United States Department of Agriculture
Natural Resources Conservation Service

Part 631 Geology
National Engineering Handbook

Chapter 3 Engineering Classification of Earth Materials

(210-631-H, 2nd Ed., Jun 2022)

Issued June 2022

Chapter 3 – Engineering Classification of Earth Materials

Table of Contents

631.0300 Introduction 631-3.1
A. General 631-3.1
B. Classification for Engineering Purposes 631-3.1
C. Earth Material Characteristics 631-3.1
631.0301 Overview of Earth Materials 631-3.2
A. Material Properties 631-3.2
B. Mass Properties 631-3.12
631.0302 Rock Characteristics Related to Engineering Properties 631-3.13
A. Mass Characteristics of Rock 631-3.13
631.0303 Geologic Properties of Materials 631-3.14
A. General 631-3.14
B. Origin 631-3.14
C. Orientation 631-3.14
D. Fossils and Artifacts 631-3.15
E. Field Tests 631-3.16
631.0304 Unified Soil Classification System (USCS) 631-3.18
A. General 631-3.18
B. Classification Groups 631-3.18
631.0305 Definitions 631-3.35
631.0306 References 631-3.36

Table of Figures

Figure 3-1. USDA textural soil classification 631-3.2
Figure 3-2. Particle gradation scales for earth materials 631-3.3
Figure 3-3. Particle shapes 631-3.4
Figure 3-4. Mineral hardness chart 631-3.5
Figure 3-5. Platy structure of clay mineral particles 631-3.6
Figure 3-6. Consistency chart for cohesive soils (silt and clay) 631-3.8
Figure 3-7. Relative density chart for cohesionless soils (sands and gravels) 631-3.9
Figure 3-8. Moisture chart 631-3.10
Figure 3-9. Conversion factors for permeability units 631-3.11
Figure 3-10. Field classification of soil materials 631-3.17
Figure 3-11. USCS classification by field tests 631-3.18
Figure 3-12. USCS components and modifiers 631-3.19
Figure 3-13. Soil components and significant properties 631-3.20
Figure 3-14. USCS plasticity chart 631-3.21
Figure 3-15. Gradation descriptors for coarse-grained soils 631-3.21
Figure 3-16. Grain-size distribution graph 631-3.22
Figure 3-17. USCS laboratory criteria 631-3.24
Figure 3-18. USCS field identification criteria 631-3.25
Figure 3-19. USCS field identification procedures 631-3.26
Figure 3-20. Manual field test for soils 631-3.28
Figure 3-21. Manual field test procedures for the engineering classification of soils 631-3.30
Figure 3-22. Engineering properties of USCS soil classes 631-3.31
Figure 3-23. Engineering properties of Unified Soil classes for embankments 631-3.32
Figure 3-24. Engineering properties of Unified Soil classes for foundations and channels 631-3.34

Part 631 – Geology

Chapter 3 – Engineering Classification of Earth Materials

631.0300 Introduction

A. General

(1) The adequacy of a geologic investigation depends on accuracy in describing and classifying earth materials at the site and interpretations for their engineering uses. Earth materials (soil and rock) are described and classified according to their engineering or behavior properties, and their geologic and physical properties.

(i) Earth materials must be classified consistently to establish correlation and stratigraphy of the site and to develop the design of the structure and construction methods to fit the site conditions.

(ii) The term "soil materials" is defined here as the unconsolidated products of erosion and decomposition of rocks. "Soil material" or "soil" consists of a heterogeneous accumulation of mineral grains, uncemented or partially cemented, with inorganic and organic material.

(2) The term "earth materials" or "geologic materials" covers all natural and processed soil and rock materials. Earth materials range on a broad continuum from loose soil or soft cohesive soil through extremely hard unjointed rock.

(3) This chapter outlines some of the more important properties of earth materials and their description and classification.

B. Classification for Engineering Purposes

(1) NRCS geologists classify earth materials according to their physical or geological characteristics and according to their use for designing and building structures using soil and rock. The traditional geological classification emphasizes origin, mineralogy, rock classification, lithology, tectonics, and structure, including formation names. The geological classification allows correlation of soil and rock units across regions and their observed or predicted occurrence at a site.

(2) Classification of earth materials for engineering purposes uses the Unified Soil Classification System (USCS), which is based on a combination of physical and behavioral properties (Wagner, 1957).

C. Earth Material Characteristics

(1) Although earth materials may be soil, rock, or combinations of soil and rock, this chapter focuses on soil materials.

(2) Title 210, National Engineering Handbook (NEH), Part 631, "Geology," Chapter 4, "Engineering Classification of Rock Materials," focuses on the use of rock in engineering applications. Some common characteristics for both soil and rock are discussed briefly in this chapter.

631.0301 Overview of Earth Materials

A. Material Properties

(1) Material properties can be measured in a laboratory using representative samples or assessed in the field on in-place material. Size, shape, mineral composition, and hardness are important considerations in establishing the origin of materials, in establishing geologic processes involved, and for determining the stratigraphy of the site. Lithologic similarity is one of the bases for establishing correlation and continuity of strata and equivalency in age. Particle characteristics also are important considerations for establishing the engineering properties and behavioral characteristics of materials.

(2) Grain Size

(i) The important size classifications are as follows: boulders, cobbles, gravel, sand, silt, and clay. Numerous grade scales have been developed to establish the size limits for each of these classifications.

(ii) For reference, figure 3-1 shows the USDA textural soil classification system.

(iii) Figure 3-2 shows some of the commonly used grade scales for comparison. Note that the range in size for a particular class of particle may differ from one classification system to another. The particle grade sizes used in the USCS are used in the engineering geology phases of NRCS work.

Figure 3-1. USDA textural soil classification

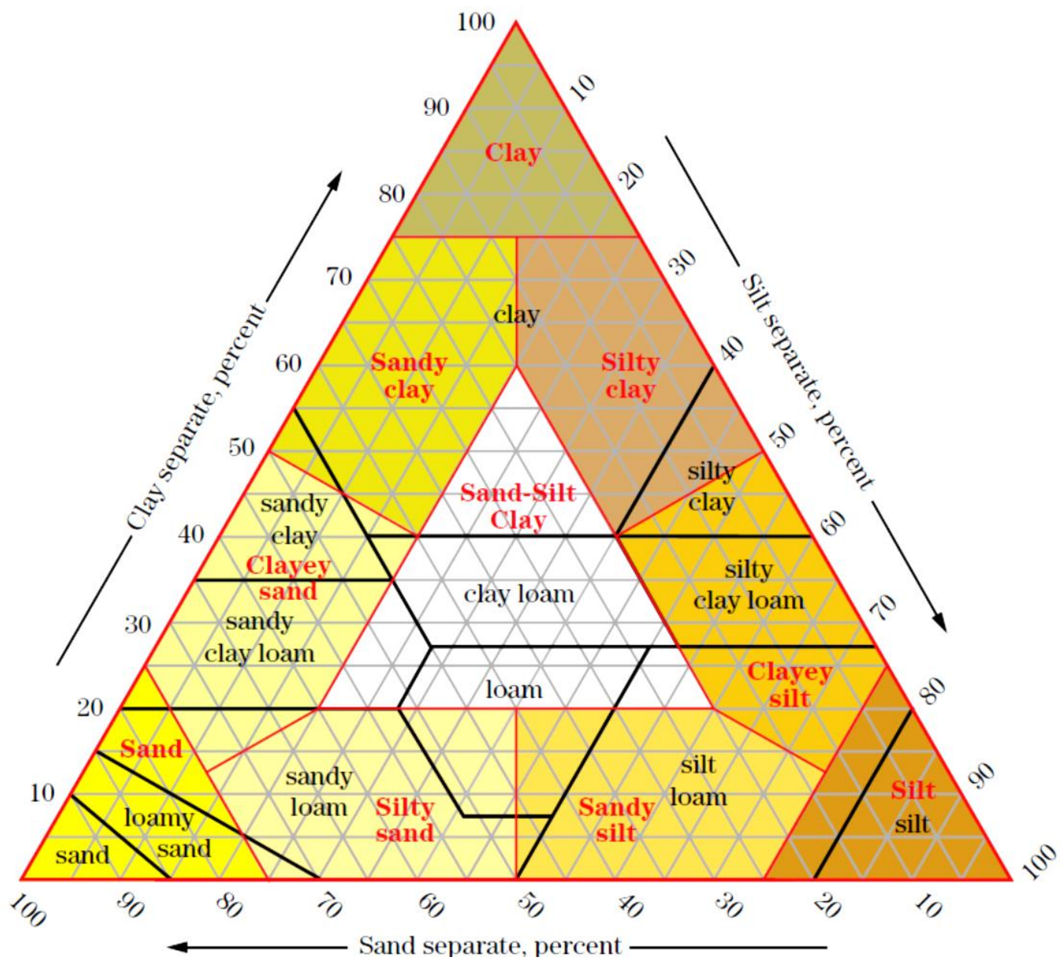


Figure 3-2. Particle gradation scales for earth materials

inches	U.S. Standard Sieve No.	mm	Unified Soil Classification System [1/]	AASHTO [2/]	AGU [3/]	USDA [4/]	Udden-Wentworth [5/]
		4026					
		2048	boulders		boulders		
		1024				boulders	boulders
		512		boulders			
12		300					
10		256					
6		128	cobbles		cobbles	cobbles	cobbles
3		75					
		64					
		32	coarse gravel	coarse gravel	coarse gravel		
1		25.4					
0.75		19					
		16					pebble gravel
0.5		12.7	fine gravel	fine gravel	medium gravel	gravel	
0.375		9.5					
		8					
0.25		6.35			fine gravel		
	4	4.76					
		4	coarse sand				granule
	10	2		coarse sand			
		1	medium sand		coarse sand	coarse sand	coarse sand
		0.5					
	40	0.425			medium sand	medium sand	medium sand
		0.25	fine sand	fine sand	fine sand	fine sand	fine sand
		0.125					
	200	0.074			very fine sand	very fine sand	very fine sand
		0.0625					
		0.05					
		0.031		silt			
		0.0156			silt	silt	silt
		0.0078	silt or clay				
		0.005					
		0.0039		clay			
		0.001			clay	clay	clay
				colloids			

Notes:
[1/] Particle Size Distribution (ASTM D6913 2017)
[2/] Unified Soil Classification System, (ASTM D2487 2000 and D2488 2000)
[3/] American Association of State Highway and Transportation Officers (AASHTO 1998 and ASTM D3282)
[4/] AGU, American Geophysical Union (Lane 1947)
[5/] USDA Textural Classification System (Soil Survey Manual 2017)
[6/] Udden-Wentworth Classification System (Udden 1914)

(3) Shape
- (i) Geologists express the degree of roundness of gravels, cobbles, and boulders on the basis of the average radius of the corners divided by the radius of the maximum inscribed circle.
- (ii) Although particle shapes can be expressed numerically by this method, such a degree of accuracy is not required for geologic investigation of dam sites. Visual estimation is sufficient for classification of equidimensional particles. Figure 3-3 shows a comparison of degrees of roundness and angularity, which serve as a guide to visual estimation and classification of roundness.
- (iii) This classification is adopted primarily for equidimensional particles of materials coarser than silt particles. Platy or flaky minerals should be described by the mineral name instead of the shape, such as biotite, muscovite, chlorite, etc.
- (iv) Where platy or prismatic rock fragments are present, the rock type or structure controlling the shape, such as bedding, cleavage, schistosity, etc., should be given as well as degree of roundness.

Figure 3-3. Particle shapes

(After 210-NEH-650, “Engineering Field Handbook,” Chapter 4)

(4) Mineral Composition

(i) The mineral composition of earth materials can vary greatly, depending on the genesis of the materials and the geologic processes involved. The mineral composition may vary also with particle size at a particular site. The proportion of platy minerals usually increases over equidimensional minerals as the particle size decreases.

(ii) Coarse-grained materials are normally dominated by rock-forming minerals that are more resistant to chemical weathering, such as quartz and heavy minerals. Rock fragments and unaltered rock-forming minerals, such as feldspar, calcite, and mica, also may be present. The less complex minerals in coarse-grained fractions can be identified readily by megascopic methods. Wherever this is possible, the effects that predominant rocks or minerals have on engineering properties should be noted, using standard geologic terms.

(iii) Fine-grained materials represent the products of chemical and mechanical weathering. The mineral composition and weathering processes control the ultimate size and shape of the fine-grained particles. Quartz, feldspar, and many other minerals may, under mechanical weathering, be reduced to fine-grained equidimensional particles, such as in rock flour. Some types of minerals are broken down mechanically into platy particles, such as micas. Alteration products of other types of minerals may result in the formation of platy particles.

(5) Hardness

(i) The hardness of individual minerals is normally expressed by geologists by means of the Mohs scale. Hardness, along with color, luster, transparency, streak, crystal form, cleavage, or fracture, and specific gravity are important properties for identification of minerals.

(ii) Hardness of individual particles is an important engineering consideration with respect to resistance to crushing when loaded. Figure 3-4 summarizes field test descriptors for hardness.

Figure 3-4. Mineral hardness chart.

Hardness	Field Test
Soft	Reserved for plastic material.
Low Hardness	Can be gouged deeply or carved with a pocket knife.
Moderately Hard	Can be readily scratched by a knife blade; scratch leaves heavy trace of dust.
Hard	Can be scratched with difficulty; scratch produces light powder and is often faintly visible.
Very Hard	Cannot be scratched.

(6) Clay Minerals

(i) Clay minerals require special attention because they affect the engineering properties of soils, primarily because of their fine-grained nature, platy shape, molecular structure, and water-bearing lattice.

(ii) Clay minerals are predominantly hydrous aluminum silicates or more rarely, hydrous magnesium or iron silicates. Clay minerals are composed of layers of silicon and oxygen (silica layer), aluminum and oxygen, or aluminum and hydroxyl ions (alumina or aluminum hydroxide layer). Figure 3-5 illustrates the platy structure of clays.

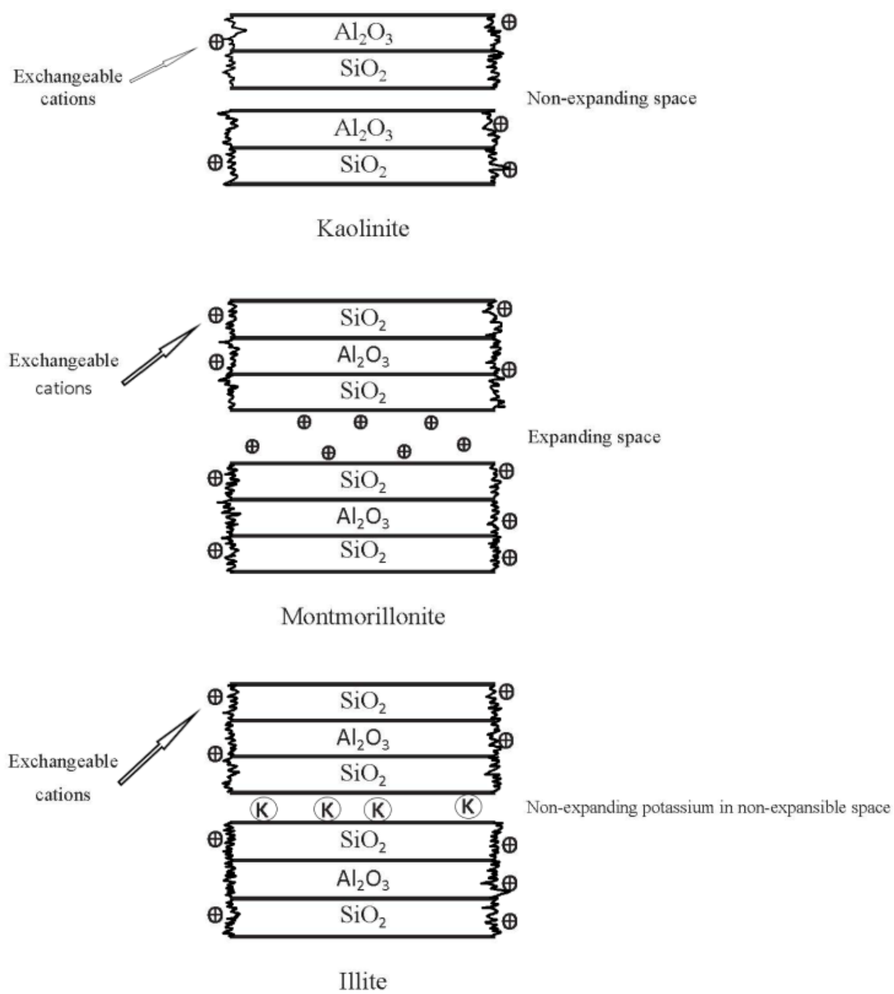
(iii) Clay minerals are categorized into three principal groups: kaolinites, montmorillonites, and illites. Because of the variable influence of each type on the engineering property of soils, it is important that the predominant clay mineral be properly identified whenever possible.

(iv) Kaolinite clays consist of two-layer molecular sheets, one of silica and one of alumina. The sheets are firmly bonded together with no variation in distance between them. Consequently, the sheets do not take up water. The kaolinite particle sizes are larger than those of either montmorillonite or illite and are more stable.

(v) Montmorillonite clays consist of three-layer molecular sheets consisting of two layers of silica to one of alumina. The molecular sheets are weakly bonded, permitting water and associated chemicals to enter between the sheets. As a result, they are subject to considerable expansion when saturated and shrinkage when drying. Montmorillonite clays are very sticky and plastic when wet and pose problems with shear and consolidation.

(vi) Illite clays have the same molecular structure as montmorillonite, but have stronger molecular bonding, resulting in less expansion and shrinkage properties. Illite particles are larger than montmorillonite and adhere to each other in aggregates.

Figure 3-5. Platy structure of clay mineral particles



(7) Color

(i) Color is an important property in identifying organic soils. The presence of organic matter, certain minerals, and some types of weathering can often be readily detected by color. Color varies widely in earth materials, but often provides a useful means of identification for geologic and engineering purposes.

(ii) Rock colors vary depending on degree of weathering, presence of staining material, and whether wet or dry. Rock colors should be described using the Munsell Rock Color Chart (Munsell, 2009).

(iii) Soil colors should use the Munsell Soil Color Chart (Munsell, 2009). The color name and color chart value and chroma should be recorded [e.g., “light brown (7.5YR, 6/3)”].

(8) Consistency

(i) Consistency describes fine-grained soil materials that tend to hold together. It also is used to describe the relative ease with which saturated cohesive soil can be deformed. In this sense, the consistency is described as very soft, soft, firm, stiff, very stiff, and hard. Figure 3-6 summarizes consistency for cohesive soils.

(ii) With increasing water content, a solid clay mass changes consistency and passes from a solid state, through a semisolid and plastic state, to a liquid state. The moisture content is expressed in percent of dry weight, at which the mass passes from one of these stages of consistency to another and is known as the Atterberg limit or limit of consistency.

(iii) Soils are classified as cohesive or cohesionless. Cohesive soils are fine-grained soils and have particles that aggregate or stick together. Generally, as the amount of clay increases, the soil has a tendency for particles to adhere, and the soil can deform. Cohesionless soils or non-cohesive soils do not adhere to each other and rely on friction between the particles.

(iv) Atterberg limits or limits of consistency are determined on soil materials passing the 40-mesh sieve (No. 40 mesh or 0.0165 inch). The shrinkage limit or the limit between the solid and semisolid states is the maximum water content at which a reduction in water content will not cause a decrease in volume of the soil mass. This value is expressed as a percent. Density, or unit weight, and moisture values are highly significant in embankment construction.

(v) The plastic limit is the water content corresponding to an arbitrary limit, fixed by a standard testing procedure, between the semisolid and plastic states of consistency. The liquid limit is the water content corresponding to the arbitrary limit, fixed by a standard testing procedure, between the plastic and liquid states of consistency. The plasticity index (PI) is a measure of the plastic state or the range of consistency within which a soil exhibits plastic properties and is numerically equal to the difference between the liquid limit and the plastic limit.

(9) Density

(i) Coarse-grained soil materials are cohesionless or non-cohesive soils. The particles do not adhere to each other as in cohesive soils, but instead rely on friction between the sands and gravel particles.

(ii) The term “density” is also used to describe the relative ease with which sand is compacted and may also be called compactness. In this sense, density or compactness is described as very loose, loose, medium dense, dense, or very dense. Figure 3-7 summarizes relative density of cohesiveness soils.

(iii) The density or unit weight of a soil is defined as its weight per unit volume. The dry density is the weight of the unit mass excluding the weight of the water. The wet density includes the weight of the contained water.

Figure 3-6. Consistency chart for cohesive soils (silt and clay) [1/]

Consistency Rating	Standard Penetration Test [2/] (N = blows / ft)	Pocket Penetrometer	Unconfined Compressive Strength (UCS) (KPa) [3/ 4/ 5/]	Material Strength Number (M_s) [6/]	Field Test
Very Soft	< 2	< 0.25	< 0.04	< 0.02	Exudes between fingers when squeezed in hand. Easily penetrated several centimeters by fist.
Soft	2 to 4	0.25 to 0.50	0.04 to 0.08	0.02 to 0.05	Easily molded with fingers. Point of geologic pick easily pushed into shaft of handle. Easily penetrated several centimeters by thumb.
Firm	4 to 8	0.50 to 1.0	0.08 to 0.15	0.05 to 0.10	Molded by fingers with some pressure. Can be penetrated several centimeters by thumb with moderate effort.
Stiff	8 to 15	1.0 to 2.0	0.15 to 0.30	0.10 to 0.20	Indented by thumb with great effort. Point of geologic pick can be pushed in up to 1 centimeter. Very difficult to mold with fingers. Just penetrated with hand spade.
Very Stiff	15 to 30	2.0 to 4.0	0.30 to 0.62	0.20 to 0.45	Indented only by thumbnail. Slight indentation by pushing point of geologic pick. Requires hand pick for excavation.
Hard [4/]	> 30	> 4.0	–	–	Indented by thumbnail with difficulty.

Notes:

[1/] Cohesive soil is material with a PI greater than 10. Use 210-NEH-628, “Dams,” Chapter 52, Table 52-2 for cohesionless soils. (ASTM D2166 2006)

[2/] Cohesive soils in which blow counts are greater than 30 or strengths greater than 0.625 Mpa, and auger refusal, can be taken as rock, for which the hardness can be obtained from 210-NEH-628, “Dams,” Chapter 52, Table 52-4.

[3/] Field vane shear strength (ASTM D2573 2008) also may be used for unconfined compressive strength (UCS) (ASTM D 2166 2006).

[4/] 1 kPa equals 1 kN/m^2.

[5/] M_s of a cohesive soil also can be determined as the product of UCS (in MPa) times its coefficient of relative density. Use 210-NEH-628, “Dams,” Chapter 52, Table 52-3 for material strength number for cohesive soil. For most cohesive soils, M_s is approximately determined by:
M_s = 0.78 (UCS)1.09 for UCS ≤ 10 MPa, and M_s = UCS for UCS > 10 MPa.

[6/] Correlation between Standard Penetration Test (SPT) and UCS should only be used as a guide, as results may vary in geologic areas. Lab strength tests are recommended on soil materials to support SPT (ASTM D1586 2018) or field assessment tests. Vane shear strength values also are applicable in the lower strength ranges.

Figure 3-7. Relative density chart for cohesionless soils[1/] (sands and gravels)

Relative Density Rating	Standard Penetration Test [2/] [4/] (N = blows / ft) [3/] [4/]	Material Strength Number (M_s) [4/]	Field Test [5/]
Very Loose	< 5	< 0.02	Particles loosely packed. High percentage of voids. Very easily dislodged by hand. Matrix crumbles easily when scraped with point of geologic pick. Raveling often occurs on excavated faces. Easily penetrated with shovel handle.
Loose	5 to 10	0.02 to 0.05	Particles loosely packed. Some resistance to being dislodged by hand. Large number of voids. Matrix shows low resistance to penetration by point of geologic pick. Easily penetrated with hand shovel.
Compact	10 to 30	0.05 to 0.10	Particles closely packed. Difficult to excavate with hand shovel. Difficult to dislodge individual particles by hand. Voids less apparent. Matrix has considerable resistance to penetration by point of geologic pick.
Dense	30 to 50	0.10 to 0.20	Particles very closely packed and occasionally very weakly cemented. Cannot dislodge individual particles by hand. The mass has very high resistance to penetration by point of geologic pick. Requires many blows of geologic pick to dislodge particles. Must be loosened with pick to excavate.
Very Dense	> 50	0.20 to 0.45	Particles very densely packed and usually cemented together. Mass has high resistance to repeated blows of geologic pick. Requires power tools for excavation. Cannot be penetrated with ¼-inch steel probe.

Notes:
[1/] Cohesionless soil is a material with a PI less than or equal to 10. Use 210-NEH-628, “Dams,” Chapter 52, Table 52-3 for cohesive soils.
[2/] SPT (ASTM D1586 2018) used for most sandy type cohesionless soils. Dynamic cone tests are used for mostly gravel type soils.
[3/] Cohesionless soils in which blow counts are greater than 50 may be taken as rock, for which the hardness may be obtained from 210-NEH-628, “Dams,” Chapter 52, Table 52-4.
[4/] Material strength numbers are updated to 210-NEH-628, “Dams,” Chapter 52 values.
[5/] Lab strength tests are recommended on soil materials to support SPT or field assessment tests.

(10) Moisture

(i) The moisture content is the ratio of the weight of water contained in the soil to the dry weight of the soil solids. A certain compaction density may be specified, and the moisture content at the time of compaction is critical.

(ii) Figure 3-8 summarizes moisture descriptions for soils. The optimum moisture content is used in compaction of earth materials. It provides the maximum dry unit weight that can be obtained for a soil or earth material. The increase in the dry unit weight means improving the soil properties, such as increased strength, decrease in permeability, and compressibility.

Figure 3-8. Moisture chart

Moisture	
Dry	Absence of moisture, dusty, dry to the touch
Slightly Moist	Apparent moisture, but well below optimum moisture content
Moist	Damp, but no visible water; at or near optimum moisture content
Very Moist	Above optimum moisture content
Wet	Visible free water; below water table

(11) Porosity

(i) Porosity is defined as the ratio of volume of voids to the total volume of the soil or rock mass. Porosity is expressed as a percentage.

$$\text{Porosity (\%)} = \frac{\text{Volume of voids in a given mass } (L^3)}{\text{Volume of given mass } (L^3)}$$

(ii) The two main types of porosity are primary and secondary.

- Primary porosity refers to openings that developed at the time the material was formed or deposited. Primary porosity of a soil depends on the range in grain sizes and shape of the grains.
- Secondary porosity refers to porosity formed after initial formation. See weathering below.

(12) Weathering

(i) Weathering is the breakdown of rocks at the Earth's surface, by the action of rainwater, extremes of temperature, and biological activity. Weathering occurs in place and should not be confused with erosion.

(ii) Weathering can be divided into physical and chemical weathering. Physical weathering is breaking the rocks into smaller pieces through freeze and thaw cycles, exfoliation, root expansion, and wetting and drying cycles. Chemical weathering involves the chemical reaction of water, atmospheric gases, and biologically produced chemicals with rocks and soils.

(iii) Weathering can be described by the degree of discoloration, hardness or the lack of hardness, cracks, and other factors.

(iv) Physical weathering, chemical, and biological action can create secondary porosity in rock masses. Secondary porosity is common in most earth materials near the Earth's surface.

(13) Permeability

(i) The permeability of a soil is its capacity to transmit fluids under pressure. It may vary in different directions. Water flow is through voids between soil grains, so the larger the size of the pores and their interconnections, the greater the flow of water.

(ii) Coarse-grained soils are more permeable than fine-grained soils. A well-graded soil, having a good distribution of particle size from large to very fine, is relatively less permeable than a poorly graded soil of a comparable size, because the finer grains fill the space between the larger particles.

(iii) Coefficient of Permeability

- The coefficient of permeability of a given soil is the volume of flow of water through a unit area, in unit time, under unit hydraulic gradient, and at a standard temperature. Area is measured at right angles to the direction of flow. Many permeability units are in use. The more common ones are as follow:

- Lugeon value or unit = 1 Lugeon = 1 liter/min/meter of borehole at a pressure of 10 kg/cm^2.
- Meinzers Units = gallons/ft^2/day under unit hydraulic gradient.
- Feet/day = ft^3/ft^2/day under unit hydraulic gradient.
- Cm/second = cm^3/cm^2/sec. under unit hydraulic gradient.
- Feet/year = ft^3/ft^2/year under unit hydraulic gradient.
- Inches/hour = $inch^3/inch^2$/hour under unit hydraulic gradient.

- All units are for a standard water temperature. For precise measurements, correction to this temperature must be made. Unit head or unit hydraulic gradient is a gradient of 1:1, or 100 percent. These units are readily interchangeable by multiplying by the proper factor as shown in figure 3-9.

Figure 3-9. Conversion factors for permeability units

From \ To	Meinzers Units	Feet/day	Cm/sec.	Feet/year	Inches/hour
Meinzers Units	1	0.13368	4.7159×10^{-5}	48.8256	0.06684
Feet/day	7.4806	1	3.5278×10^{-4}	365.2422	0.5
Cm/sec.	2.12049×10^{4}	2.83464×10^{3}	1	1.03530×10^{7}	1.41731×10^{3}
Feet/year	0.02048	2.7379×10^{-3}	9.6590×10^{-7}	1	1.3689×10^{-3}
Inches/hour	14.9611	2.0	7.0556×10^{-4}	730.4844	1

(iv) Consolidation

- Consolidation refers to the gradual reduction in volume of a soil under load.
- Normally, fine-grained soils consolidate more than coarse-grained soils, and poorly graded soils consolidate more than well-graded soils.
- Other commonly used terms related to consolidation are compressibility, settlement, degree of compaction, and degree of collapsibility.
- Density, plasticity, porosity, permeability, and organic content are important factors in determining the degree of compressibility.

(v) Shear Strength

- Shear strength is the resistance of soil particles to sliding on one another.
- Shear strength is made up of two components: interparticle friction and cohesion.
- Shear strength also depends on other factors, such as material composition, stress history, temperature, strain, strain rate, and structure.
- The shear strength of clean sands and gravels and non-plastic silts can be attributed to friction.
- Highly plastic clays have mostly cohesive shear strength.

(vi) Soil Gradation

- The term gradation is used here to describe the grain-size distribution of unconsolidated materials in engineering terminology.
- For engineering purposes, the fine fraction (< 200 mesh sieve) is classified as silt or clay based on plasticity rather than on grain-size diameter.
- This system is not entirely adequate to define all physical characteristics needed for identification and correlation purposes. Gradation is an indicator of hydraulic conductivity, compressibility, and shear strength, and it is used

to calculate the coefficient of uniformity and coefficient of curvature. Engineering behavior of a soil is also dependent on other factors, such as plasticity, structure, and mineral type. Soils containing fibrous peat, wood fragments, cement, and lime can affect the washing and sieving procedures and the gradation of the soil (ASTM D6913 2017).

B. Mass Properties

(1) General

(i) Although individual particle characteristics are important for identification purposes and have an influence on engineering properties, associations of different particles impart mass characteristics and properties to both rock and soil materials, which are entirely different from those of the individual particles. This section briefly outlines mass characteristics that need to be described to develop adequate interpretations for geologic engineering purposes.

(ii) Mass properties of geologic materials are large-scale features that cannot be sampled, but can only be observed, measured, and documented in the field. These properties include regional features, such as geologic structure or karst topography.

(iii) Geologic structure refers to the orientation and deformation characteristics, such as faults and joints.

(iv) Karst topography is formed primarily in limestone terrain and characterized by joints that have been widened by dissolution.

(2) Discontinuities

(i) Mass properties also include discontinuities that are distinct breaks or abrupt changes in the mass. The two broad types of discontinuities are stratigraphic and structural, depending on mode of formation.

(ii) Stratigraphic discontinuities originate when the geologic material is formed under distinct changes in deposition or erosion.

- They are characterized by abrupt lateral or vertical changes in composition or other material property, such as texture or hardness.
- These features apply to all stratified soil and rock and can occur in many shapes, described with common geologic terms, such as blanket, tongue, shoestring, or lens.
- Abrupt changes in composition or material property can result in contrasting engineering behavior of the adjacent geologic materials. A common example of a stratigraphic discontinuity is the soil/bedrock interface.

(iii) Structural discontinuities are extremely common in almost any geologic material. They include fractures of all types that develop some time after a soil or rock mass has formed.

- Almost all types of bedrock are fractured near the Earth’s surface.
- Forces acting on the mass that cause deformation include physical geologic stresses within the Earth’s crust; biological, such as animal burrows or tree roots; or artificial, such as blasting.
- Fractures in rock materials may be systematically oriented, such as joint sets, fault zones, and bedding plane partings, or may be randomly oriented.
- In soil materials, fractures may include soil joints, desiccation cracks, and remnant structure from the parent bedrock in residual soils.

631.0302 Rock Characteristics Related to Engineering Properties

A. Mass Characteristics of Rock

Permeability, consolidation, shearing resistance, durability, and workability of rock depend on the mass characteristics of the rock. Structures may require expensive rock excavation or treatment of foundations, abutments, and reservoir basins.

(1) Permeability

(i) Foundations, abutments, and reservoir basins that are highly fractured and contain solution channels, or are the products of differential weathering, may be highly permeable. A low porosity rock mass may be highly permeable due to fractures and joints. Jointing is not restricted to any particular type of rock, but certain types of rocks may locally exhibit larger or more closely spaced joints. Surficial joints and cracks may be termed lineaments.

(ii) Fluid transmission ratings for various rock materials or classes are shown in 210-NEH-631, Chapter 4, “Engineering Classification of Rock Materials,” and Chapter 31, “Groundwater Investigations.”

(iii) Differential weathering may be found in many types of igneous and metamorphic rocks and certain sedimentary rocks. Differential weathering of cherty limestones, for example, may result in highly permeable rock foundations.

(iv) It is important that the rate of permeability and the depth and direction of water movement be determined as accurately as possible to determine requirements for foundation treatment. Field investigations may require angular test borings, pressure testing, use of dyes or other tracer compounds, or other methods to properly determine permeability of rock.

(2) Consolidation

(i) The bearing strength of rock is normally adequate to support dams designed by NRCS. However, consolidation may be a problem in certain types of rock, such as weakly cemented shales and siltstones, and rocks that have been altered to clay minerals. In each instance, samples of questionable materials must be obtained for laboratory analysis, following the same procedures used for soil materials.

(ii) Caverns or mines may present a problem of bearing or stability, depending on the size and location of openings. Their locations must be mapped and evaluated for site feasibility, design, and construction.

(3) Shearing Resistance

(i) Problems related to shear may result from poorly cemented shales and siltstones or highly weathered rock of low shear strength.

(ii) Materials that dip in an adverse direction and are subject to saturation or unloading of toe supports by excavation are of particular concern. This includes strata dipping downstream in foundations, or strata dipping toward the centerline (parallel to the slope of the abutment) of proposed auxiliary spillway excavations. Rock strata of low shear strength must be thoroughly delineated and evaluated for design and construction.

(iii) Cost of rock excavation may be greatly influenced by the nature of rock and secondary alteration. The geologist must describe the properties, quality, and quantity of rock proposed for excavation in terms translatable into workability by construction equipment, so that the amounts of rock excavation can be determined.

(iv) For further details on classification of rock for excavation, see 210-NEH-642, “Specifications.” Also refer to 210-NEH-631, Chapter 4, “Engineering

Classification of Rock Materials," figures for relative ratings of earth materials for construction quality of rock and excavation characteristics.

631.0303 Geologic Properties of Materials

A. General

Detailed descriptions of the geological properties of materials support interpretations for their use in engineering applications and complement field and laboratory testing. Formation or rock unit names and names applied to geomorphic surfaces are useful for correlation across wide regions. Just as the rock facies vary in character from one place to another in the same formation, so do the engineering characteristics.

B. Origin

(1) Type of Deposit

(i) Type of deposit describes the mode, agent, and processes of formation of the deposit. It provides information on the continuity of strata and the uniformity of physical characteristics that may be encountered. For example, deposits of loess and glacial lake deposits (varved clays) may be remarkably consistent in thickness of strata and physical characteristics of materials. Other types, such as stream bar deposits, may pinch out in a matter of a few feet, and the particle characteristics may vary widely over short distances. It is important, therefore, that the type of deposit be accurately described to properly extrapolate continuity and physical characteristics of materials.

(ii) Standard geologic terms should be used to describe the type of deposit. Such terms as granite, volcanic ash, marl, limestone, and gneiss, along with the formation name or age, are commonly used to describe rock materials. Because of the highly variable characteristics of sediments, however, more definitions are needed to imply mode of origin. Such deposits should be described as fan, dune, colluvium, stream channel, and other types denoting origin to properly interpret physical characteristics.

(2) Age

(i) The age of a stratum establishes its vertical position in the geologic column and its relationship to other strata.

(ii) Age should always be indicated using accepted geologic eras, periods, epochs, and ages when identifiable.

C. Orientation

(1) Stratigraphy

(i) Stratigraphy is the formation, composition, thickness, sequence, and correlation of earth materials. Knowledge of the stratigraphy, such as the continuity or discontinuity of certain beds or the distribution of critical horizons, may be very important in interpreting site conditions.

(ii) Stratigraphy of the site is established from the study of particle and mass characteristics and the interpretation and extrapolation of the boring and test hole data. Particle characteristics, their origin, mode of transportation (wind, water, ice, and gravity), and the processes of deposition and consolidation are elements of stratigraphy.

(iii) Guiding factors are the petrographic characteristics of the materials and the type, age, depth, thickness, sequence, and continuity of the deposits. Petrology of the rocks includes mineral composition, size, shape, and spatial arrangement of the particles.

(2) Depth, Thickness, and Continuity

(i) The depth and thickness of materials at specific points at a site are determined from exposure and subsurface boring or test holes. Continuity must be interpreted based on depth, thickness, type, and similarity of deposits and particle and bulk characteristics measured and described at different observation points. To facilitate interpretation of continuity, all measurements of depth should be referenced to a common elevation based either on mean sea level or an assumed datum plane. It is important that the vertical and areal continuity be determined for those materials that may influence the design and construction of a dam.

(ii) Depth and thickness of identified strata are plotted at their proper elevations. Continuity lines are drawn (using dashed lines) where correlation of similar strata from different bore holes is evident. Forms NRCS-CPA-35A, -35B, -35C, and -35D, "Plan and Profiles for Geologic Investigation," are provided for this purpose, or their equivalents may be used. If a stratum in the vertical column of one observation cannot be correlated with any stratum in the next column, continuity has not been established. If correct interpretations have been made, the particular stratum is considered to be discontinuous. This should be shown by correlation lines that pinch out between bore holes.

(iii) Discontinuous strata are a common occurrence in types of materials having lenticular beds or where faults or other structural movements have resulted in shifting of beds to positions where they are not concordant. Whenever the limits of continuity cannot be established, and the discontinuity cannot be accounted for in the interpretations, additional test holes are needed to confirm lateral and longitudinal continuity or discontinuity.

(3) Structure

(i) The term "structure," as applied to the geology of a dam site, refers to all of the geologic structural features either at the dam site or influencing the site. These features include faults, folds, unconformities, joints, rock cleavage, etc.

(ii) Structure has an important influence on the geologic conditions of a site and the ultimate stability and safety of an engineering structure. Problems of leakage, sliding of embankments, uplift pressure in foundations, and differential settlement are often traced back to inadequate delineation and consideration of the geologic structure at the site.

(iii) See 210-NEH-631, Chapter 4, "Engineering Classification of Rock Materials," for a further discussion of structure of rock materials.

D. Fossils and Artifacts

(1) Paleontology

(i) Evidence of past life is important for correlation purposes to establish continuity. Fossils are keys to correlation of rock strata. Plant and animal remains may affect engineering properties of the rock (usually adversely). Peat, muck, and carbonized plant remains, therefore, have little value as construction materials. Tests or shells of foraminifera, algae, coral, and other fossilized plants and animal parts impart specific behavioral characteristics to engineering materials.

(ii) Descriptions of fossils, where they have little or no influence on the engineering properties of materials, should be limited to brief notes needed for correlation purposes. More detailed descriptions are needed where such materials have an influence on the engineering properties. These should include description of the nature of the materials, including name, their extent, and distribution in the formation. Additionally, in some locations, if vertebrate fossils are encountered, the proper authorities must be contacted.

(2) Archeology and Cultural Resources

(i) Direct or indirect evidence of prehistoric and historic artifacts and features may be encountered during investigations. Sampling may reveal man-made implements, cuttings, fire pits, or structures.

(ii) Evidence of prehistoric and historic sites includes features, such as structures, hearths, artifact scatters, or roads. Human artifacts may include projectile points, shards, and scrapings. Prehistoric human activity areas include quarries, animal kill sites, fire rings, and controlled burn remains.

(iii) If uncertain about what has been encountered, call the NRCS State or Area Cultural Resources Specialist (CRS) or Cultural Resources Coordinator (CRC), report your findings, and ask for guidance on how to proceed.

(iv) NRCS has policy to avoid damage or effects to cultural resources that meet specific significance criteria. However, it is important to determine if the property meets the criteria for protection. The NRCS CRS or CRC can help make this determination. If bone is encountered that may be human remains, immediately notify the CRS or CRC. They will help identify the bone and, if necessary, help notify the proper authorities.

E. Field Tests

(1) Unconsolidated Materials

(i) The geologist may need to make field tests to further delineate geologic properties and to classify materials more accurately. The classification of unconsolidated materials for engineering purposes is done according to the USCS, using standard field tests. These standard tests are described in the USCS in section 631.0304. In addition to these standard tests, additional tests may be used to classify materials and identify special properties. Some of these tests for field classification of materials are described in figure 3-10.

(ii) The field procedure does not require specialized equipment. Small bottles of clear water and diluted hydrochloric acid are used. Acetone and other reagents may also be needed to perform other tests shown in figure 3-10. Experience in classifying materials in the USCS can be learned initially through the use of Nos. 4, 40, and 200 U.S. Standard sieves in the field in the initial stages of training to aid in identifying relative quantities of coarse- and fine-grained samples.

- Acetone is used as a test for gypsum.
- A test solution of nitrobenzene and crystal violet identifies clay mineralogy.
- Field tests shown in figure 3-10 can help determine the USCS classification. See figure 3-11.

Figure 3-10. Field classification of soil materials

<table>
<tr><th>Test</th><th>Description</th></tr>
<tr><td>Acid test</td><td>Effervescence when a drop of diluted hydrochloric acid (one-tenth normal) is placed on a sample of soil or rock indicates the presence of calcium carbonate.</td></tr>
<tr><td>Trailing fines</td><td>When a small sample of pulverized dry soil is shaken in the palm of the hand at a slight angle, the fines portion will trail behind. This is an aid in determining the relative proportion of the various grain sizes.</td></tr>
<tr><td>Shine test</td><td>When a dry or moist lump of soil is cut with a knife, a shiny surface indicates the presence of plastic clay.</td></tr>
<tr><td>Taste test[1/]</td><td>A dry lump of soil with high clay content will adhere to the tongue.</td></tr>
<tr><td>Ribbon test</td><td>Plastic clays form a ribbon when squeezed between the finger and thumb with a sliding motion. The strength of the ribbon is an indication of the plasticity of the soil.</td></tr>
<tr><td>Field test for plasticity</td><td>FIELD TEST FOR PLASTICITY
1. Wet the soil until its moisture content is such that a 1.5-inch diameter ball will show a flattened contact surface of 7/8-inch diameter when dropped from a height of two feet.
2. Roll the smallest thread possible without crumbling.
<table>
<tr><th>Thread Diameter</th><th>Descriptive Term</th><th>Description</th><th>Typical USCS Classification</th></tr>
<tr><td>1/4 inch</td><td>Silt</td><td>Silt</td><td>ML (non-plastic)</td></tr>
<tr><td>1/8 to 1/16 inch</td><td>Clayey Silt</td><td>Clayey Silt</td><td>CL-ML (low plasticity)</td></tr>
<tr><td>1/32 inch</td><td>Silty Clay</td><td>Silty Clay</td><td>CL</td></tr>
<tr><td>1/64 inch</td><td>Clay</td><td>Clay</td><td>CH</td></tr>
<tr><td></td><td></td><td>Plastic Silt</td><td>MH</td></tr>
</table></td></tr>
<tr><td>Dry strength</td><td>1. A portion of the soil is allowed to dry out completely in the air.
2. An angular fragment (about ½ inch) of the dried soil is pressed between the fingers.</td></tr>
<tr><td>Stickiness</td><td>A high degree of stickiness in the natural state is indicative of higher plasticity.</td></tr>
<tr><td>Grittiness test[1/]</td><td>Place a small amount of soil between the teeth; the presence of grit will indicate silt or sand. If no grit, then pure clay is present.</td></tr>
<tr><td>Odor</td><td>Organic soils have a pronounced and distinctive odor. Heating may intensify organic odors.</td></tr>
<tr><td>Test for gypsum</td><td>If gypsiferous soils are suspected, it may be necessary to conduct the following simple test:
1. Place 0.20 pound of air-dry soil in a one-quart bottle and fill the bottle with distilled water.
2. Shake the soil-water mixture for about 20 minutes and then allow it to settle for 10 or more hours.
3. After this settling period, the solution above the soil will be clear if soil contains significant amounts of gypsum. If the solution is cloudy, significant amounts of gypsum probably are not present.
4. Carefully pour about 1/2 ounce of the clear solution into a glass container without disturbing the settled soil in the bottom of the bottle.
5. Add 1/2 ounce of acetone to the solution. The presence of milky, cloudy precipitate in the test solution indicates gypsum.</td></tr>
<tr><td>Crystal-violet test</td><td>The crystal-violet staining solution causes montmorillonite to appear green at first and then change to greenish yellow or orange yellow. The sample must be treated with hydrochloric acid prior to applying the stain. Illite attains a dark green color with this test. Kaolinite merely absorbs the violet dye. The test solution consists of 25 cc of nitrobenzene and 0.1 gram of crystal violet.</td></tr>
<tr><td>Malachite-green test</td><td>Clay minerals of the kaolinite group show bright apple green color after application of a malachite green solution and treated with hydrochloric acid. The solution consists of 25 cc of nitrobenzene and 0.1 gram of malachite green. Montmorillonite and illite clays usually show a greenish yellow or pale-yellow color.</td></tr>
</table>

1/ This test should not be performed when hazardous waste contamination is suspected or known to be present.

Figure 3-11. USCS classification by field tests

USCS	Description	Dilatancy Test	Test Tube Test	Plasticity	Dry Strength	Stickiness	Shine Test
SC, SP	Fine Sand	Rapid	30 seconds	None	None	None	None
ML	Silt	Moderate	50 minutes	None	Very low	None	None
ML	Silt	Slow	+ 50 minutes	Slight	Low	None	None
ML	Clayey Silt	None	Hours	Medium	Low to high	Slight	Smooth and dull
CL	Silty Clay	None	Hours	High	Medium to high	Moderate to high	Moderately slick and smooth
CH	Clay	None	+ 24 hours	Very high	High to very high	High to very high	Slick and waxy
ML-OL	Organic Silt	Moderate	± 50 minutes	Slight to medium	Low	None	Dull and silky
CL-OL	Organic Clay	None	± 24 hours	Medium to high	Medium to high	Moderate to high	Dull, smooth, and silky

631.0304 Unified Soil Classification System (USCS)

A. General

The USCS provides a method of classifying and grouping unconsolidated earth materials according to their engineering properties. It is based on soil behavior, which reflects the physical properties of the soil and its constituents. Refer to ASTM Standards D2487 and D2488.

B. Classification Groups

The classification consists of 15 soil groups, each having distinctive engineering properties. Boundary classifications are provided for soils that have characteristics of two groups. Letter symbols have been derived from terms that are descriptive of the soil components, gradation, and liquid limit. These are combined to identify each of the 15 soil groups. Figure 3-12 lists letter symbols for the USCS components and modifiers.

Figure 3-12. USCS components and modifiers

Component		Modifier	
Symbol	**Name**	**Symbol**	**Name**
None	Boulders or Cobbles	W P	Well graded Poorly graded
G	Gravel		
S	Sand		
S	Sand	M	Silty or clayey
M	Silt	L H	Low liquid limit High liquid limit
C	Clay	L H	Low liquid limit High liquid limit
O	Organic	L H	Low liquid limit High liquid limit
Pt	Peat	--	--

(1) Soil Components

(i) The term “soil components” applies to the solid mineral grains comprising earth materials. These components range in size from over 12 inches to colloidal size.

(ii) The particle size, gradation, shape, and mineral composition affect the behavior of the soil, as do the moisture content and the inclusion of other materials, such as organic matter, gases, and coatings of cementing minerals. Figure 3-13 lists various soil components with their associated grain sizes, descriptions, and some of their significant properties. Comparison of grain-size boundaries of the USCS with those of other commonly used grade scales is shown in figure 3-2.

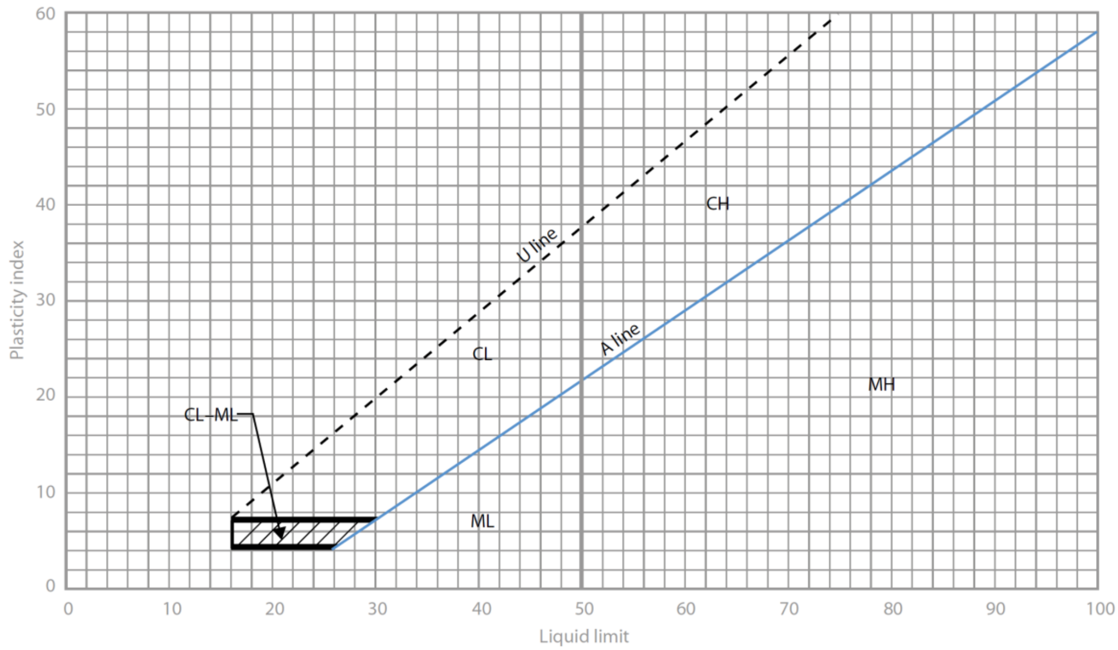
- A 1/4-inch sieve is approximately equivalent to the No. 4 U.S. Standard sieve. The No. 200 U.S. Standard sieve size is about the smallest particle visible to the naked eye. The No. 40 sieve size is the limit between medium and fine sand, and “Atterberg limit tests” are performed on the fraction finer than the No. 40 size in the laboratory.
- The “Atterberg limit tests” define the finer fraction plasticity. Figure 3-14, USCS Plasticity Chart, classifies the finer grained soil relative to liquid limit and PI.

Figure 3-13. Soil components and significant properties

Soil Component	Symbol	Grain-Size Range and Description	Significant Properties
Boulder	None	Rounded to angular, bulky, hard, rock particle, average diameter > 12 in.	Boulders and cobbles are very stable components, used for fills and ballast, and to stabilize slopes (riprap). Because of size and weight, their occurrence in natural deposits tends to improve the stability of foundations. Angularity of particles increases stability.
Cobble	None	Rounded to angular, bulky, hard, rock particle, average diameter < 12 in. and > 3 in.	
Gravel	G	Rounded to angular, bulky, hard, rock particle, passing 3-in. sieve (76.2 mm) retained on No. 4 sieve, (4.76 mm).	Gravel and sand have essentially the same engineering properties, differing mainly in degree. The No. 4 sieve is an arbitrary division and does not correspond to a significant change in properties. They are easy to compact, are little affected by moisture, and not subject to frost action. Gravels are generally more pervious, stable, and resistant to erosion and piping than sands. Well-graded sands and gravels are generally less pervious and more stable than poorly graded. Irregularity of particles increases the stability slightly. Finer, uniform sand approaches the characteristics of silt; i.e., decrease in permeability and reduction in stability with increase in moisture.
Coarse		3 – 3/4 in.	
Fine		3/4 in. – No. 4 sieve (4.76 mm).	
Sand	S	Rounded to angular, bulky, hard, rock particle, passing No. 4 sieve (4.76 mm), retained on No. 200 sieve (0.074 mm).	
Coarse		No. 4 – 10 sieves: 4.76 – 2.0 mm.	
Medium		No. 10 – 40 sieves: 2.0 – 0.42 mm.	
Fine		No. 40 – 200 sieves: 0.42 – 0.074 mm.	
Silt	M	Particles < No. 200 sieve (0.074 mm) identified by behavior; i.e., slightly or non-plastic regardless of moisture and exhibits little or no strength when air dried.	Silt is inherently unstable, particularly when moisture is increased, with a tendency to become "quick" when saturated. It is relatively impervious, difficult to highly susceptible to frost heave, is easily erodible, and is subject to piping and boiling. Bulky grains reduce compressibility. Flaky grains, such as mica, increase compressibility and cause the silt to be "elastic."
Clay	C	Particles < No. 200 sieve (0.074 mm) identified by behavior; i.e., it can be made to exhibit plastic properties within a certain range of moisture and exhibits considerable strength when air dried.	The distinguishing characteristic of clay is cohesion or cohesive strength, which increases with decrease in moisture. The permeability of clay is low. It is difficult to compact when wet and impossible to drain by ordinary means. When compacted, clay is resistant to erosion and piping, but is subject to expansion and shrinkage with changes in moisture. The properties of clay are influenced by particle size and shape (flat, plate-like particles), and by the types of clay minerals, which affects the base exchange capacity.
Organic Matter	O	Organic matter in various sizes and stages of decomposition.	Organic matter present in even moderate amounts increases the compressibility of a soil and reduces the stability of the fine-grained components. Organic matter may also decay, creating voids, or by chemical alteration change the properties of a soil. Organic soils are, therefore, not desirable for engineering uses.

Note: Adopted from the Use of the Unified Soil Classification by the Bureau of Reclamation, (Wagner 1957 and Wentworth 1922).

Figure 3-14. USCS plasticity chart



(After 210-NEH-650, "Engineering Field Handbook," Chapter 4)

(2) Gradation

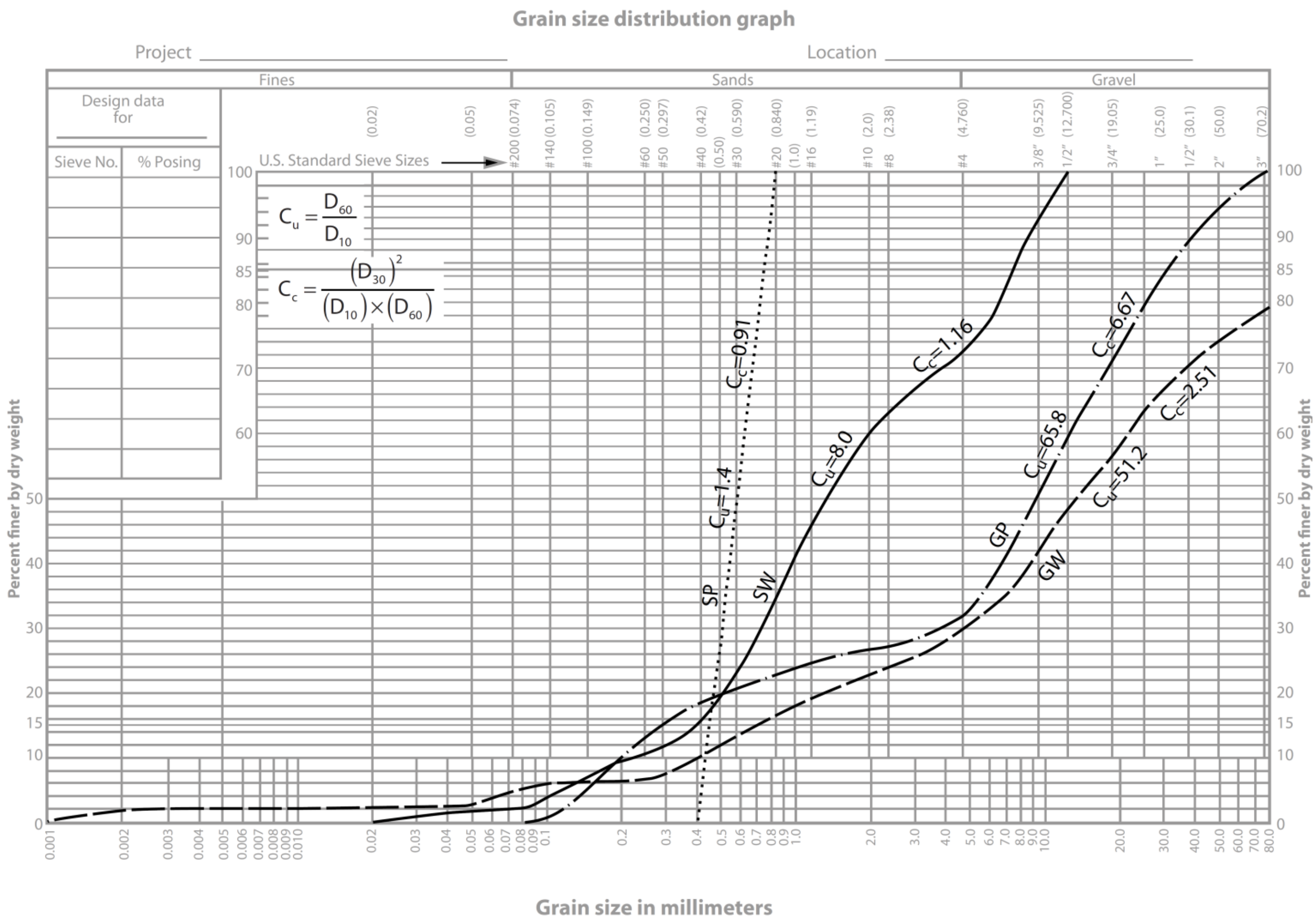
(i) Coarse-grained soil gradation descriptors are shown in figure 3-15. The amounts of the various sized grains are determined by sieving and mechanical analysis and the results plotted on Form NRCS-ENG-353. The type of gradation is readily apparent from the shape of the grain-size curve. Figure 3-16 illustrates the grain-size distribution graphs of some typical soils.

Figure 3-15. Gradation descriptors for coarse-grained soils

Gradation	Description
Well graded	Soils that have a wide range of particle sizes and a good representation of all particle sizes between the largest and the smallest are said to be well graded. $Cu \geq 4$ and $1 \leq Cc \leq 3$, where $Cu = D_{60}/D_{10}$ and $Cc = (D_{30})^2/D_{60}D_{10}$
Poorly graded	Soils in which most particles are about the same size or have a range of sizes with intermediate sizes missing (skip grades) are said to be poorly graded. The gradation or grain-size distribution of soils consisting mainly of coarse grains is diagnostic of the physical properties of the soil. However, gradation is much less significant for predominantly fine-grained soils. $Cu<4$ and/or $1>Cc>3$

(ii) When plotted on semi-log graph paper, poorly graded soils have steeply sloping curves, very flat curves, or abrupt changes in the slope of the curves. Well-graded soils plot as smooth curves. To qualify as well-graded, the gradation must meet certain requirements in respect to coefficient of uniformity and coefficient of curvature of the plotted graph.

Figure 3-16. Grain-size distribution graph



(iii) The coefficient of uniformity (C_u), which is a measure of size range of a given sample, is the ratio of that size, of which 60 percent of the sample is finer (D_{60}) to that size, of which 10 percent of the sample is finer (D_{10}). The coefficient of the curvature (C_c), which defines the shape of the grain-size curve, is the ratio of the square of that size, of which 30 percent of the sample is finer (D_{30}), to the product of the D_{60} and D_{10} sizes. These ratios can be simply written:

Coefficient of Uniformity

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

Coefficient of Curvature

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

(iv) See figure 3-17 for an explanation of the use of these coefficients and other criteria (Atterberg limits) for laboratory identification procedures.

(4) Field Classification Procedures

(i) Complete field descriptions of soil materials encountered during a geologic investigation are needed. The following characteristics should be identified, field tested, and documented in logs of test holes, trenches, or pits:

- approximate percentage of coarse-grain fraction, including sizes, maximum size, shape, and hardness
- mode of origin
- type of deposit
- structure
- cementation
- dispersion
- moisture and drainage conditions
- organic content
- color
- plasticity
- degree of compaction
- USCS classification (typical name and group symbol)
- local or geologic names.

(ii) Figures 3-18 and 3-19 list the classification characteristics of the soil groups. Only the primary constituents of unconsolidated material can be classified in the field in the USCS. More exact mechanical analyses must be made in the laboratory. Comparison of laboratory analyses with the original field classifications serves as an important learning and feedback loop to enable geologists to classify soils in a particular area with greater accuracy.

(iii) A representative sample is required for classification. The average size of the largest particle is estimated, boulders and cobbles are removed, and their percentage by weight removed from the total sample recorded. The amount of over-sized material may be important in the selection of sources for embankment material. The distribution of boulders and cobbles and an estimate of their percentage in foundation materials should be noted so that their effect on physical properties of the materials and possible construction problems can be evaluated.

Figure 3-17. USCS laboratory criteria

COARSE-GRAINED SOILS < 50% of material passes No. 200 sieve size	**GRAVELS** < 50% of the coarse fraction passes the No. 4 sieve size.	**CLEAN GRAVELS** < 5% passing the No. 200 sieve size	Borderline cases require the use of dual symbols	**WELL GRADED** Meets gradation requirements	GRADATION REQUIREMENTS ARE: $C_u = \frac{D_{60}}{D_{10}} > 4$ and $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}} > 1 < 3$	**GW**
				POORLY GRADED Does not meet gradation requirements		**GP**
		GRAVELS WITH FINES > 12% passing the No. 200 sieve size		Plasticity limits of material passing No. 40 sieve size plots below “A” line and PI < 4.	Plasticity limits above “A” line with PI > 4 < 7 are border-line cases and require use of dual symbols.	**GM**
				Plasticity limits of material passing No. 40 sieve size plots above “A” line or PI > 7.		**GC**
	SANDS ≥ 50% of the coarse fraction passes the No. 4 sieve size	**CLEAN SANDS** < 5% passing the No. 200 sieve size	Borderline cases require the use of dual symbols	**WELL GRADED** Meets gradation requirements	GRADATION REQUIREMENTS ARE: $C_u = \frac{D_{60}}{D_{10}} > 6$ and $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}} > 1 < 3$	**SW**
				POORLY GRADED Does not meet gradation requirements		**SP**
		SANDS WITH FINES 12% passing the No. 200 sieve size		Plasticity limits of material passing No. 40 sieve size plots below “A” line and PI < 4.	Plasticity limits above “A” line with PI > 4 < 7 are border-line cases and require use of dual symbols.	**SM**
				Plasticity limits of material passing No. 40 sieve size plots above “A” line or PI > 7.		**SC**
FINE-GRAINED SOILS > 50% of material passes the No. 200 sieve size	**SILTS AND CLAYS** Liquid Limit < 50	Below “A” line and PI, < 4		Above “A” line with PI > 4 < 7 are border-line cases requiring use of dual symbols.		**ML**
		Above “A” line and PI > 7				**CL**
		Below “A” line and PI < 4 and $\frac{L.L.(oven\ dry\ soil)}{L.L.(air\ dry\ soil)}$				**OL**
	SILTS AND CLAYS Liquid Limit > 50	Below “A” line				**MH**
		Above “A” line				**CH**
		Below “A” line and PI < 4 and $\frac{L.L.(oven\ dry\ soil)}{L.L.(air\ dry\ soil)}$ < 0.7				**OH**
HIGHLY ORGANIC SOILS				$\frac{L.L.(oven\ dry\ soil)}{L.L.(air\ dry\ soil)} < 0.7$		**PT**

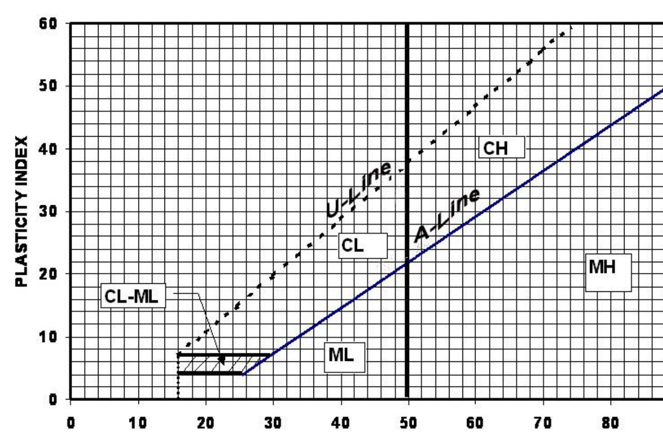


Figure 3-18. USCS field identification criteria

Major division		Group			Subgroup	Description	Symbol
COARSE-GRAINED SOILS > 50% of material (by weight) is of individual grains visible to the naked eye	No. 200 sieve size is about the smallest particle visible to the naked eye.	**GRAVEL AND GRAVELY SOILS** < 50% of the coarse fraction passes the No.4 sieve size	Borderline cases require the use of dual symbols	For visual classification, the ¾ in. size may be used as equivalent to the No. 4 sieve size.	**CLEAN GRAVELS** Will not leave a dirt stain on a wet palm.	Wide range in grain sizes and substantial amounts of all intermediate particle sizes.	**GW**
						Predominantly one size or a range of sizes with some intermediate sizes missing.	**GP**
					GRAVELS WITH FINES Will leave a dirt stain on a wet palm.	Non-plastic fines or fines with low plasticity (for identification of fines, see characteristics of ML below).	**GM**
						Plastic fines (for identification of fines, see characteristics of CL below).	**GC**
		SAND AND SANDY SOILS > 50% of the coarse fraction passes the No.4 sieve size	Borderline cases require the use of dual symbols		**CLEAN SANDS** Will not leave a dirt stain on a wet palm.	Wide range in grain sizes and substantial amounts of all intermediate particle sizes.	**SW**
						Predominantly one size or a range of sizes with some intermediate sizes missing.	**SP**
					SANDS WITH FINES Will leave a dirt stain on a wet palm.	Non-plastic fines or fines with low plasticity (for identification of fines, see characteristics of ML below).	**SM**
						Plastic fines (for identification of fines, see characteristics of CL below).	**SC**

Major division		Group	See Identification Procedures	**ODOR**	**DRY CRUSHING STRENGTH**	**DILATENCY (SHAKE) REACTION**	**TOUGHNESS**	**RIBBON (NEAR THE P.L.)**	**SHINE (NEAR THE P.L.)**	Symbol
FINE-GRAINED SOILS > 50% of material (by weight) is of individual particle not visible to the naked eye	No. 200 sieve size is about the smallest particle visible to the naked eye.	**SILTS AND CLAYS** (Low Plastic)			Slight	Rapid	Low to None	None	Dull	**ML**
					High	Medium to None	Medium	Weak	Slight to Shiny	**CL**
				Pronounced	Medium	Slow to None	Low	None	Dull to Slight	**OL**
		SILTS AND CLAYS (Highly Plastic)			Medium	Very Slow to None	Medium	Weak	Slight	**MH**
					Very High	None	High	Strong	Shiny	**CH**
				Pronounced	High	None	Low to Medium	Weak	Dull to Slight	**OH**
HIGHLY ORGANIC SOILS	Readily identified by color, odor, spongy feel, and frequently by fibrous texture									**PT**

(iv) Step-by-step procedures for classifying soils in the field are shown in figure 3-20.

(v) Figures 3-21, 3-22, 3-23, and 3-24, Engineering Properties of Unified Soil Classes, present a general evaluation of the engineering properties of the various classes. They provide guidance in determining the suitability of a soil for engineering purposes.

Figure 3-19. USCS field identification procedures

<table>
<tr><th>Field Identification Procedures for Fine-Grained Soils or Fractions</th><th colspan="2">Information Required During Logging</th><th></th></tr>
<tr><td rowspan="11">These procedures are to be performed on the minus No. 40 sieve size particles, or < 1/64 in. For field classification purposes, screening is not intended. Simply remove the coarse particles by hand that interfere with the tests.

Dry Strength (Crushing Characteristics)
After removing particles > No. 40 sieve size, mold a pat of soil to the consistency of putty, adding water if necessary. Allow the pat to dry completely by oven, sun, or air drying, and then test its strength by breaking and crumbling between the fingers. This strength is a measure of the character and quantity of the colloidal fraction contained in the soil. The dry strength increases with increasing plasticity.

High dry strength is characteristic for clays of the CH group. Inorganic silt has only very slight dry strength. Silty fine sands and silts have about the same slight dry strength, but can be distinguished by feel when powdering the dried specimen. Fine sand feels gritty, whereas silt has the smooth feel of flour.

Calcium carbonate or iron oxides may cause higher dry strength in dried material. If acid causes a fizzing reaction, calcium carbonate is present.

Dilatancy (Reaction to Shaking)
After removing particles > No. 40 sieve size, prepare a pat of moist soil with a volume of about 0.5 in^3. Add enough water, if necessary, to make the soil soft but not sticky.

Place the pat in the open palm of one hand and shake horizontally, striking vigorously against the other hand several times. A positive reaction is the appearance of water on the surface of the pat, which changes to a livery consistency and becomes glossy. When the sample is squeezed between the fingers, the water and gloss disappear from the surface, the pat stiffens, and it finally cracks or crumbles. The rapidity of appearance of water during shaking and of its disappearance during squeezing assist in identifying the character of the fines in a soil.

Very fine clean sands give the quickest and most distinct reaction, whereas a plastic clay has no reaction. Inorganic silts, such as rock flour, show a moderately quick reaction.</td><td rowspan="7">COARSE-GRAINED SOILS</td><td rowspan="7">For undisturbed soils, add information on stratification, degree of compactness, cementation, moisture conditions, and drainage characteristics.

Give typical name: indicate approximate percentages of sand and gravel; maximum size; angularity, surface condition, and hardness of the coarse grains; local or geologic name; other pertinent descriptive information; and symbol in parentheses.

Example:

<u>Silty sand</u>, gravelly; about 20% hard, angular gravel particles ½ in. maximum size; rounded and subangular sand grains coarse to fine; about 15% non-plastic fines with low dry strength; well compacted and moist in place; alluvial sand; (SM).</td><td>GW GP</td></tr>
<tr><td>GM</td></tr>
<tr><td>GC</td></tr>
<tr><td>SW</td></tr>
<tr><td>SP</td></tr>
<tr><td>SM</td></tr>
<tr><td>SC</td></tr>
<tr><td rowspan="4">FINE-GRAINED SOILS</td><td rowspan="4">For undisturbed soils, add information on structure, stratification, consistency in undisturbed and remolded states, and moisture and drainage conditions.

Give typical name: indicate degree and character of</td><td>ML</td></tr>
<tr><td>CL</td></tr>
<tr><td>OL</td></tr>
<tr><td>MH</td></tr>
</table>

<table>
<tr><th>Field Identification Procedures for Fine-Grained Soils or Fractions</th><th colspan="2">Information Required During Logging</th><th></th></tr>
<tr><td rowspan="3">Toughness (Consistency Near Plastic Limit)
After removing particles > No. 40 sieve size, a specimen of soil about 0.5 in^3 cube in size is molded to the consistency of putty. If too dry, water must be added and if sticky, the specimen should be spread out in a thin layer and allowed to lose some moisture by evaporation. Then the specimen is rolled out by hand on a smooth surface or between the palms into a thread about 1/8 in. in diameter. The thread is then folded and rerolled repeatedly. During this manipulation, the moisture content is gradually reduced; and the specimen stiffens, finally loses its plasticity, and crumbles when the plastic limit is reached.

After the thread crumbles, the pieces should be lumped together, and a slight kneading action continued until the lump crumbles.

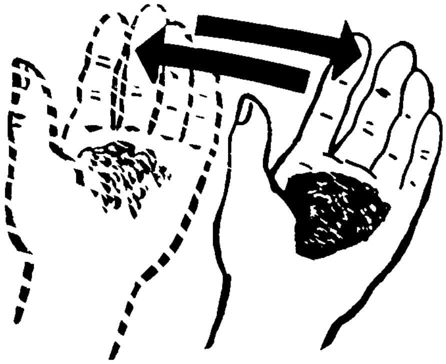
The tougher the thread near the plastic limit and the stiffer the lump when it finally crumbles, the greater is the colloidal clay fraction in the soil. Weakness of the thread at the plastic limit and quick loss of coherence of the lump below the plastic limit indicate either inorganic clay of low plasticity, or materials such as kaolin-type clays and organic clays, which occur below the A-line.

Highly organic clays have a very weak and spongy feel at the plastic limit. Non-plastic soils cannot be rolled into a thread at any moisture content. The toughness increases with the PI.</td><td rowspan="2"></td><td rowspan="3">plasticity, amount and maximum size of coarse grains, color in wet condition, odor if any, local or geologic name, other pertinent descriptive information, and symbol in parentheses.

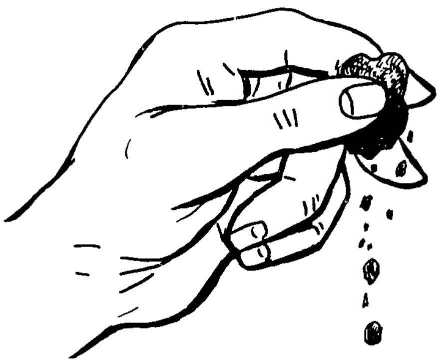
Example:

<u>Clayey silt</u>, brown, slightly plastic, small percentage of fine sand, numerous vertical root holes, firm and dry in place, loess, (ML).</td><td>CH</td></tr>
<tr><td>OH</td></tr>
<tr><td>ORGANIC SOILS</td><td>PT</td></tr>
</table>

Figure 3-20. Manual field test for soils



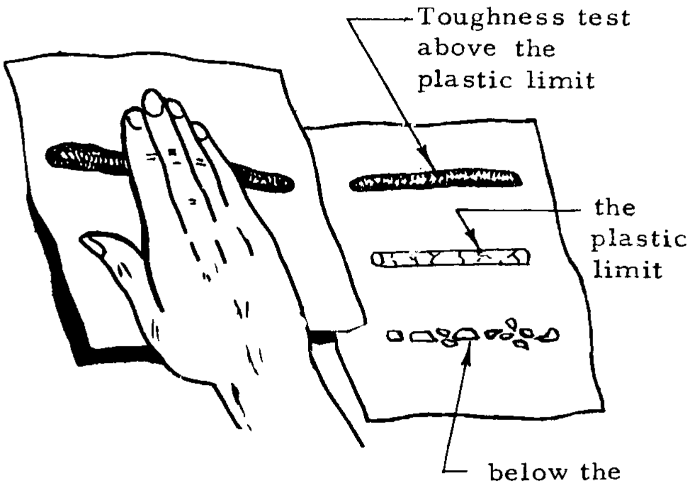
Dilatency Test: Shaking wet soil



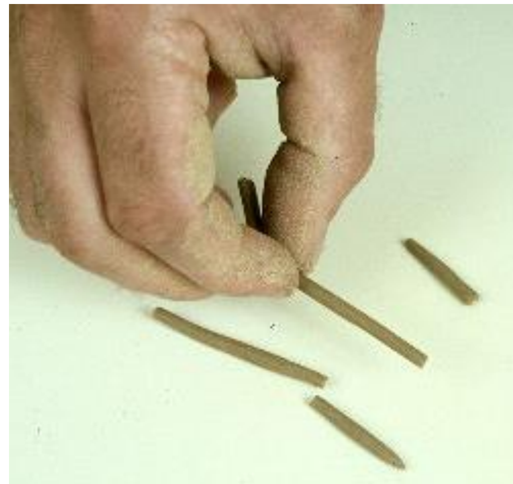
Dry Strength Test: Crumbling dry sample between fingers

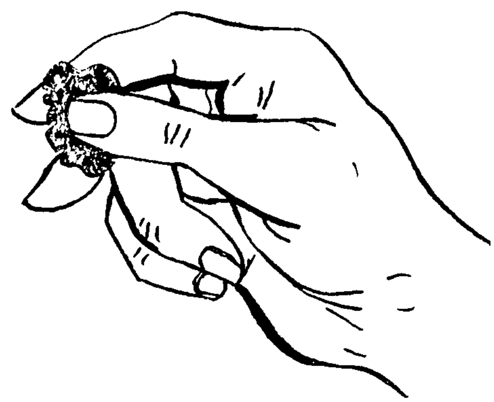
Shine Test

Ribbon Test



Rolling soil into threads





Remolding tough thread at plastic limit into lump and deforming

Figure 3-21. Manual field test procedures for the engineering classification of soils

Step	Test Procedure
1	Spread the sample on a flat surface or in the palm of the hand to aid in observing the relative amounts of coarse- and fine-grained components. Classify the soil as coarse-grained or fine-grained. The division between coarse and fine grain is the 200-mesh sieve.
2	If fine-grained, see step 6 below. If coarse-grained, classify as gravel or sand. Classify as gravel if > 50% of coarse fraction > No. 4 sieve (about 1/4 inch). Classify as sand if > 50% of coarse fraction is < No. 4 sieve.
3	If gravel or sand, determine whether it is “clean” having < 5% fines; borderline, 5 to 12% fines; or “dirty” having > 12% fines. Fines are defined as the fraction < the 200-mesh sieve size. < 5% fines will not stain the hands when wet.
4	If the gravel (G) or sand (S) is clean, decide if it is well-graded (W) or poorly graded (P). Well-graded materials have a good representation of all particle sizes, or poorly graded (P) can have excess or absence of intermediate particle sizes. Assign an appropriate group name and symbol for the material (GP, GW, SP, SW).
5	If the gravel or sand contains > 12% fines, it is classified as GM, GC, SM, or SC, depending on the type of fines. The procedure for identifying type of fines is given in the following steps: Borderline cases, where fines range from 5 to 12%, are classified in the laboratory with dual symbols, i.e., GP-GC, SP-SC. Classification of borderline cases, as well as boundary cases between various groups, requires precise laboratory analysis for proper classification. Such analyses cannot be made in the field. When field classification indicates that material might fall into one of two classifications, both symbols should be indicated, such as (GP or GC) or (SW or SP).
6	For fine-grained soils or the fine-grained fraction of a coarse-grained soil, the “dilatancy,” “dry strength,” and “toughness” tests are performed according to the instructions given on the left-hand side of figure 3-19. The group name and symbol are arrived by selection of that group, the characteristics of which most nearly compare to that of the sample. These characteristics are in the lower part of figure 3-19.
7	Highly organic soils are classified as peat (Pt). These are identified by color, odor, spongy feel, and fibrous texture.
8	Fine-grained soils that have characteristics of two groups, either because of percentage of the coarse-grained components or plasticity characteristics, are given boundary classifications, such as (ML-MH), (CL-CH), (OL-OH), (CL-ML), (MH-CH). Common boundary classifications between coarse- and fine-grained soils are (SM-ML) and (SC-CL).
9	Miscellaneous tests and criteria may be used to identify other substances and constituents. Some of these are outlined under Field Tests, 631.0303(E).

Figure 3-22. Engineering properties of USCS soil classes

Typical Names	Important Properties						UNIFIED SOIL CLASSES
	Shear Strength	Compress-ibility	Workability as Construction Material	Permeability			
				When Compacted	K Cm/sec	K Ft/day	
Well-graded gravels, gravel-sand mixtures, little or no fines	Excellent	Negligible	Excellent	Pervious	$K > 10^{-2}$	K > 30	**GW**
Poorly graded gravels, gravel-sand mixtures, little or no fines	Good	Negligible	Good	Very Pervious	$K > 10^{-2}$	K > 30	**GP**
Silty gravels, gravel-sand-silt mixtures	Good to Fair	Negligible	Good	Semi-Pervious to Impervious	$K = 10^{-3}$ to 10^{-6}	K = 3 to 3×10^{-3}	**GM**
Clayey gravels, gravel-sand-clay mixtures	Good	Very Low	Good	Impervious	$K = 10^{-3}$ to 10^{-6}	$K = 3 \times 10^{-3}$ to 3×10^{-5}	**GC**
Well-graded sands, gravelly sands, little or no fines	Excellent	Negligible	Excellent	Pervious	$K > 10^{-3}$	K > 3	**SW**
Poorly graded sands, gravelly sands, little or no fines	Good	Very Low	Fair	Pervious	$K > 10^{-3}$	K > 3	**SP**
Silty sands, sand-silt mixtures	Good to Fair	Low	Fair	Semi-Pervious to Impervious	$K = 10^{-3}$ to 10^{-6}	K = 3 to 3×10^{-3}	**SM**
Clayey sands, sand-clay mixtures	Good to Fair	Low	Good	Impervious	$K = 10^{-6}$ to 10^{-8}	$K = 3 \times 10^{-3}$ to 3×10^{-5}	**SC**
Inorganic silts and very fine sands, rock flour, silty or clayey fine sands, or clayey silts with slight plasticity	Fair	Medium to High	Fair	Semi-Pervious to Impervious	$K = 10^{-3}$ to 10^{-6}	K = 3 to 3×10^{-3}	**ML**
Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, and lean clays	Fair	Medium	Good to Fair	Impervious	$K = 10^{-6}$ to 10^{-8}	$K = 3 \times 10^{-3}$ to 3×10^{-5}	**CL**
Organic silts and organic silty clays of low plasticity	Poor	Medium	Fair	Semi-Pervious to Impervious	$K = 10^{-4}$ to 10^{-6}	$K = 3 \times 10^{-1}$ to 3×10^{-3}	**OL**
Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts	Fair to Poor	High	Poor	Semi-Pervious to Impervious	$K = 10^{-4}$ to 10^{-6}	$K = 3 \times 10^{-1}$ to 3×10^{-3}	**MH**
Inorganic clays of high plasticity, fat clays	Poor	High to Very High	Poor	Impervious	$K = 10^{-6}$ to 10^{-8}	$K = 3 \times 10^{-3}$ to 3×10^{-5}	**CH**
Organic clays of medium to high plasticity, organic silts	Poor	High	Poor	Impervious	$K = 10^{-6}$ to 10^{-8}	$K = 3 \times 10^{-3}$ to 3×10^{-5}	**OH**
Peat and other highly organic soils	**NOT SUITABLE FOR CONSTRUCTION**						**PT**

Figure 3-23. Engineering properties of Unified Soil classes for embankments

Embankments								UNIFIED SOIL CLASSES
Compaction Characteristics	Standard Procter Unit Density lbs/ft^3	Type of Rpller Desirable	Relative Characteristics		Resistance to Piping	Ability to Take Plastic Deformation Under Load Without Shearing	General Description and Use	
			Permea-bility	Compressi-bility				
Good	125 – 135	Crawler tractor or steel-wheeled and vibratory	High	Very Slight	Good	None	Very stable, pervious shells of dikes and dams	**GW**
Good	115 – 125	Crawler tractor or steel-wheeled and vibratory	High	Very Slight	Good	None	Reasonably stable, pervious shells of dikes and dams	**GP**
Good with Close Control	120 – 135	Rubber-tired or sheepsfoot	Medium	Slight	Poor	Poor	Reasonably stable, not well suited to shells, but may be used for impervious cores or blankets	**GM**
Good	115 – 130	Rubber-tired or sheepsfoot	Low	Slight	Good	Fair	Fairly stable, may be used for impervious core	**GC**
Good	110 – 130	Crawler tractor or steel-wheeled	High	Very Slight	Fair	None	Very stable, pervious sections, slope protection required	**SW**
Good	100 – 120	Crawler tractor or steel-wheeled	High	Very Slight	Fair to Poor	None	Reasonably stable, may be used in dike with flat slopes	**SP**
Good with Close Control	110 – 125	Rubber-tired or sheepsfoot	Medium	Slight	Poor to Very Poor	Poor	Fairly stable, not well suited to shells, but may be used for impervious cores or dikes	**SM**
Good	105 – 125	Rubber-tired or sheepsfoot	Low	Slight	Good	Fair	Fairly stable, use for impervious core for flood control structures	**SC**
Good with Close Control Essential	95 – 120	Sheepsfoot	Medium	Medium	Poor to Very Poor	Very Poor (varies with water content)	Poor stability, may be used for embankments with proper control	**ML**
Fair to Good	95 – 120	Sheepsfoot	Low	Medium	Good to Fair	Good to Poor	Stable, impervious cores and blankets	**CL**
Fair to Poor	80 – 100	Sheepsfoot	Medium to Low	Medium to High	Good to Poor	Fair	Not suitable for embankments	**OL**

Embankments									UNIFIED SOIL CLASSES
Compaction Characteristics	Standard Procter Unit Density lbs/ft^3	Type of Rpller Desirable	Relative Characteristics		Resistance to Piping	Ability to Take Plastic Deformation Under Load Without Shearing	General Description and Use		
			Permea-bility	Compressi-bility					
Poor to Very Poor	70 – 95	Sheepsfoot	Medium to Low	Very High	Good to Poor	Good	Poor stability, core of hydraulic fill dam, not desirable in rolled-fill construction		**MH**
Fair to Poor	75 – 105	Sheepsfoot	Low	High	Excellent	Excellent	Fair stability with flat slopes, thin cores, blanket and dike section		**CH**
Poor to Very Poor	65 – 100	Sheepsfoot	Medium to Low	Very High	Good to Poor	Good	Not suitable for embankments		**OH**
DO NOT USE FOR EMBANKMENT CONSTRUCTION									**PT**

Figure 3-24. Engineering properties of Unified Soil classes for foundations and channels

CHANNELS		FOUNDATION					UNIFIED SOIL CLASSES
Long Duration to Constant Flow		Foundation soils, being undisturbed, are influenced to a great degree by their geologic origin. Judgment and testing must be used in additioin to the generalizations below.					
Relative Desireability		Bearing Value	Relative Desireability		Requirements for Seepage Control		
Erosion Resistance	Compacted Earth Lining		Seepage Important	Seepage Not Important	Permanent Reservoir	Floodwater Retarding	
1	-	Good	-	1	Positive cutoff or blanker	Control only within volume acceptable, plus pressure relief if required	**GW**
2	-	Good	-	3	Positive cutoff or blanker	Control only within volume acceptable, plus pressure relief if required	**GP**
4	4	Good	2	4	Core trench to none	None	**GM**
3	1	Good	1	6	None	None	**GC**
6	-	Good	-	2	Positive cutoff or upstream blanket and toe drains or wells	Control only within volume acceptable, plus pressure relief if required	**SW**
7 if gravelly	-	Good to Poor, depends on density	-	5	Positive cutoff or upstream blanket and toe drains or wells	Control only within volume acceptable, plus pressure relief if required	**SP**
8 if gravelly	5 erosion critical	Good to Poor, depends on density	4	7	Upstream blanket and toe drains or wells	Sufficient control to prevent dangerous seepage piping	**SM**
5	2	Good to Poor	3	8	None	None	**SC**
-	6 erosion critical	Very Poor, susceptible to liquefaction	6, if saturated or pre-wetted	9	Positive cutoff or upstream blanket and toe drains or wells	Sufficient control to prevent dangerous seepage piping	**ML**
9	3	Good to Poor	5	10	None	None	**CL**
-	7 erosion critical	Fair to Poor, excessive settlement	7	11	None	None	**OL**
-	-	Poor	8	12	None	None	**MH**
10	8 volume change critical	Fair to Poor	9	13	None	None	**CH**
-	-	Very Poor	10	14	None	None	**OH**
-	-	**REMOVE FROM FOUNDATION**					**PT**

Note: No. 1 is the best numerical rating.

631.0305 Definitions

Boulder	Particles of rock that will not pass a 12-inch square opening.
Clay	Particles that pass the No. 200 sieve. They are considered plastic and have considerable dry strength.
Coarse-Grained	A soil that contains less than 50% fines.
Cobble	Particles of rock that will pass a 12-inch square opening and be retained on a 3-inch sieve.
Earth Material	Soil or rock.
Fine-Grained	A soil that contains 50% or more of fines.
Fines	Particles smaller than No. 200 mesh sieve, identified by behavioral characteristics rather than specific grain sizes. The particles are considered silts and clays.
Gradation	Relative size distribution of particles.
Grain	A rock or mineral particle.
Gravel	Particles of rock that will pass a 3-inch sieve and is retained on a No. 4 sieve.
Organic Clay	A clay with sufficient organic content to influence the soil properties.
Organic Silt	A silt with sufficient organic content to influence the soil properties.
Peat	A soil composed primarily of vegetable tissue in various stages of decomposition.
Poorly Graded	Skip grades or excess of certain size ranges may be well sorted.
Rock	A compact, semi-hard to hard, semi-indurated to indurated, consolidated mass of natural materials composed of one or more minerals.
Sand	Particles of rock that will pass a No. 4 sieve and is retained on a No. 200 sieve.
Silt	Particles that pass the No. 200 sieve. They are considered non-plastic or very slightly plastic and have little or no dry strength.
Soil	Unconsolidated, unindurated, or slightly indurated, loosely compacted products of disintegration and decomposition processes of weathering.
Well-Graded	No sizes lacking or no excess of any size range, poorly sorted.

631.0306 References

A. AASHTO. 1998. American Association of State Highway Transportation Officials. Standard Specifications for Transportation Materials and Methods of Sampling and Testing, Part 1, Specifications. Washington, DC. Reference AASHTO Method M 145 (1995).

B. ASTM D1586. 2018. ASTM International. Standard Test Method for Standard Penetration Test (SPT) and Split-Barrel Sampling of Soils. DOI: 10.1520/D1596_D1586M-18. West Conshohocken, PA. http://www.astm.org/

C. ASTM D2166. 2006. ASTM International. Standard Test Method for Unconfined Compressive Strength of Cohesive Soil. DOI: 10.1520/D2166–06. West Conshohocken, PA. http://www.astm.org/

D. ASTM D2487. 2011. ASTM International. Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System), DOI: 10.1520/D2487–11. West Conshohocken, PA. http://www.astm.org/

E. ASTM D2488. 2009. ASTM International. Standard Practice for Description and Identification of Soils (Visual-Manual Procedure), DOI: 10.1520/ D2488–09A. West Conshohocken, PA. http://www.astm.org/

F. ASTM D2573. 2008. ASTM International. Standard Test Method for Field Vane Shear Test in Cohesive Soil, DOI: 10.1520/D2573–08. West Conshohocken, PA. http://www.astm.org/

G. ASTM D3282. 2009. ASTM International. Standard Practice for Classification of Soils and Soil- Aggregate Mixtures for Highway Construction Purposes, DOI: 10.1520/D3282–09. Reference AASHTO Soil Classification System. West Conshohocken, PA. http://www.astm.org/

H. ASTM D6913. 2017. ASTM International. Standard Test Method for Particle-Size Distribution (Gradation) of Soils Using Sieve Analysis. DIO: 10.1529/D6913_D6913M-17. West Conshohocken, PA. http://www.astm.org/

I. Lane, E. W. 1947. Report of the Subcommittee on Sediment Terminology, Transactions, American Geophysical Union, Vol. 28, No.6, Washington, DC. pp 936-938. Reference AGU classification system, American Geophysical Union.

J. Munsell. 2009 Revised Edition. Munsell Rock Color Chart; Munsell Color, Grand Rapids, MI. https://munsell.com/

K. Munsell. 2009 Revised Edition. Munsell Soil Color Chart; Munsell Color, Grand Rapids, MI. https://munsell.com/

L. Udden, J.A., 1914. Mechanical composition of clastic sediments, Bull. Geol. Soc. Am. 25, 655–744.

M. U.S. Department of Agriculture (USDA). 2017. Soil Survey Manual (SSM), USDA Agricultural Handbook No. 18, National Cooperative Soil Survey, Washington, DC. https://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/soils/ref/?cid=nrcs142p2_054262

N. U.S. Department of Agriculture (USDA), Natural Resources Conservation Service (NRCS). 1997. Chapter 52, Field Procedures Guide for the Headcut Erodibility Index, National Engineering Handbook, Part 628, Dams. Washington, DC. https://directives.sc.egov.usda.gov/OpenNonWebContent.aspx?content=36147.wba

O. Wagner, A.A. 1957. The use of the Unified Soil Classification System by the Bureau of Reclamation: Proceedings, 4th International Conference on Soil Mechanics and Foundation Engineering (London), Vol. 1, p. 125.

P. Wentworth, C.K. 1922. A scale of grade and class terms for clastic sediments, J. Geology V. 30, 377–392.

Q. U.S. Department of Agriculture (USDA), Natural Resources Conservation Service (NRCS). 2021. Chapter 4, Elementary Soils Engineering, Engineering Field Handbook, Part 650, National Engineering Handbook, Washington, DC. https://directives.sc.egov.usda.gov/OpenNonWebContent.aspx?content=46259.wba