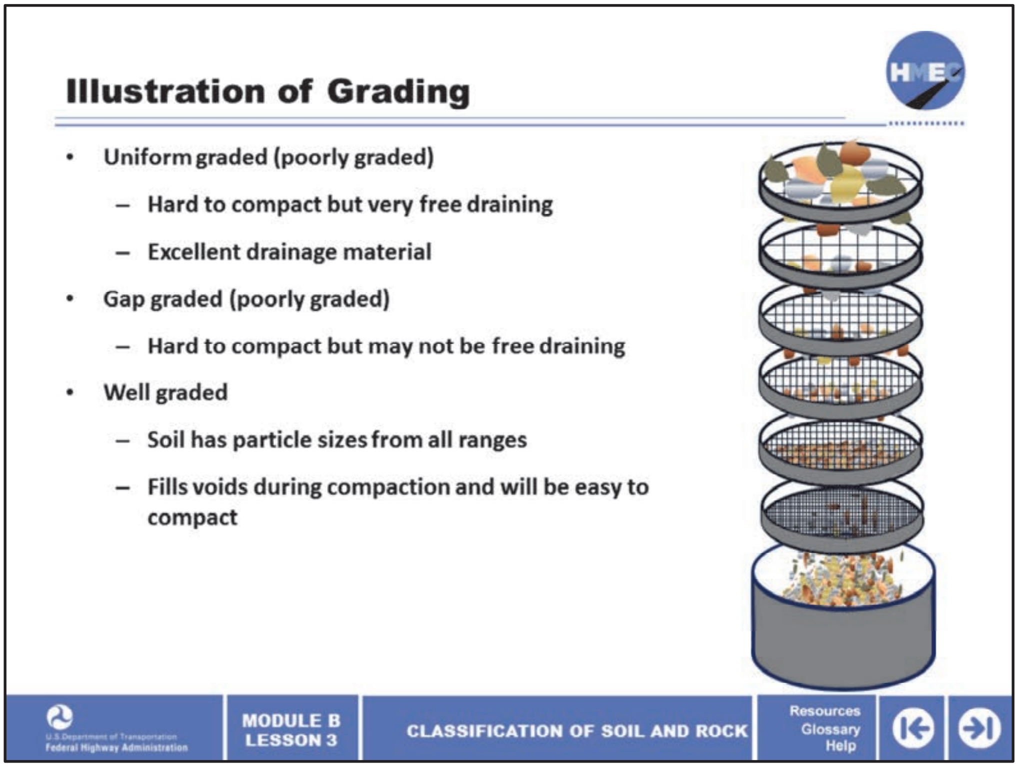


The grain size distribution curve is a graphical representation of the particle size distribution of the material. The GSD indicates whether the material is classified as a coarse or fine grained soil. The GSD also allows us to determine whether the material is well graded, uniformly graded, or gap graded. The gap-graded plot on this illustration provides a good example of an instance when erroneous assumptions could be made based on a simple visual inspection.

The sample has more than 20% of particles larger than ¾ of an inch in size, some which are close to 3 inches. However, since greater than 50% of the material is smaller than the #200 sieve, this material is classified as fine soil. That tells us that even though this sample has large particles included in the matrix, its engineering properties are controlled by the fine particle fraction.

The friction angle of granular soil is dependent on the grain size and gradation of the soil. Well-graded soils will have greater particle interlock and therefore greater friction between soil grains resulting in a higher friction angle and strength as compared to poorly graded soils.

Image description: Graph of a grain size distribution curve.

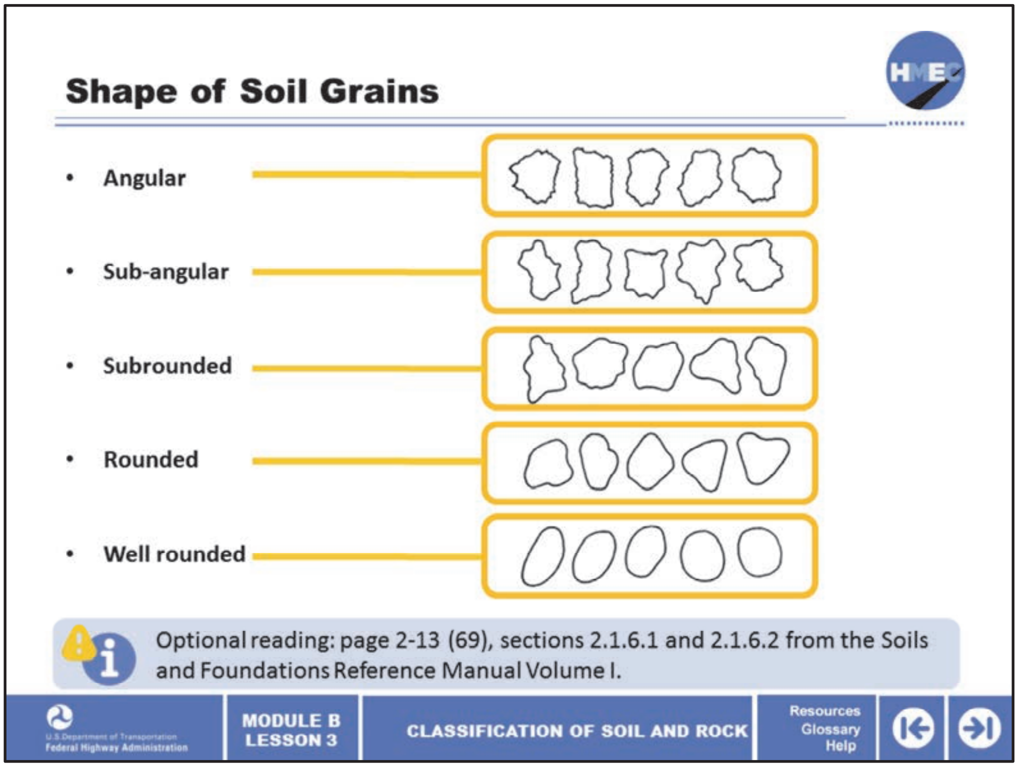


Let's look at a visual illustration of three common grain size distribution curves.

GSD is critical to the engineering properties and performance of coarse soils. If coarse soil has a uniform particle size, such as shown on the first two sieves it is known as poorly/uniformly graded, most particles are a similar size. It will be hard to compact (like marbles), but very free draining. With the proper filter, it will make an excellent drainage material.

If the uniform-graded coarse soil also has fine material but no medium particle sizes as shown with the next four sieves, it is known as poorly/gap graded. It may be hard to compact (like two sizes of marbles). If the fines are minus #200 sieve it may not be free draining. When the coarse soil has particle sizes from all ranges as shown by the seven sieves it is known as well graded. Because there is a full range of particle sizes to fill the voids during compaction it will be easy to compact. It may be free draining depending on the amount of minus #200 sieve material.

Image description: Illustration of six different size sieves with soil pouring through them into a receptacle.



Coarse-grained soil particles have a number of different shapes depending on the method of deposition. They can be angular, sub-angular, subrounded, rounded or well rounded. Most truly angular particles are the product of crushing rock to produce aggregate.

The size, shape, and angularity of soil grains influence the friction angle of cohesionless soils. More angular particles will result in greater particle to particle friction resulting in a greater friction angle. Knowledge of these influences allows us to select the proper material for embankments, backfills and pavement subgrades.

The particle shape characteristics of the aggregate also significantly affect the workability, strength, and durability of the concrete and asphalt concrete. Concrete mixtures containing rough textured or crushed aggregate would show somewhat higher strength at early ages than corresponding concrete containing smooth or naturally weathered aggregate of similar mineralogy.

For optional reading, refer to page 2-13 (69) to view sections 2.1.6.1 Bulky Shape and 2.1.6.2 Platy Shape from the Soils and Foundations Reference Manual Volume I. Read more about the shape of grain sizes and their properties.

Image description: Illustration of angular grains.

Image description: Illustration of sub-angular grains.

Image description: Illustration of subrounded grains.

Image description: Illustration of rounded grains.

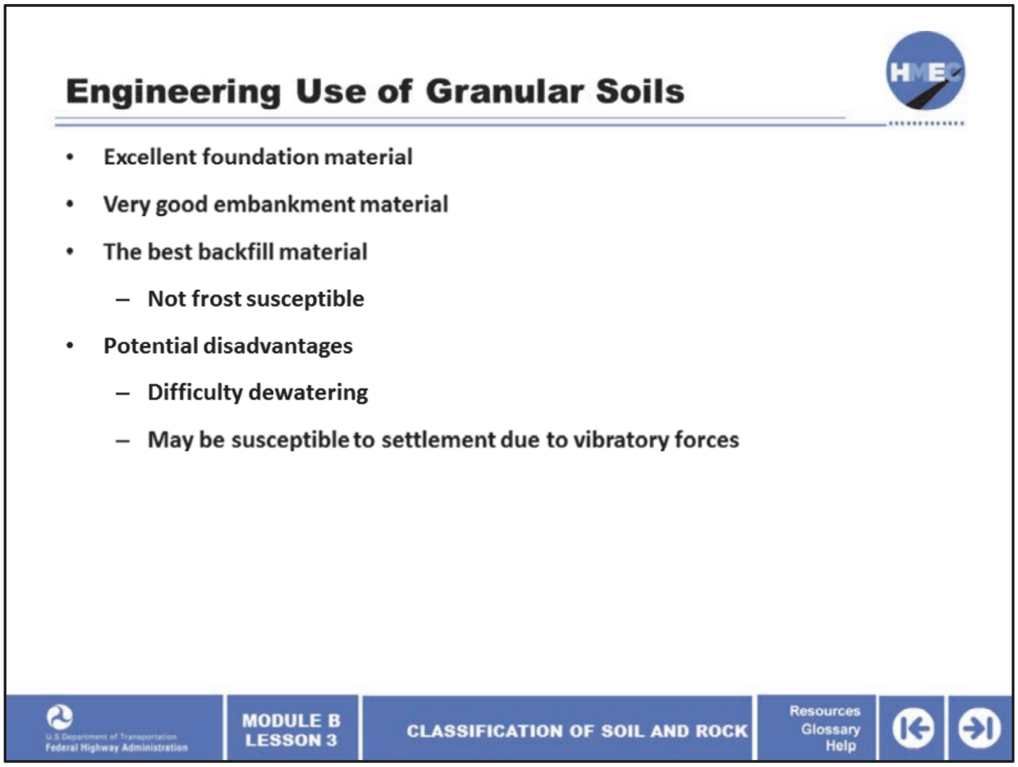
Image description: Illustration of well rounded grains.

Apparent Density of Coarse-Grained Soils

N_{60}	Apparent Density	Relative Density, %
0–4	Very loose	0–20
>4–10	Loose	20–40
>10–30	Medium dense	40–70
>30–50	Dense	70–85
>50	Very Dense	85–100
The above guidance may be misleading in gravelly soils.		

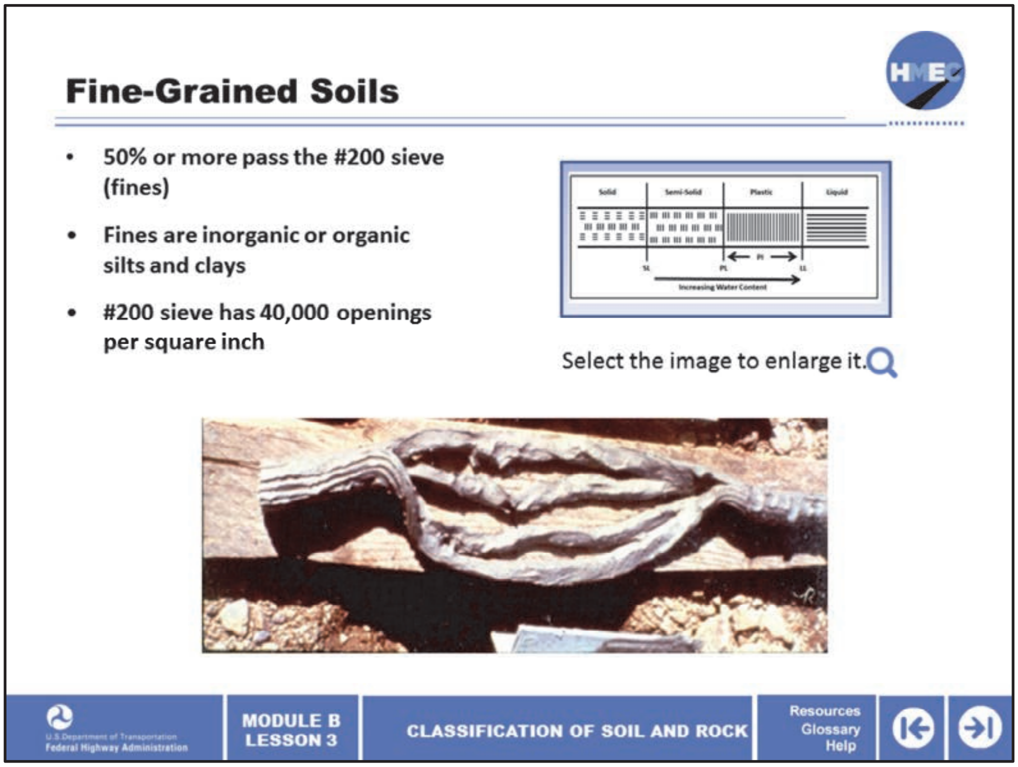
Apparent and relative density of coarse-grained soils can be useful engineering properties to evaluate issues of settlement and/or collapse. They can be estimated by a standard penetration test with corrected blow count data (N_{60}), which will be discussed in detail during Lesson 4. N is the number of hammer blows required to drive the sampler 12 inches into the ground**.**

The density of granular soil also influences the friction angle of the soil. Higher density yields a low void ratio, which means the soil grains are closer together resulting in more interlocking providing a higher friction angle and greater strength. This guidance may be misleading in gravelly soils or cobbles. If a large gravel or a cobble is caught beneath the sampler, an artificially high N value may be recorded.



Let's discuss the engineering use of granular soils. They make excellent foundation material. They make very good embankment material, as long as their erosion potential is properly addressed. When free draining, they make the best backfill material and are not frost susceptible. Potential disadvantages include difficulty dewatering. In addition, some granular soils can be susceptible to settlement when exposed to vibratory forces.

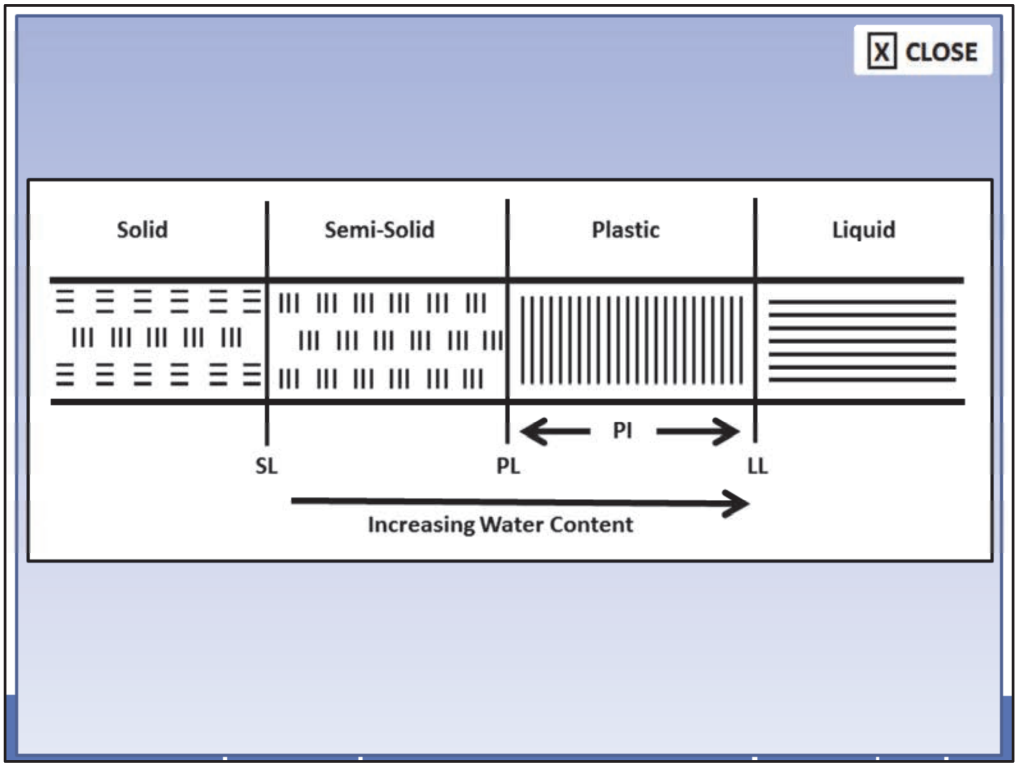
This issue can be mitigated in constructed features by proper compaction. Remember that the friction angle (and therefore strength) of granular soils is strongly influenced by density. Proper compaction increases soil density providing higher strength.



Now let's discuss what constitutes fine-grained soils and their engineering properties. Fine-grained soils are those in which 50% or more pass the #200 sieve (<.075 mm)(fines). The fines are inorganic or organic silts and clays. A #200 sieve has 40,000 openings per square inch. Fine grained soils are classified by Atterberg index tests, liquid limit, and plastic limit. The photograph is a sample of highly plastic clay. The illustration is an example of Atterberg limits. Select the image to enlarge it and learn more.

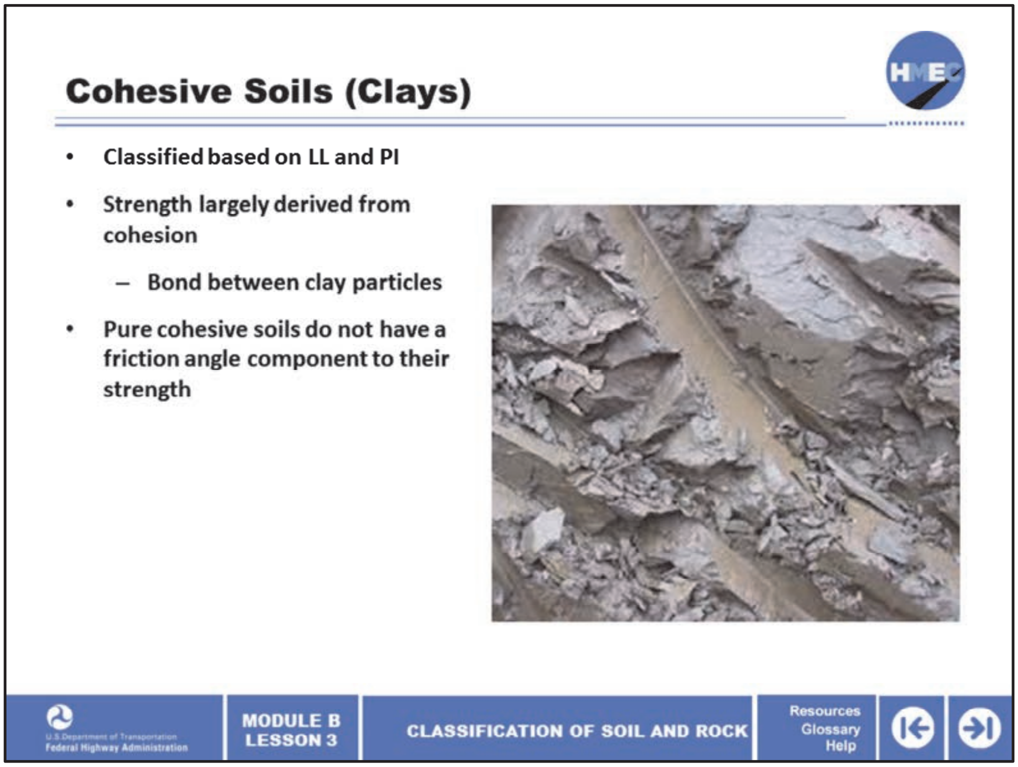
Image description: Photo of a sample of highly plastic clay.

Image description: Illustration of an example of Atterberg limits.



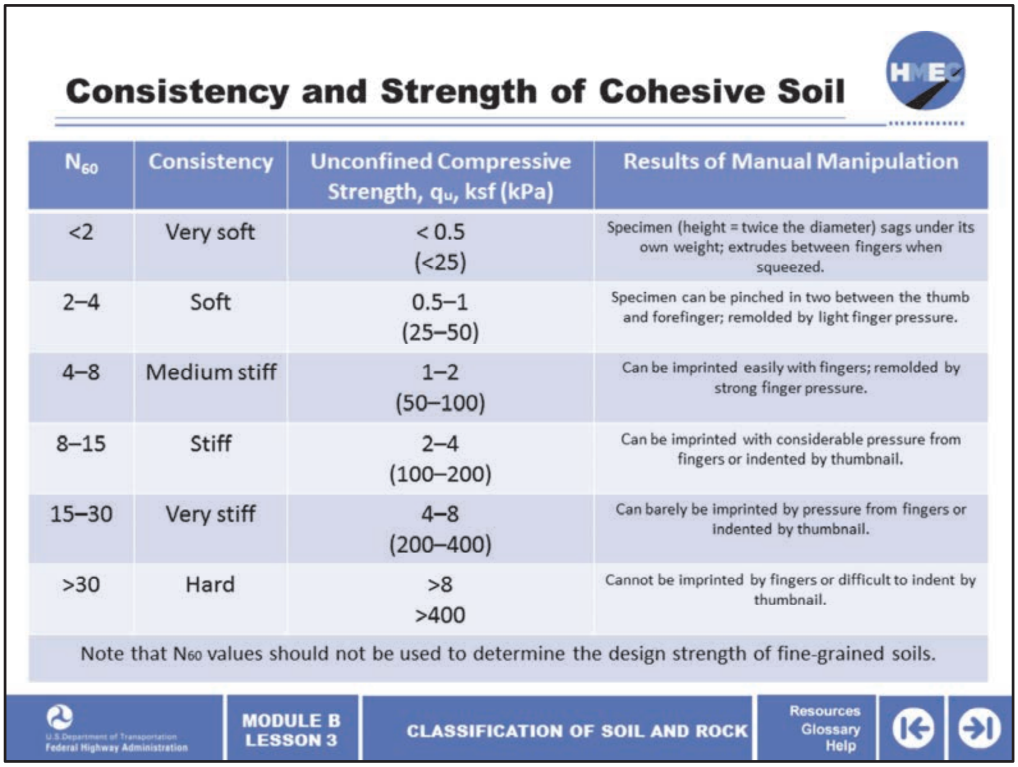
The Atterberg index tests determine the liquid limit (LL), the plastic limit (PL), and the shrinkage limit (SL) of the soil sample. The difference in water content between the LL and PL is the plasticity index (PI), which is used in conjunction with the LL to classify fine-grained soils.

Image description: Illustration of an example of Atterberg limits.



First let's discuss clays, we will discuss silts and organic soils later in the lesson. Clays are cohesive soils that are classified based on their LL and PI. Again, the PI is the difference in water content between the LL and PL (plastic limit). Their strength is derived from cohesion, which is the bond between clay particles. Pure cohesive soils do not have a friction angle component to their strength.

Image description: Photo of clay.



Consistency and Strength of Cohesive Soil

N_{60}	Consistency	Unconfined Compressive Strength, q_u, ksf (kPa)	Results of Manual Manipulation
<2	Very soft	< 0.5 (<25)	Specimen (height = twice the diameter) sags under its own weight; extrudes between fingers when squeezed.
2–4	Soft	0.5–1 (25–50)	Specimen can be pinched in two between the thumb and forefinger; remolded by light finger pressure.
4–8	Medium stiff	1–2 (50–100)	Can be imprinted easily with fingers; remolded by strong finger pressure.
8–15	Stiff	2–4 (100–200)	Can be imprinted with considerable pressure from fingers or indented by thumbnail.
15–30	Very stiff	4–8 (200–400)	Can barely be imprinted by pressure from fingers or indented by thumbnail.
>30	Hard	>8 >400	Cannot be imprinted by fingers or difficult to indent by thumbnail.

Note that N_{60} values should not be used to determine the design strength of fine-grained soils.

Consistency and strength are two engineering properties that we use to evaluate the use and performance of cohesive soils. This table provides consistency and strength data for cohesive soils and relates those properties to corrected SPT blowcounts N_{60}.

For example, let's look at a soil with medium stiff consistency. We would expect the blowcounts to be in the 4–8 blows per foot range, and the strength to be about 1,000–2,000 psi. If handling a sample of this material we would expect to be able to imprint it easily with our fingers.

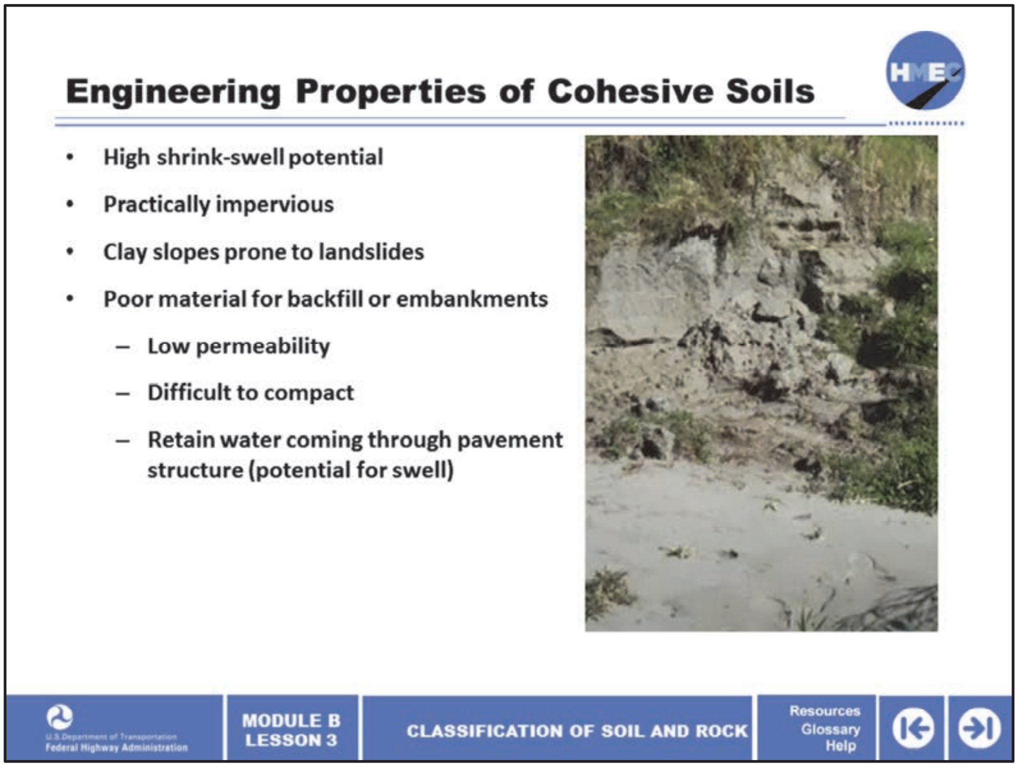
Engineering Properties of Cohesive Soils

- Often possess low shear strength
- Plastic and compressible
- Strength reduced by wetting or disturbance

Cohesive soils (clays) have a wide range of engineering properties depending on how they were deposited and also, on their stress history (we will discuss stress history in later lessons, but basically stress history is the loads a soil particle has been subjected to in the past).

If clays are normally consolidated, that is they have not been subject to high loads at sometime in the past, they often possess low shear strength, are plastic and compressible and their strength is reduced even more by wetting or disturbance.

Image description: Photo of a construction site.



Additional engineering properties associated with normally consolidated clays include, high shrink-swell potential as they are wetted or dried. Clays are practically impervious. Because of clay's low permeability clay slopes are prone to landslides. Recall the issues with paleosols from Lesson 2.

Clays also make poor backfill or embankment material, because they have low permeability, are difficult to compact, and retain any water coming through the pavement structure (potential for swell).

Image description: Photo of a collapsed clay embankment.

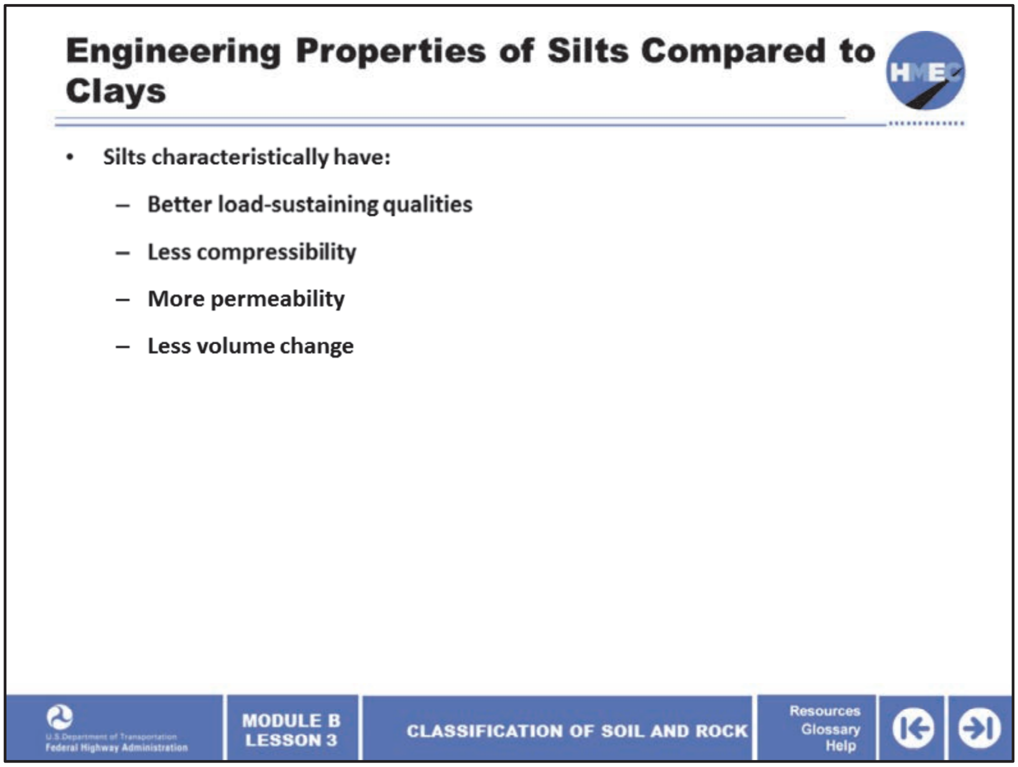
Silts

- Similar to clays but exhibit no cohesion
  - Strength of silt deposits are due to friction angle and confining stress
- Engineering properties of silts
  - No cohesion
  - Relatively low shear strength
  - Relatively low permeability
  - High capillarity
  - Frost susceptibility

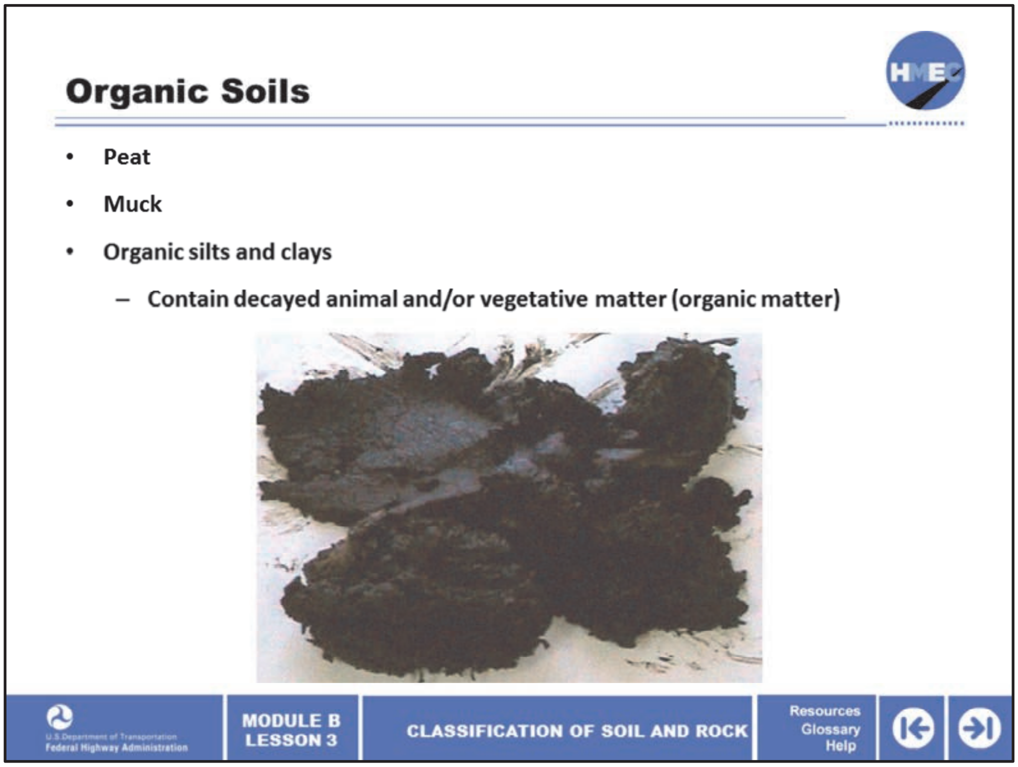
Now let's discuss silts. Silts are similar to clays, however, because of their larger particle size, mineralogy, and the shape of those particles, they typically do not get their strength from cohesion. Strength of silt deposits are due to their friction angle and confining stress similar to coarse grained soils.

Engineering properties of silts are similar to clays, but have no cohesion. They have relatively low shear strength and relatively low permeability. Because they have small pores between particles, silts have a high potential for drawing water into their pores through capillary action, therefore they are frost susceptible soils. As shown in the photograph, silts are sensitive to vibration; particularly when the groundwater is near the ground surface.

Image description: Photo of heavy equipment sunk in a mud puddle.

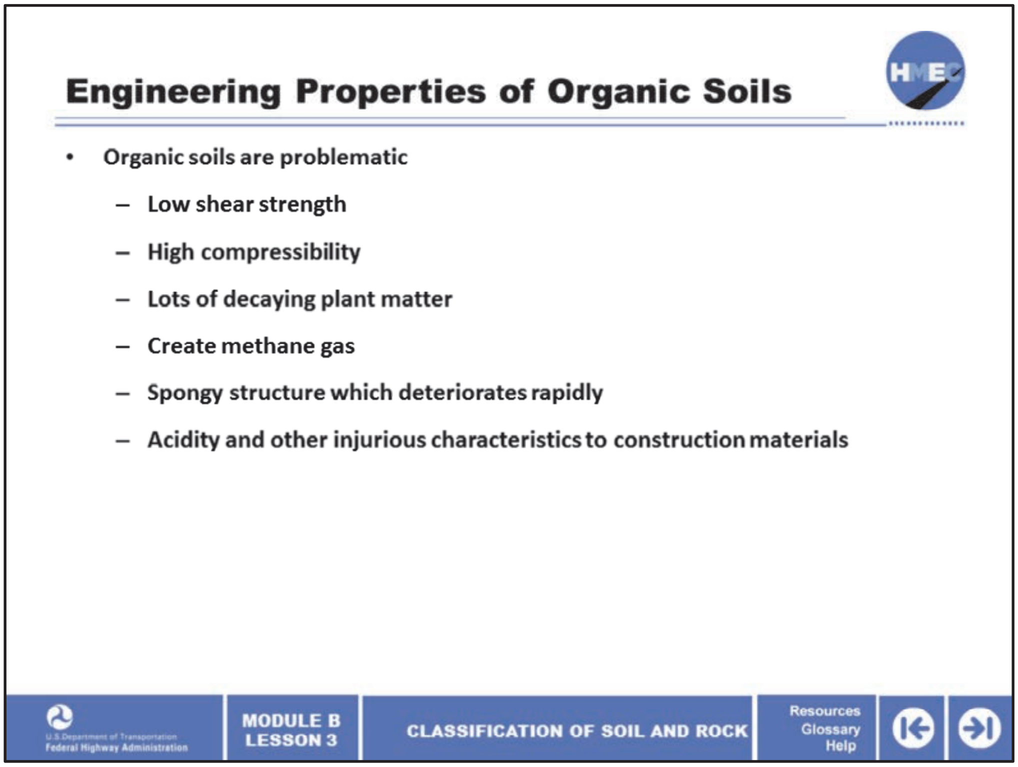


Let's contrast engineering properties of silt and clay. Silts typically have better load-carrying qualities, less volume change and therefore less compressibility, and they are more permeable than clays.



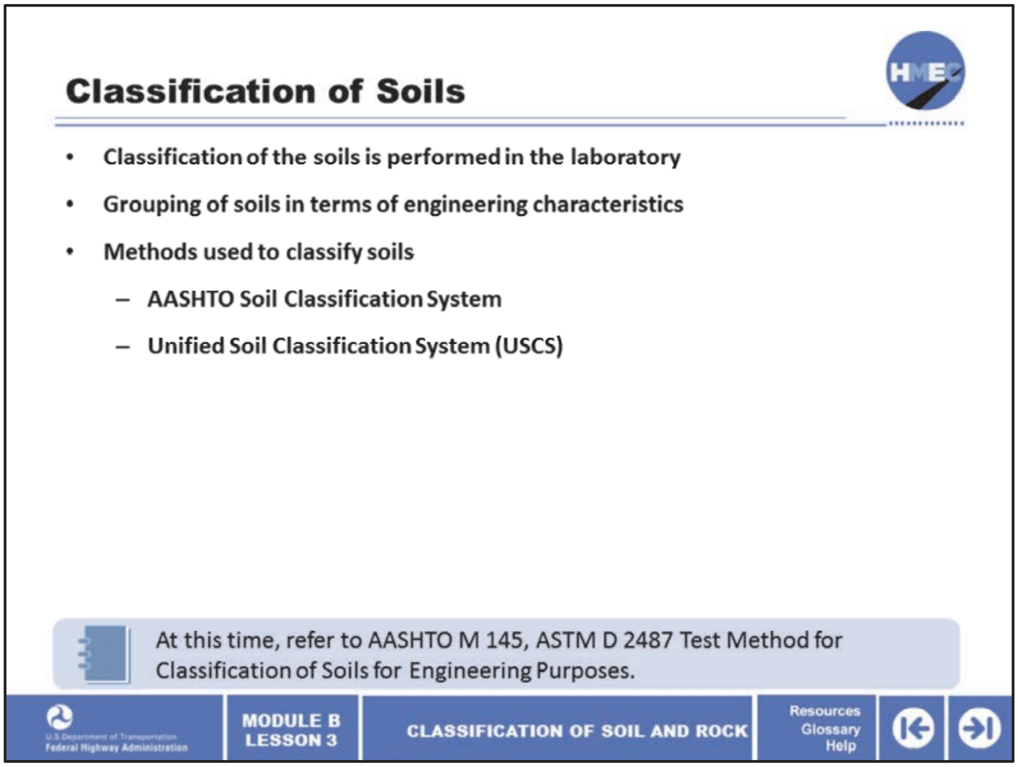
Finally, let's discuss organic soils. Organic soils include peat, muck, and organic silts and clays. They contain decayed animal and/or vegetative matter (inorganic silts and clays that contain large amounts of organic matter). These are not topsoil, which is the relatively thin layer of soil on the surface composed of partially decomposed organic matter.

Image description: Photo of organic soil.



Organic soils are problematic. They have very low shear strength and are highly compressible. They have lots of plant matter, which will continue to decay and cause future problems, even if we deal with the immediate settlement and strength issues.

Organics decomposing in an aerobic environment creates methane gas, which can be released during excavation or exploration. They have a spongy structure which deteriorates rapidly. Organics are typically acidic, which will corrode or deteriorate many construction materials. Organic soils are trouble. Excavate and replace (i.e. dispose of excavated material) whenever possible.



Now that we have learned how to identify and describe soils and discussed their engineering properties and uses, let's discuss how we classify soils into useful groups.

Classification is a laboratory based process of grouping soils with similar engineering characteristics into categories based on index test results; e.g., group name and symbol (AASHTO M 145, ASTM D 2487).

The important distinction between classification and both identification and description is that standard AASHTO or ASTM tests must be performed to determine a soil's classification. The field personnel should only identify and describe the soils encountered. Group symbols associated with classification should not be used in the field. It is important to send the soil samples to a laboratory for accurate visual identification classification by a technician experienced in soils work.

We have discussed the need to classify soils using laboratory tests and engineering properties, now let's discuss two methods used to classify soils. The Unified Soil Classification System (USCS) and the American Association of State Highway and Transportation Organizations (AASHTO) Soil Classification System are two methods commonly used by transportation agencies.

Classification is a formal process and is based upon laboratory test results and, therefore, is less subjective than MUD description process.

At this time, refer to AASHTO M 145, ASTM D 2487 Test Method for Classification of Soils for Engineering Purposes.

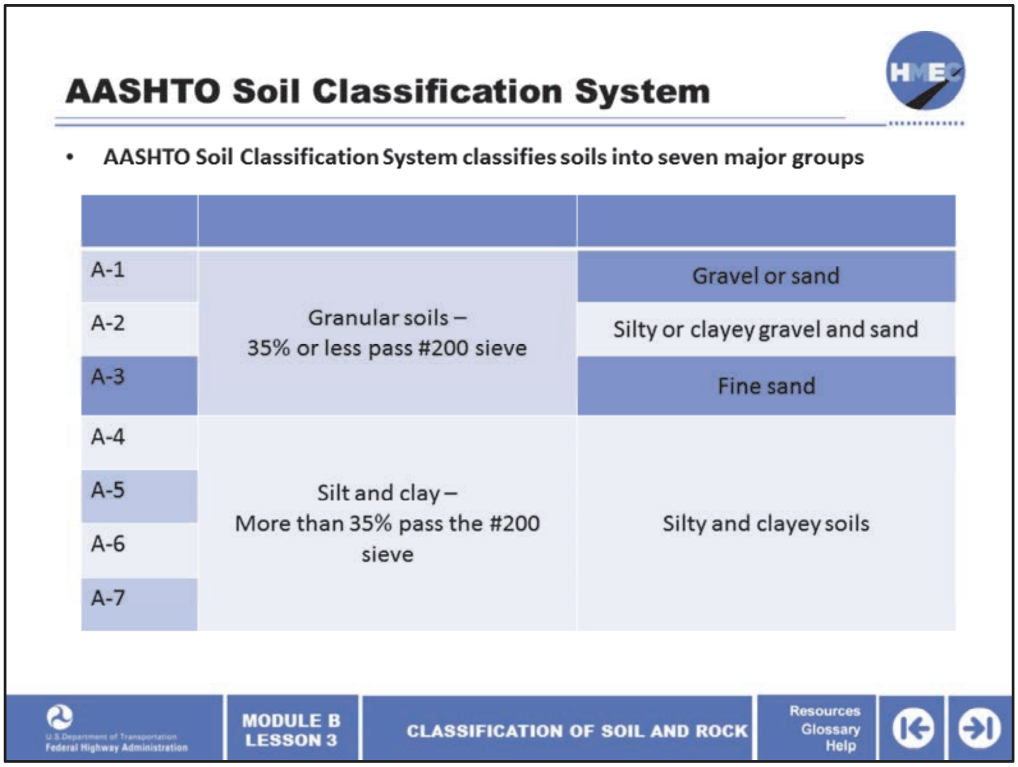
Hyperlink description: http://harpersenterprise.adobeconnect.com/hmec_resource_m145/

AASHTO Soil Classification System

- **Useful in determining the relative quality of soil material for use in earthwork structures particularly:**
  - **Embankments**
  - **Subgrades**
  - **Subbases**
  - **Bases**

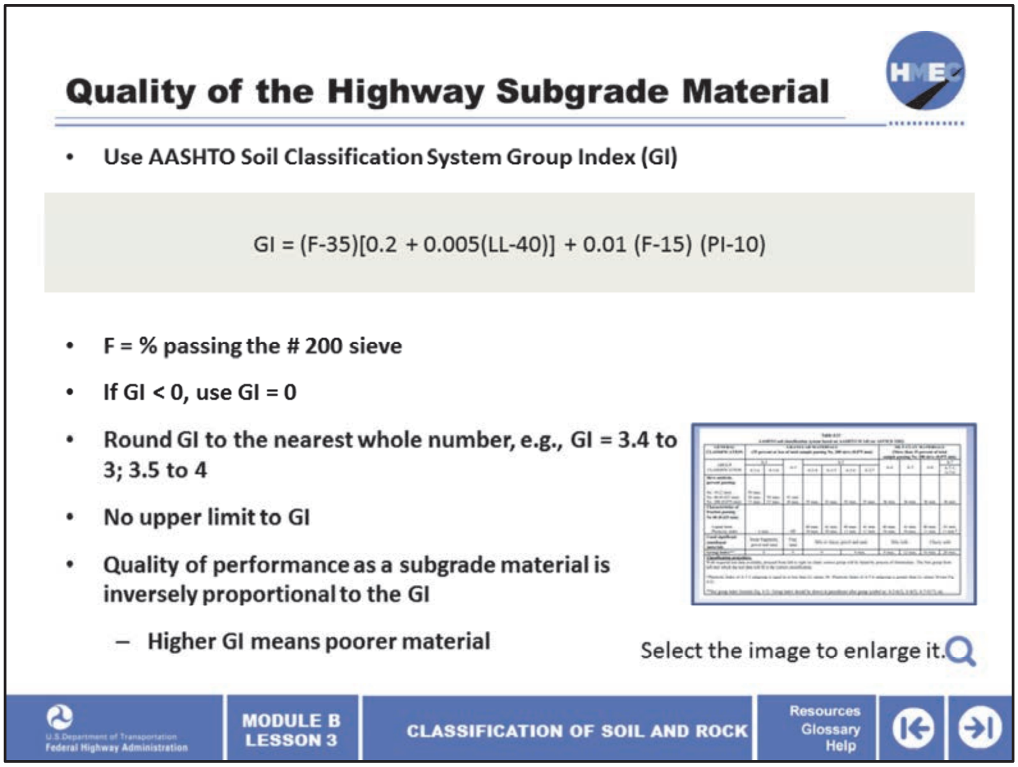
Transportation agencies want to relate soil classification to transportation type structures. The AASHTO Soil Classification System is useful in determining the relative quality of the soil material for use in earthwork structures, particularly embankments, subgrades, subbases, and bases.

Image description: Photo of a very wet embankment with a trucks tires sinking in the mud.



The AASHTO Soil Classification System classifies soils into seven major groups A-1 to A-7. Most of the major groups have subgroups based on the gradation, plasticity index, and group index (which we will discuss later). A-1, A-2, and A-3 are granular soils with 35% or less passing the #200 sieve.

These groups include gravel or sand (A-1), fine sand (A-3), and silty or clayey gravel and sand (A-2). A-4, A-5, A-6, and A-7 are soils where more than 35% passes the #200 sieve. These groups include silty and clayey soil.



The AASHTO Soil Classification group index (GI) is used to evaluate the quality of highway subgrade material. GI is calculated using the formula shown here and test results for percent passing the #200 sieve, LL, and PI. F equals the percentage passing the #200 sieve. If the GI is less than zero, use GI equals zero. The GI is rounded to a whole number and included with the AASHTO designation; it is inversely proportional to subgrade quality.

In the example shown here, 3.4 rounds down to 3; and 3.5 rounds up to 4. Higher GI means poorer material. Select the image to enlarge it and learn more about the AASHTO Soil Classification System.

Image description: Table 4-13 showing AASHTO soil classification system based on AASHTO M 145 (or ASTM D 3282)

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Table 4-13
AASHTO soil classification system based on AASHTO M 145 (or ASTM D 3282)

GENERAL CLASSIFICATION	**GRANULAR MATERIALS (35 percent or less of total sample passing No. 200 sieve (0.075 mm)**							**SILT-CLAY MATERIALS (More than 35 percent of total sample passing No. 200 sieve (0.075 mm)**			
GROUP CLASSIFICATION	A-1		A-3	A-2				A-4	A-5	A-6	A-7
	A-1-a	A-1-b		A-2-4	A-2-5	A-2-6	A-2-7				A-7-5, A-7-6
Sieve analysis, percent passing:											
No. 10 (2 mm)	50 max.										
No. 40 (0.425 mm)	30 max.	50 max.	51 min.								
No. 200 (0.075 mm)	15 max.	25 max.	10 max.	35 max.	35 max.	35 max.	35 max.	36 min.	36 min.	36 min.	36 min.
Characteristics of fraction passing No 40 (0.425 mm)											
Liquid limit				40 max.	41 min.	40 max.	41 min.	40 max.	41 min.	40 max.	41 min.
Plasticity index	6 max.		NP	10 max.	10 max.	11 min.	11 min.	10 max.	10 max.	11 min.	11 min.*
Usual significant constituent materials	Stone fragments, gravel and sand		Fine sand	Silty or clayey gravel and sand				Silty soils		Clayey soils	
Group Index**	0		0	0		4 max.		8 max.	12 max.	16 max.	20 max.

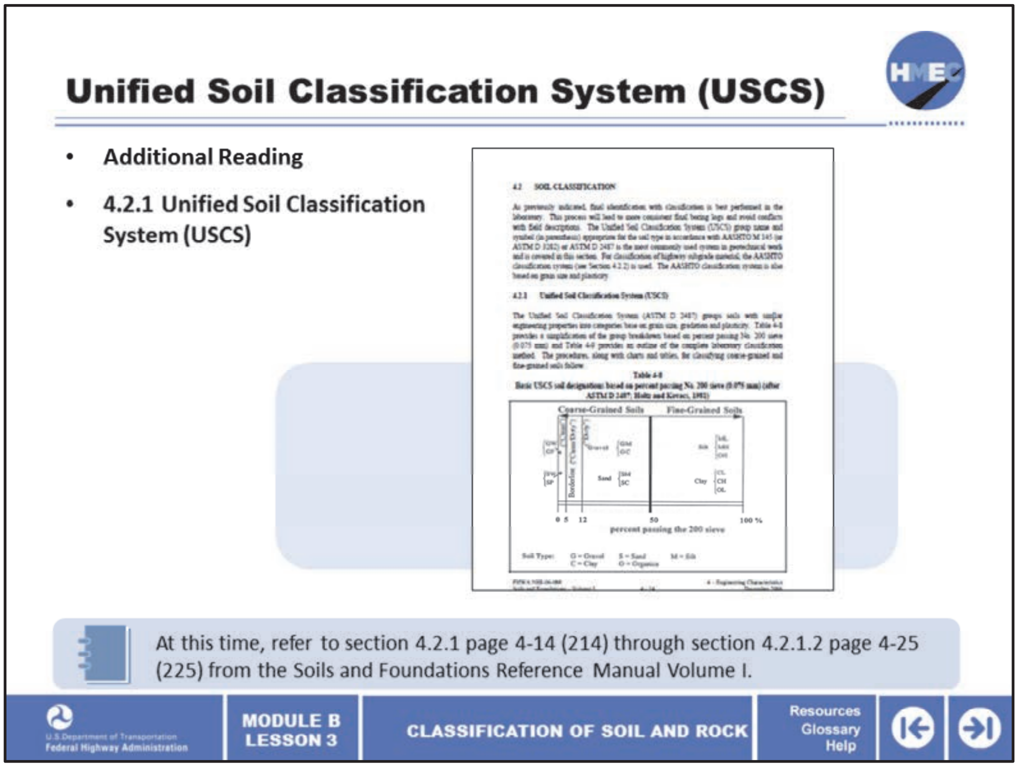
Classification procedure:
With required test data available, proceed from left to right on chart; correct group will be found by process of elimination. The first group from left into which the test data will fit is the correct classification.

*Plasticity Index of A-7-5 subgroup is equal to or less than LL minus 30. Plasticity Index of A-7-6 subgroup is greater than LL minus 30 (see Fig 4-5).

**See group index formula (Eq. 4-3). Group index should be shown in parentheses after group symbol as: A-2-6(3), A-4(5), A-7-5(17), etc.

With test results for a soil, this table is used to classify the material in accordance with the AASHTO Soil Classification System. This reference is on page 4-27 (227 in PDF) of the Soil and Foundations Manual.

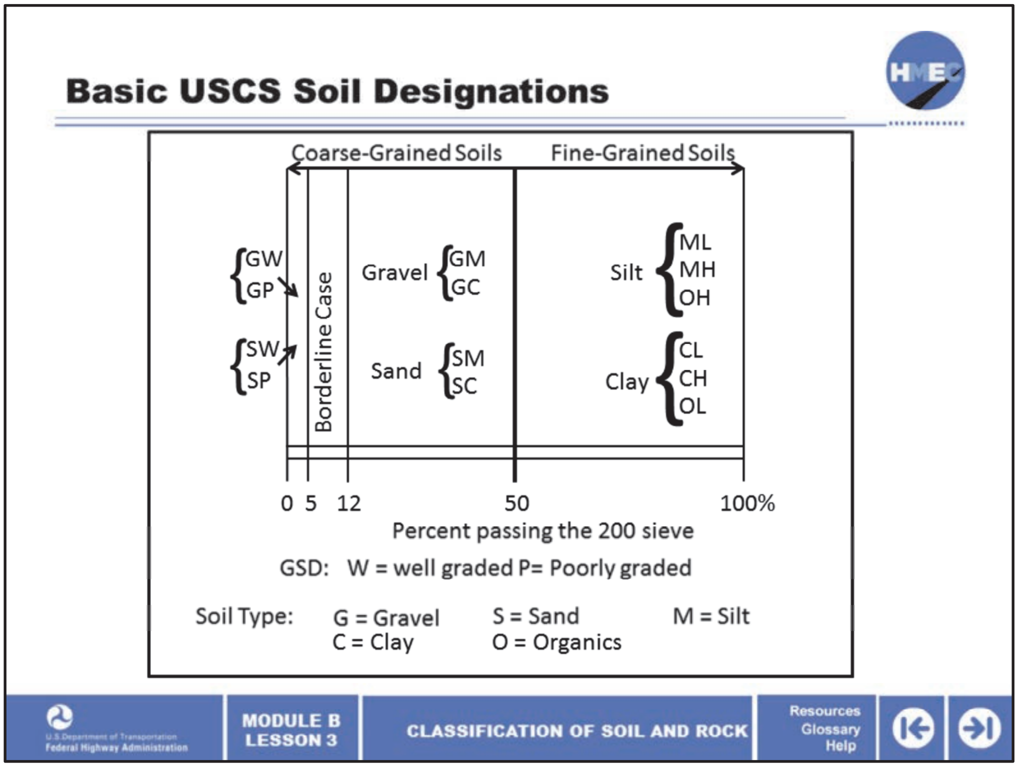
Image description: Table 4-13 showing AASHTO soil classification system based on AASHTO M 145 (or ASTM D 3282).



Please take a few moments to read section 4.2.1 Unified Soil Classification System (USCS) starting on page 4-14 (214) through section 4.2.1.2 Classification of Fine-Grained Soils ending on page 4-25 (225) from the Soils and Foundations Reference Manual Volume I. Once you are done, then please continue on through the lesson.

The following screens will discuss more on this topic.

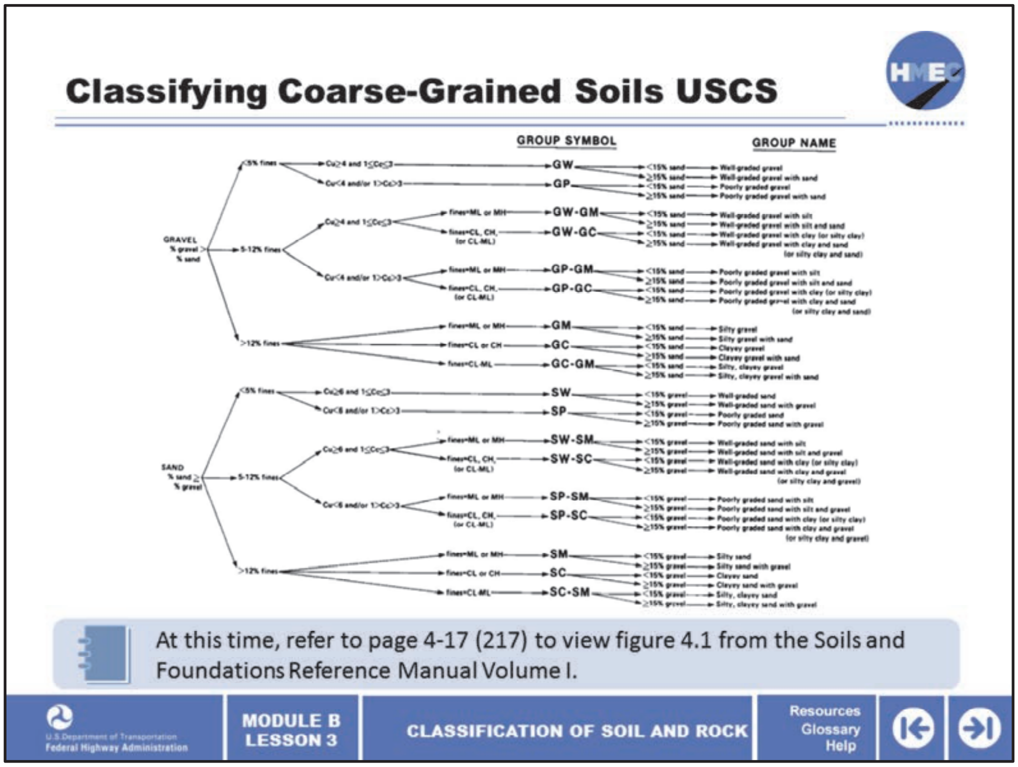
Image description: Page 4-14 of the Unified Soil Classification System.



Another soil classification system used by transportation agencies is the Unified Soil Classification System (USCS). The USCS (ASTM D 2487) groups soils with similar engineering properties into categories based on grain size, gradation, and plasticity. This graphic provides a simplification of the group breakdown based on percent passing the #200 sieve.

Looking at the graphic, let's start with percent passing the #200 sieve. If less than 50% passes the #200 sieve, it is either a sand or a gravel. If the sand or gravel has less than 5% fines, we know the fines won't affect behavior. Therefore, it will be classified as sand or gravel that is either well graded or poorly graded (SW, SP, GW, or GP). If it has more than 12% fines, the fines will affect engineering properties and the designation will include silty or clayey. If 50% or more passes the #200 sieve the soil is classified as silt, clay, or organic with appropriate adjectives (ML, CL, etc). Fine-grained soils are given a designation of L or H for low or high plasticity depending on their liquid limit. The two-letter designation tells you a lot about the soil.

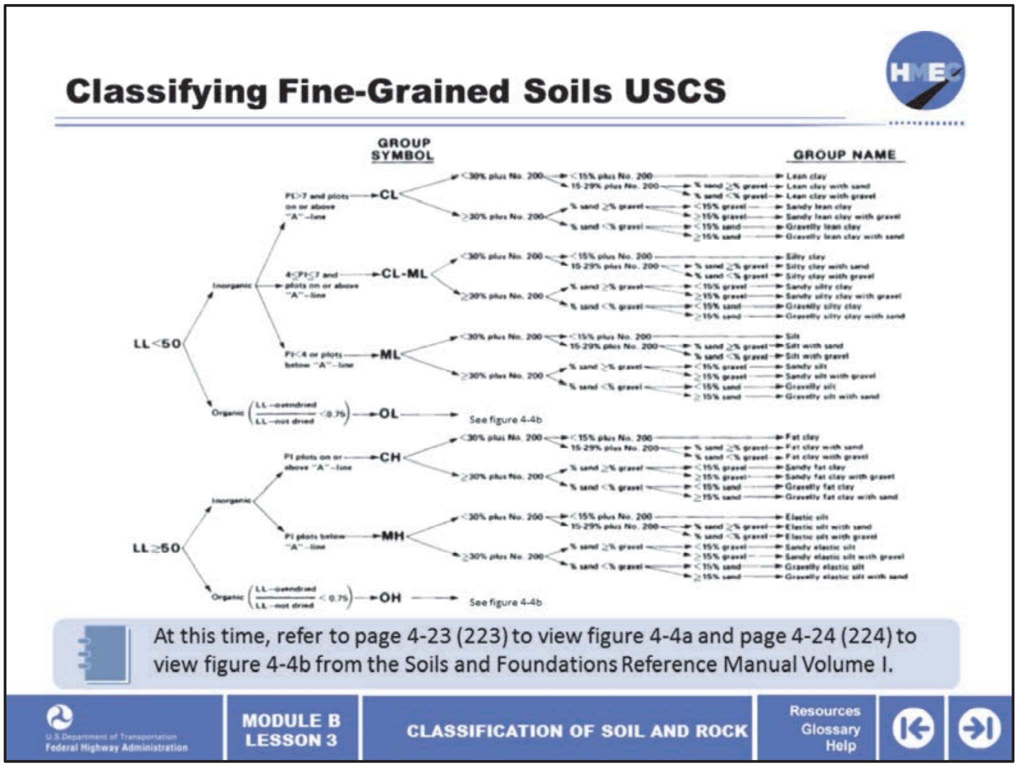
Image description: Illustration of basic USCS soil designations.



The USCS uses a system of flowcharts to guide us through the classification process. Follow the flowchart from left to right to develop the designation for the soil classification and group name for coarse-grained soils. C_u is the coefficient of uniformity.

Please refer to the previously assigned reading on page 4-17 (217) to view figure 4.1 from the Soils and Foundations Reference Manual Volume I. Figure 4.1 is the flow chart to determine the group symbol and group name for coarse-grained soils (ASTM D 2487).

Image description: USCS flowchart.

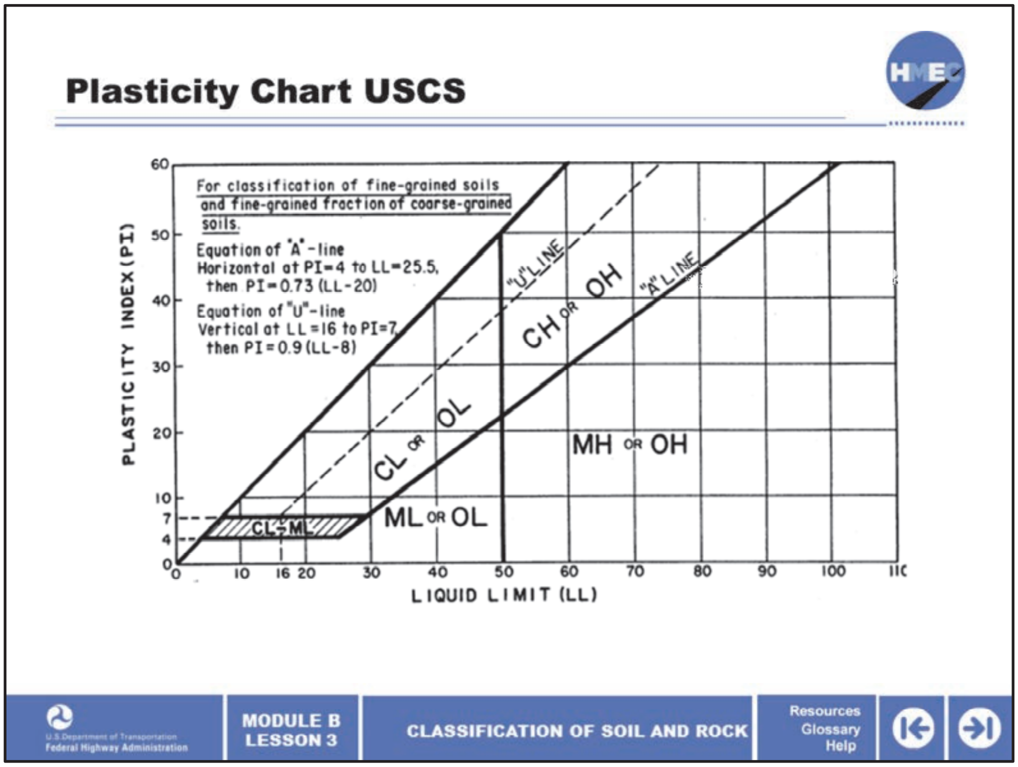


This is the flowchart for fine-grained soils. Please refer to the previously assigned reading on page 4-23 (223) to view figure 4-4a from the Soils and Foundations Reference Manual Volume I.

Figure 4-4a is the flow chart to determine the group symbol and group name for fine-grained soils (ASTM D 2487). Follow the flowchart from left to right to develop the designation for the soil classification and group name. The A line is described on the following slide.

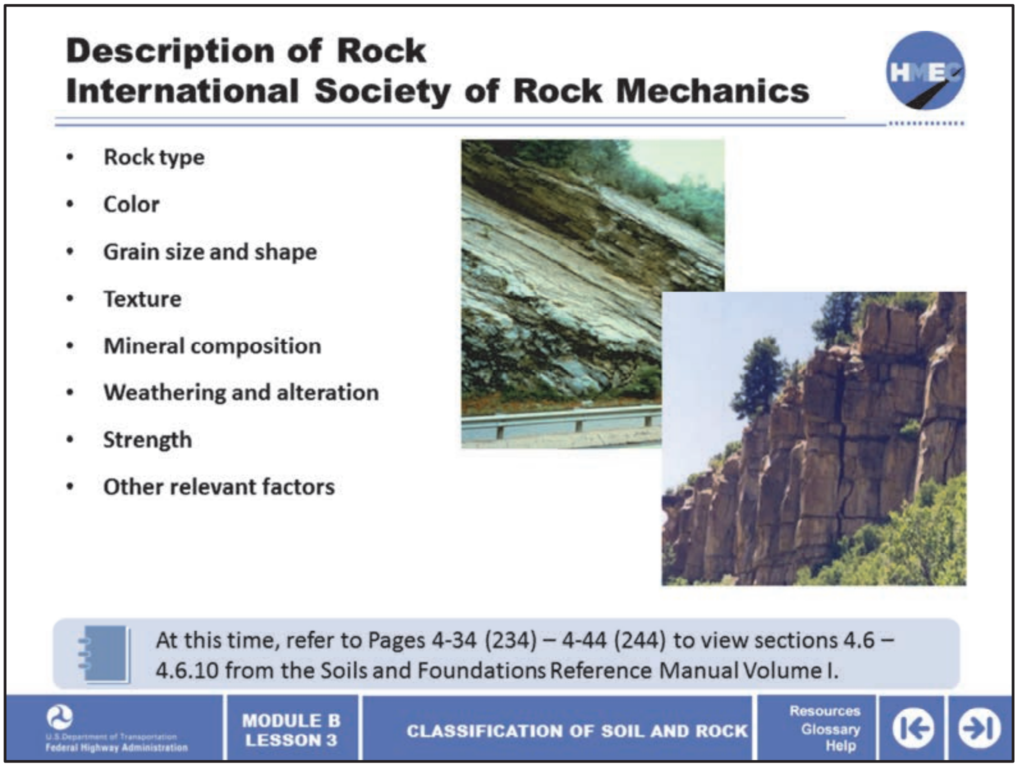
For additional classification of organic soils, see page 4-24 (224) Figure 4-4b. Figure 4-4b is the flow chart to determine the group symbol and group name for organic soils (ASTM D 2487).

Image description: Flowchart for fine-grained soils.



This is the plasticity chart. Every fine-grained soil has a unique position on this chart. The A line is the break between silt and clay. If the plot is above the A line it means for a given LL it has a higher PI, it is a clay. A plot below the A line is a silt. The 50% LL line is the break between high and low plasticity. So we have four quadrants—the universe of fine-grained soils.

Image description: Plasticity chart.



Now, let's switch from soil identification, description, and classification to rock description.

The description of rock should include rock type, color, grain size and shape, texture (such as stratification and foliation), mineral composition, weathering and alteration, strength, and others (such as hardness, fractures and discontinuity). A key point to keep in mind is that the rock mass controls behavior not the intact rock. What that means to us as engineers is that the strength of the intact rock core, although important, may be less important than the joint condition and spacing. Look at the photos and think about how the size, spacing, and direction of joints will influence behavior of the rock mass as a load-carrying element.

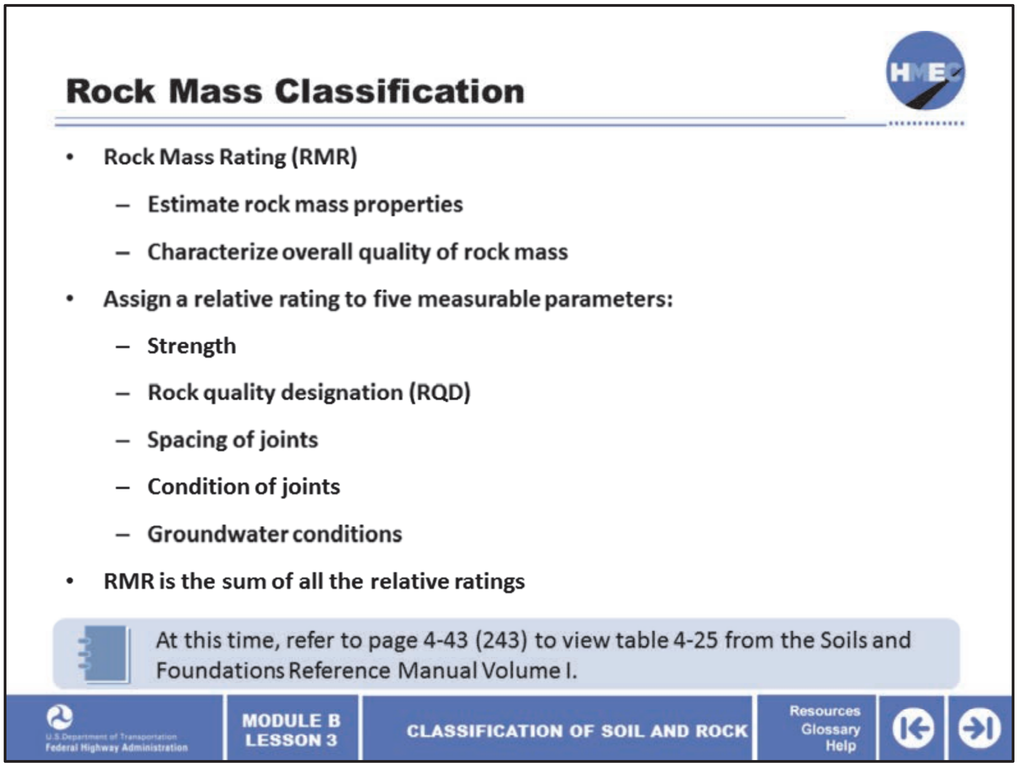
The International Society of Rock Mechanics (ISRM) provides guidelines for description of rock. The *Rock and Mineral Identification for Engineers* booklet that was provided at the beginning of this lesson will provide additional information.

Please take a moment and go to pages 4-34 (234) through 4-44 (244) to view sections 4.6 – 4.6.10 from the Soils and Foundations Reference Manual Volume I.

Hyperlink description: http://www.fhwa.dot.gov/pavement/pccp/fhwahi91205.pdf

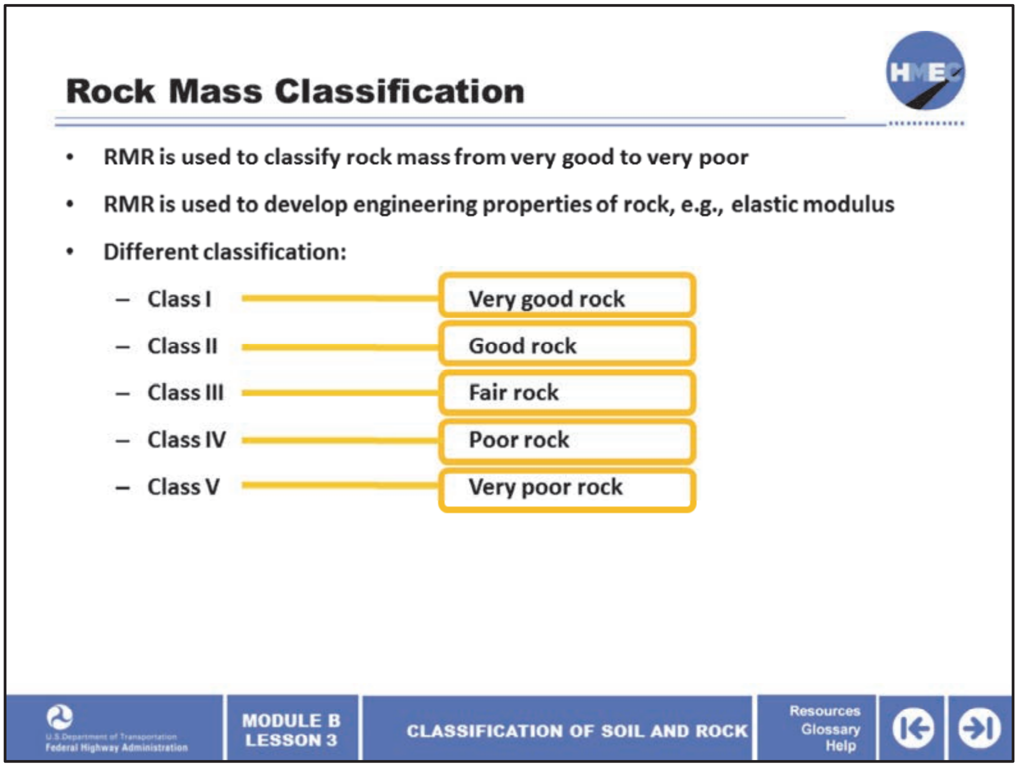
Image description: Photo of rock slope along a road.

Image description: Photo of rock cliff.



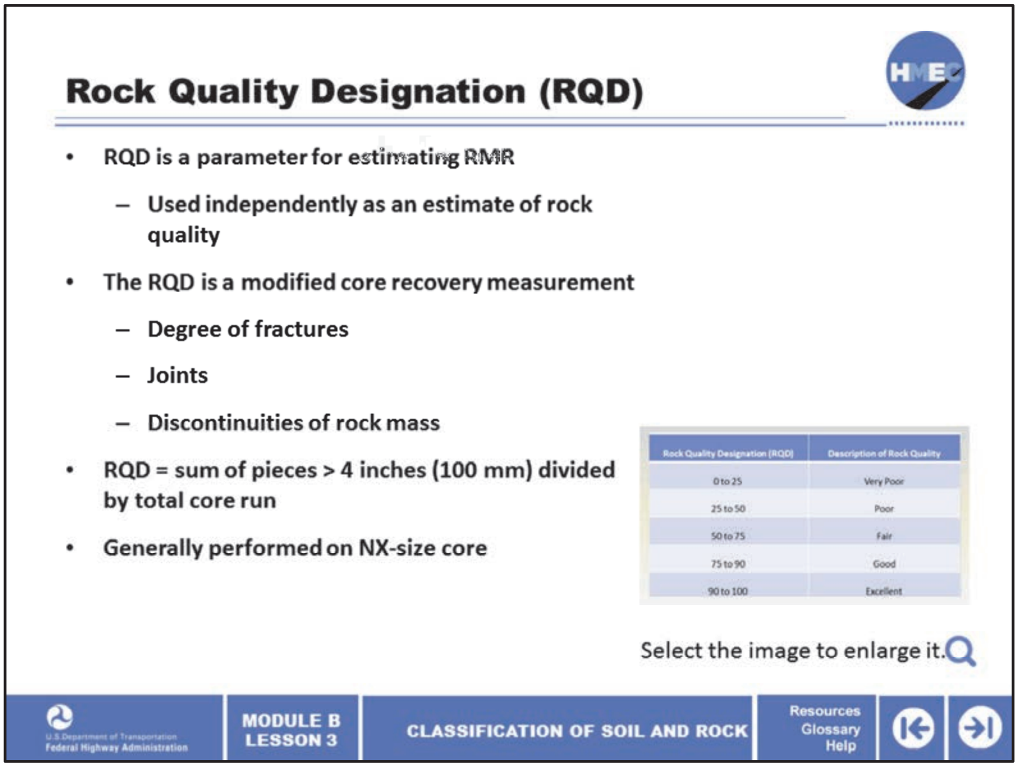
Because the rock mass controls behavior, the rock mass rating (RMR) was developed to estimate rock mass properties and characterize the overall quality of the rock mass. A relative rating is assigned to five measureable parameters including strength, rock quality designation (RQD), spacing of joints, condition of joints, and groundwater conditions. RMR is the sum of all the relative ratings. Various design methods have been derived around the RMR.

Please refer to the previously assigned reading on page 4-43 (243) to review table 4-25 from the Soils and Foundations Reference Manual Volume I. This table will provide more information about the RMR.



RMR is used to classify rock mass from very good to very poor. The class of rock determined by RMR is then used to develop engineering properties for the rock mass such as elastic modulus. The RMR is a better system of looking at rock mass performance than simply using RQD. Here we show the different classifications:

- Class I is very good rock;
- Class II is good rock;
- Class III is fair rock;
- Class IV is poor rock; and
- Class V is very poor rock.



RQD is used as a parameter for estimating RMR, but it is also often used independently as an estimate of rock quality. The RQD is a modified core recovery measurement. It is a measure of the degree of fractures, joints and discontinuities of the rock mass. The RQD is determined by summing up the lengths of all the pieces of core that are at least 4 inches long.

That sum is divided by the length of the core run (typically 60 inches) to get the RQD as a percentage. The RQD is an index of rock quality in that problematic rock that is highly weathered, soft, fractured, sheared, and jointed typically yields lower RQD values. This procedure is generally acceptable for NX cores (2 1/8 inches in diameter) and those slightly smaller and slightly larger and for wire line NQ, HQ, and PQ cores.

Select the image to enlarge it and learn more about RQD.

Image description: Rock Quality Designation table.

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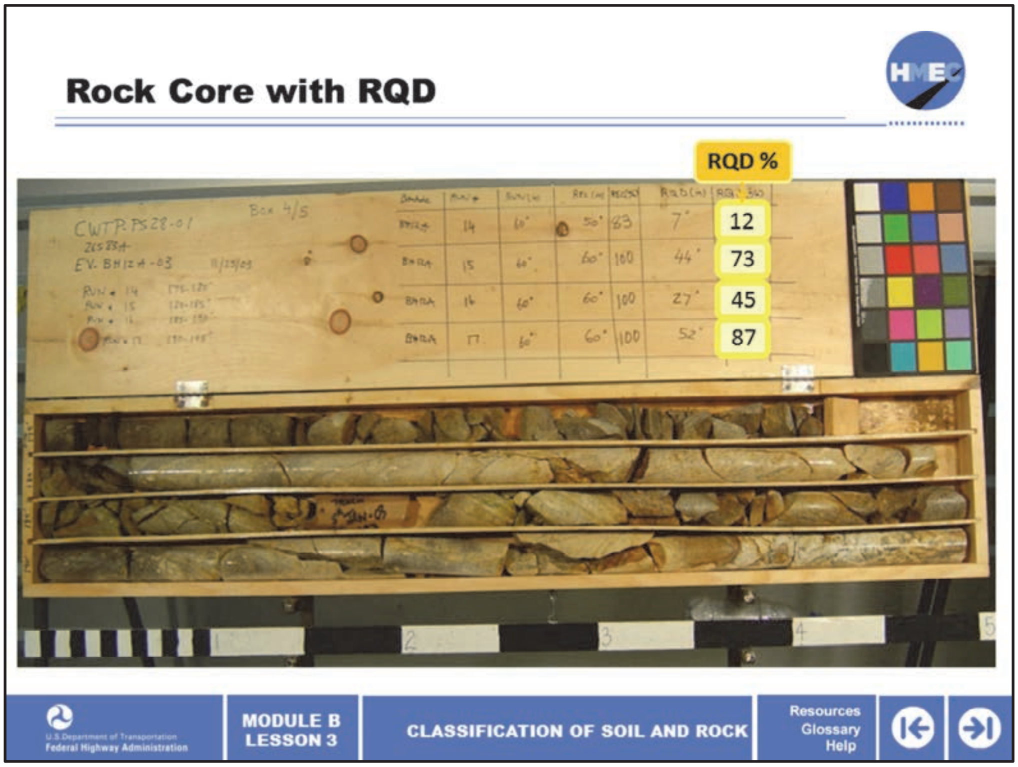
Rock Quality Designation (RQD)	Description of Rock Quality
0–25	Very Poor
25–50	Poor
50–75	Fair
75–90	Good
90–100	Excellent

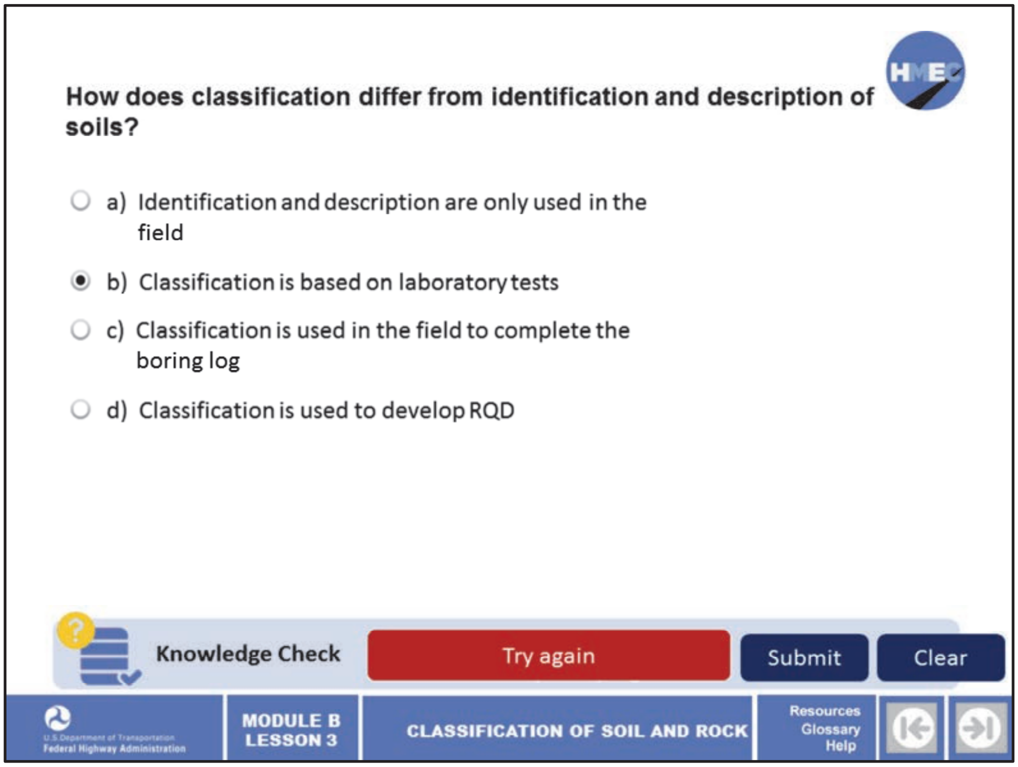
The RQD percentages are used to indicate the quality of the rock from very poor to excellent.

Image description: Rock Quality Designation table.



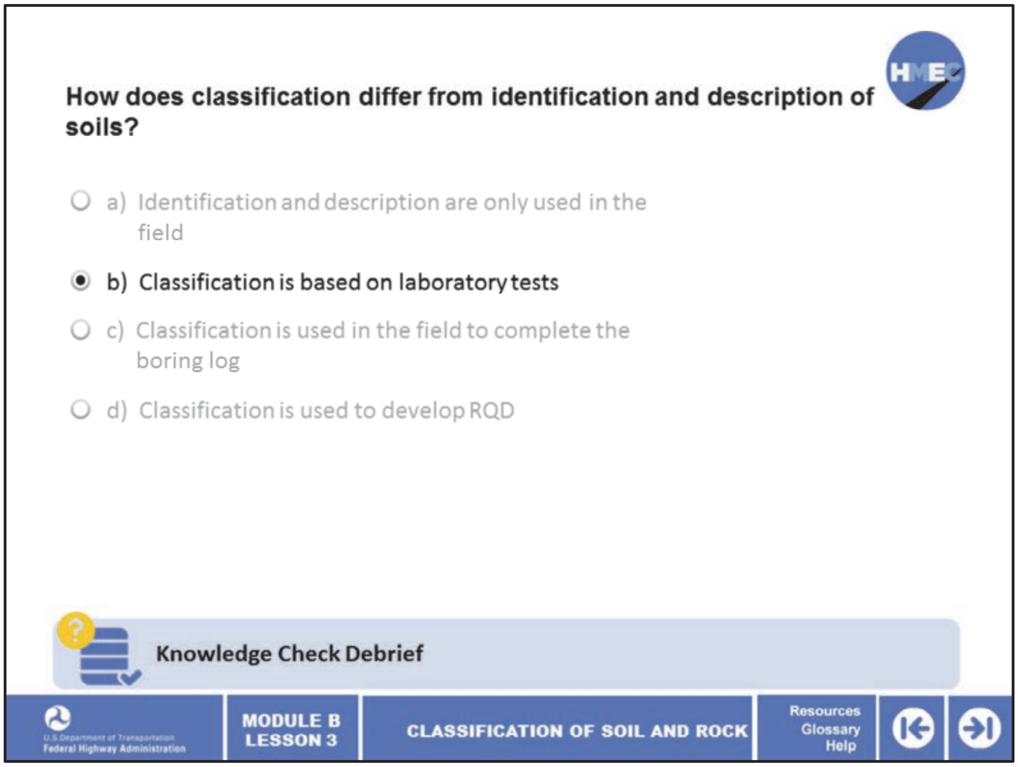
This picture is of a rock core with RQDs. From top to bottom, the core runs have RQDs equal to 12%, 73%, 45%, and 87%.

Image description: Photo of rock core with RQDs.

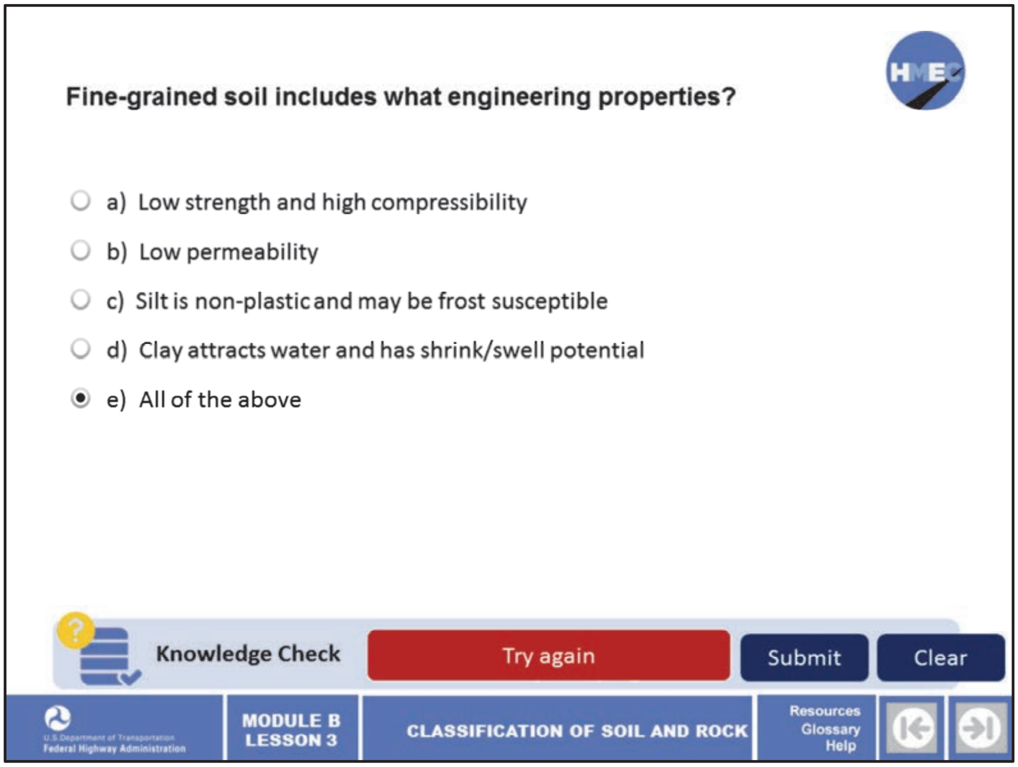


Select the best answer. How does Classification differ from Identification and Description of soils?

a) Identification and description are only used in the field;
b) Classification is based on laboratory tests;
c) Classification is used in the field to complete the boring log; or
d) Classification is used to develop RQD.

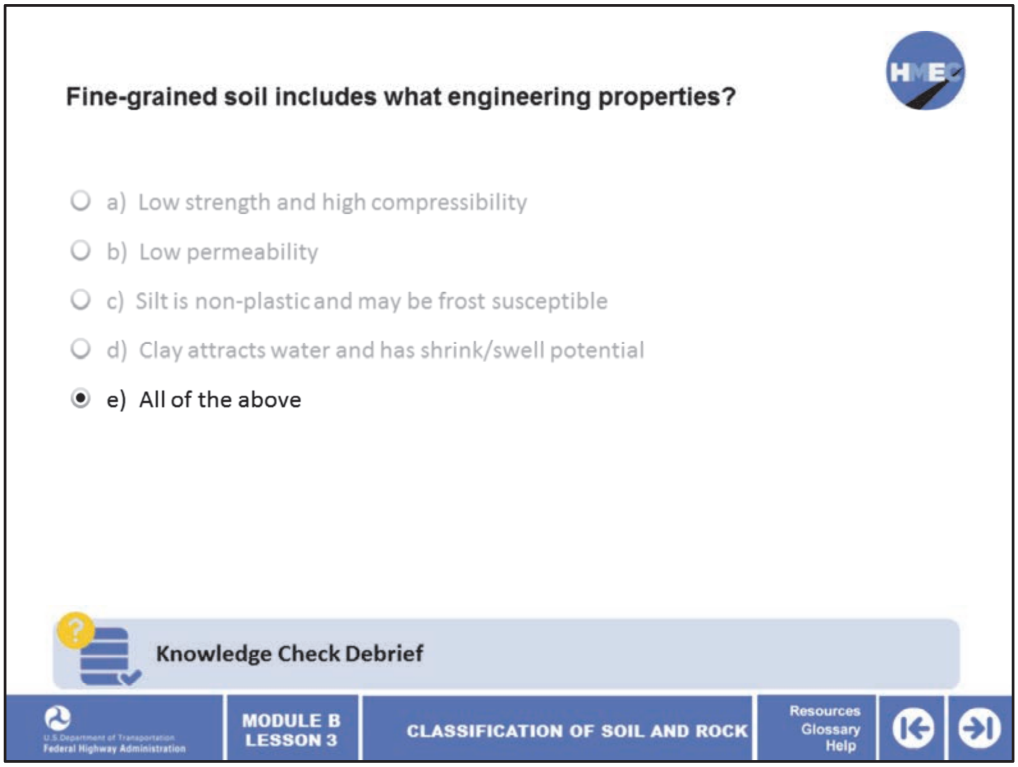


The correct answer is b) Classification is based on laboratory tests. Classification is based on laboratory test results and is used to group soils with similar engineering characteristic into categories. Identification and description are used both in the field to communicate on the boring log and to track the sample through the laboratory process, not just in the field. Classification designations should not be used in the field to describe the soil samples on boring logs.

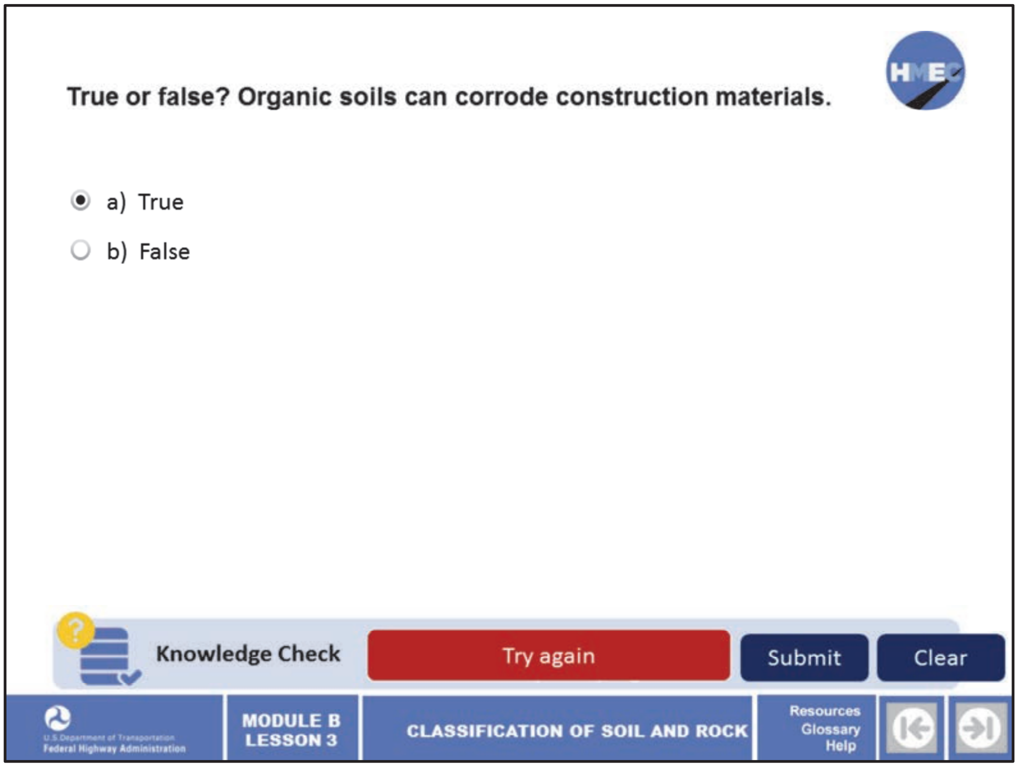


Select the best answer. Fine-grained soil includes what engineering properties?

a) Low strength and high compressibility;
b) Low permeability;
c) Silt is non-plastic and may be frost susceptible;
d) Clay attracts water and has shrink/swell potential; or
e) All of the above.

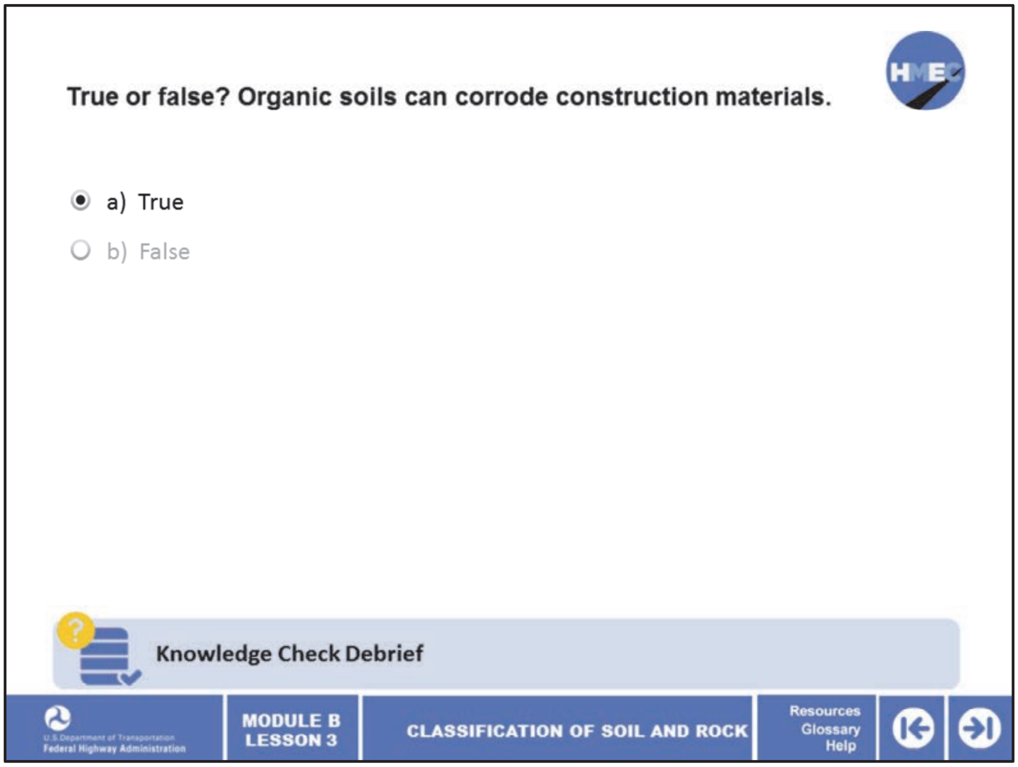


The correct answer is e) All of the above. Both silts and clays are low strength and highly compressible. Although silt may be somewhat higher strength and less compressible than clay. Silt is non-plastic and because of its pore size can be subject to capillary action and therefore can be frost susceptible. Clay has a high affinity to water and is therefore subject to shrink and swell action.

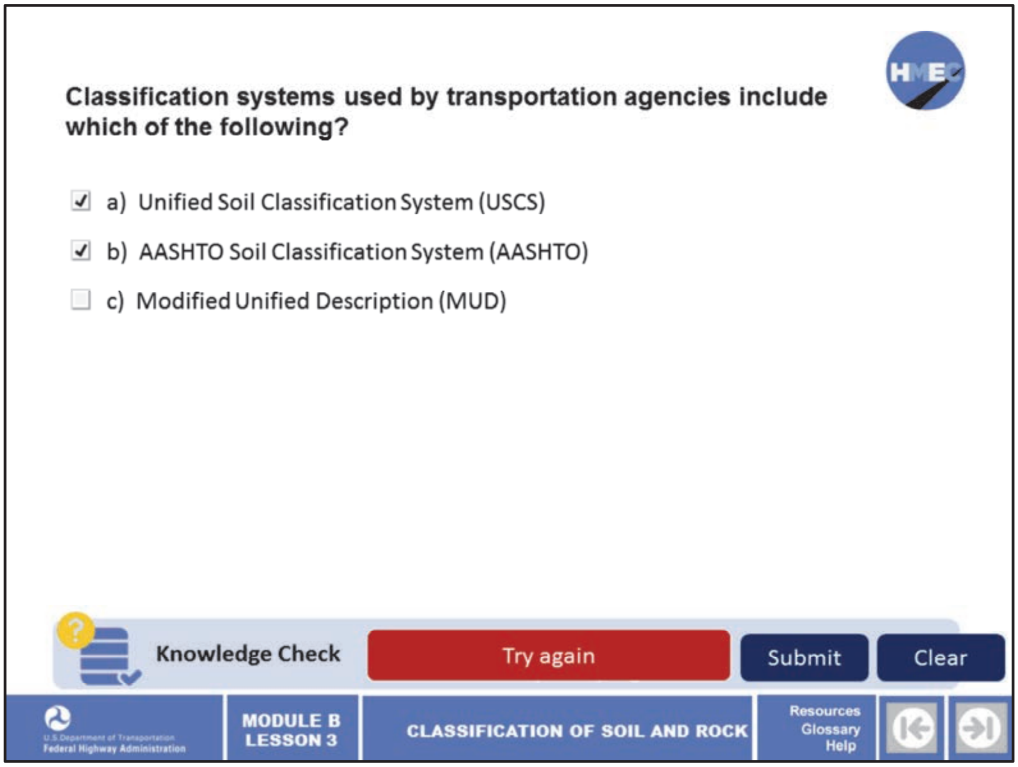


True or false? Organic soils can corrode construction materials.

a) True; or
b) False.

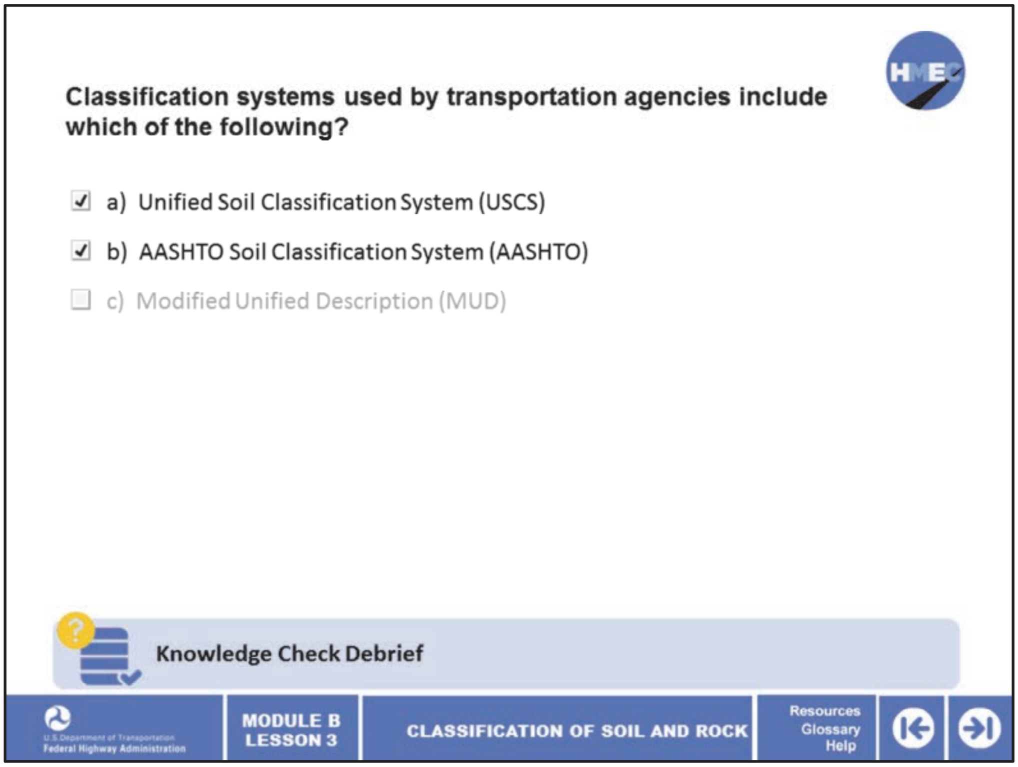


The correct answer is a) True. Organic soils can be acidic and can corrode or deteriorate construction materials.

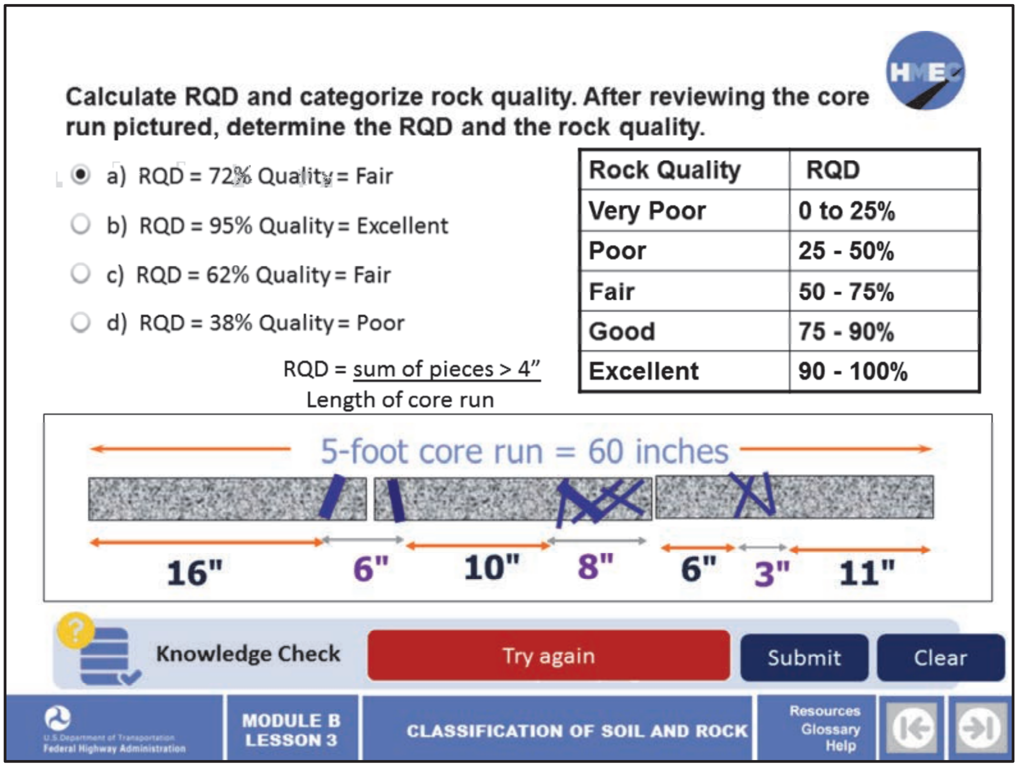


Select all that apply. Classification systems used by Transportation Agencies include which of the following?

a) Unified Soil Classification System (USCS);
b) AASHTO Soil Classification System (AASHTO); and
c) Modified Unified Description (MUD).



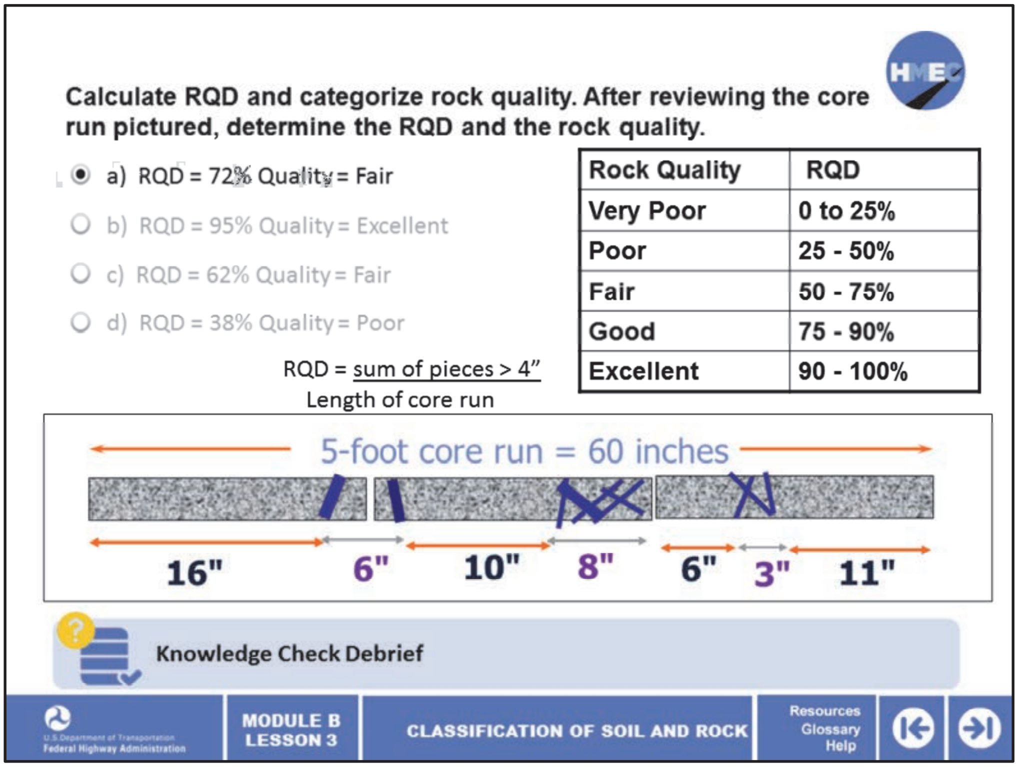
The correct answers are a) Unified Soil Classification System (USCS) and b) AASHTO Soil Classification System (AASHTO). Both the AASHTO system and the USCS are used by transportation agencies to classify soils. The MUD system is used to identify and describe soils, not to classify them.



Calculate RQD and categorize rock quality. After reviewing the core run pictured, determine the RQD and the rock quality.

a) RQD = 72% Quality = Fair;
b) RQD = 95% Quality = Excellent;
c) RQD = 62% Quality = Fair; or
d) RQD = 38% Quality = Poor.

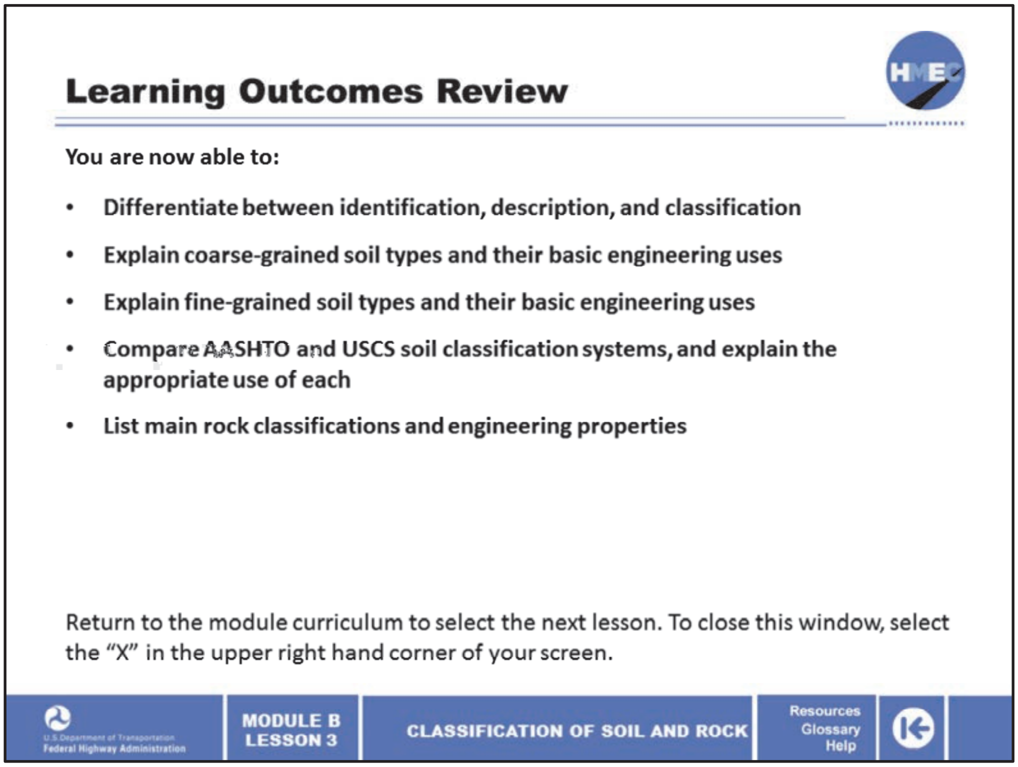
Image description: Photo of a core run.



The correct answer is a) RQD = 72% Quality = Fair. RQD is calculated by summing up the core pieces that are greater than 4 inches and dividing that sum by the core run length. The pieces greater than 4 inches include 16”+10”+6”+11” = 43”. The core run is 60 inches long. Therefore 43”/60” = 71.66 say 72%. RQD = 72%.

Reading from the table, since the RQD is between 50% and 75% the rock quality is fair. Note the additional dimensions of 6 inches and 8 inches shown below the core run are not included, since they are not full piece lengths of sound core. They span joints in the core run and consist of two or more small pieces of core.

Image description: Photo of a core run.



You have completed Module B, Lesson 3: Classification of Soil and Rock. You are now able to:

- Differentiate between identification, description, and classification;
- Explain coarse-grained soil types and their basic engineering uses;
- Explain fine-grained soil types and their basic engineering uses;
- Compare AASHTO and USCS soil classification systems, and explain the appropriate use of each; and
- List main rock classifications and engineering properties.

Close this lesson, and return to the module curriculum to select the next lesson. To close this window, select the "X" in the upper right-hand corner of your screen.