United States Department of Agriculture
Natural Resources Conservation Service

Part 631
National Engineering Handbook

Chapter 3 Engineering Classification of Earth Materials

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Preface

Chapter 3, Engineering Classification of Earth Materials, and related chapters in the National Engineering Handbook (NEH), Part 631 replace NEH Section 8, Engineering Geology, released in 1978.

Chapter 3 Engineering Classification of Earth Materials

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631.0300 Introduction

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

The Natural Resources Conservation Service (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, techtonics, 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. 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.

Although earth materials may be soil, rock, or combinations of soil and rock, this chapter focuses focus on soil materials. The National Engineering Handbook (NEH), part 631, chapter 4, focuses on the engineering classification of rock materials.

Some common characteristics for both soil and rock are described briefly in this chapter.

(a) Terminology

The following is a list of some of the more important terms and their meanings used to describe earth materials in this chapter.

Rock—A compact, semi-hard to hard, semi-indurated to indurated, consolidated mass of natural materials composed of one or more minerals

Soils—Unconsolidated, unindurated, or slightly indurated, loosely compacted products of disintegration and decomposition processes of weathering

Earth materials—Soil or rock.

Grain—A rock or mineral particle.

Gradation—Relative size distribution of particles

Well graded—No sizes lacking or no excess of any size range, poorly sorted.

Poorly graded—Skip grades or excess of certain size ranges, may be well sorted.

Silt and clay—Particles smaller than Number 200 mesh sieve, identified by behavioral characteristics rather than specific grain sizes—also called fines.

631.0301 Physical and mineralogical characteristics of earth materials

(a) Particle characteristics

Particle characteristics, including size, shape, mineral composition, and hardness, are important considerations in establishing the origin of materials, 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.

(1) Size

The important size classifications are: boulders, cobbles, gravel, sand, silt, and clay. Numerous grade scales have been developed to establish the limits of size for each of these classifications. Table 3–1 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. For reference, figure 3–1 shows the USDA textural classification system.

(2) Shape

Geologists express the degree of roundness of particles on the basis of the average radius of the corners divided by the radius of the maximum inscribed circle. 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 3–2 shows a comparison of degrees of roundness and angularity, which serve as a guide to visual estimation and classification of roundness.

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. 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 3–1 USDA textural soil classification (USDA 1951)

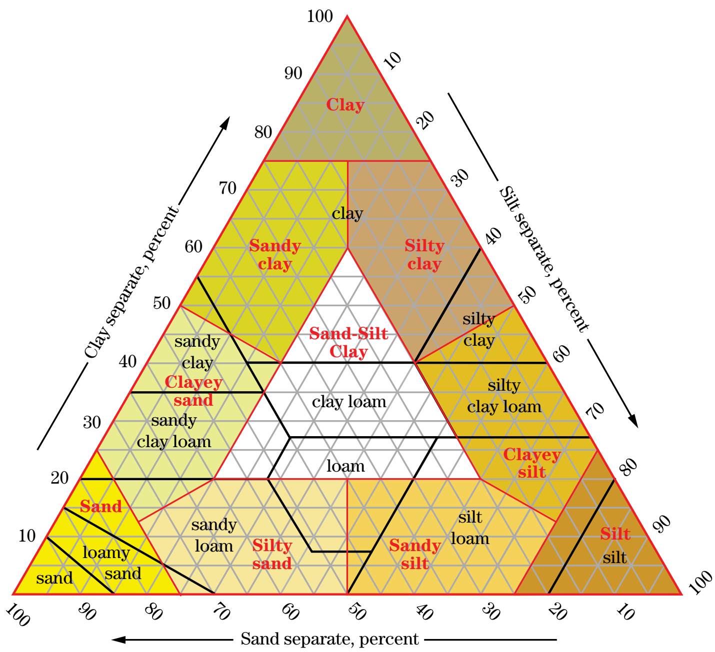


Figure 3–2 Particle shapes

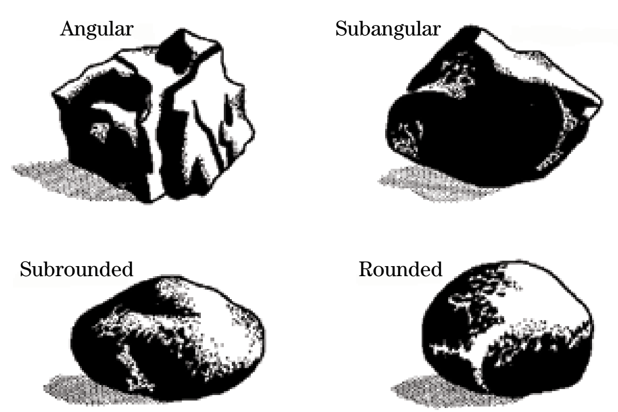


Table 3–1 Particle gradation scales for earth materials

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	boulders	boulders
		1024		boulders			
		512					
12		300					
10		256	cobbles		cobbles		
6		128				cobbles	cobbles
3		75					
		64					
		32	coarse gravel	coarse gravel			
1		25.4			coarse gravel		
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			

1/ Unified Soil Classification System, ASTM D2487
2/ AASHTO, American Association of State Highway and Transportation Officers (AASHTO 1998)
3/ AGU, American Geophysical Union (Lane 1947)
4/ USDA textural classification system (USDA 1951)
5/ Udden-Wentworth classification system (Udden 1914; Wentworth 1922)

(3) Mineral composition

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.

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. 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.

(4) Hardness

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 is an important property for identification of minerals. Hardness of individual particles is an important engineering consideration in respect to resistance to crushing when loaded. Table 3–2 summarizes field test descriptors for hardness.

(5) Clay minerals

Clay minerals require special attention because of how they affect the engineering properties of soils, primarily because of their fine-grained nature, platy shape, molecular structure, and water-bearing lattice. 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 3–3 illustrates the platy structure of clays.

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

The 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.

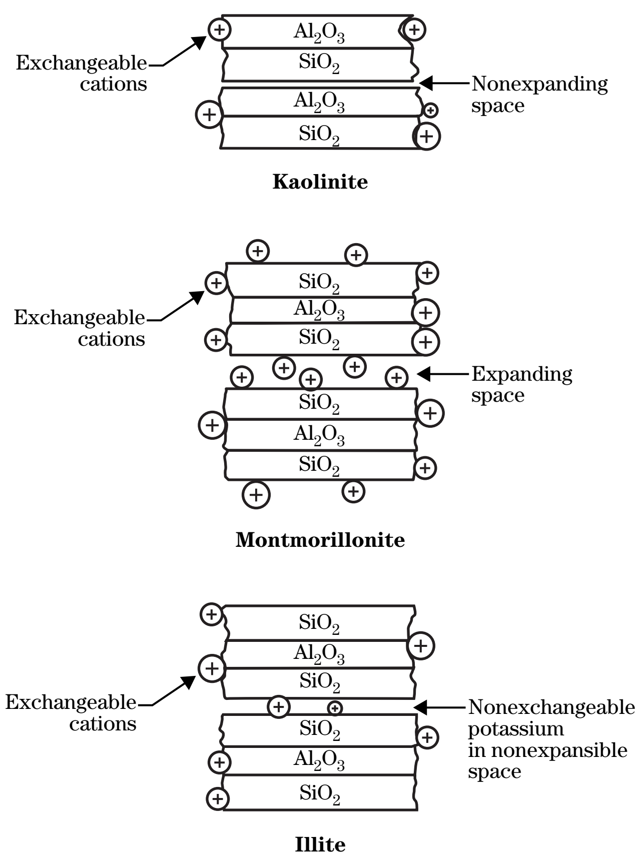
The montmorillonite clays consist of three-layer molecular sheets consisting of two layers of silica to one of alumina. The molecular sheets are weakly bonded, permitting water and associated chemicals to enter between the sheets. As a result, they are subject to considerable expansion when saturated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

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

Table 3–2 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 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

Figure 3–3 Representation of the structure of clay mineral particles



(b) Mass characteristics

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.

(1) Soil materials

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. Soil materials may be referred to as "cohesive and fine-grained," or "noncohesive and coarse-grained."

(2) Color

Color varies widely in earth materials but often provides a useful means of identification for geologic and engineering purposes. The presence of organic matter, certain minerals, and some types of weathering can often be readily detected by color. Rock colors vary depending on degree of weathering, presence of staining material, and whether wet or dry. Rock colors should be described using the Rock Color Chart (Munsell 2009a). Soil colors should use the Munsell Soil Color Charts (Munsell 2009b). The color name and color chart value and chroma should be recorded (e.g., light brown (7.5YR, 6/3)).

(3) Consistency

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 contents, expressed in percent of dry weight, at which the mass passes from one of these stages of consistency to another are known as the Atterberg limits or limits of consistency. The term "consistency" 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, medium, stiff, very stiff, and hard. The term "consistency" 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. Table 3–3 summarizes consistency.

Atterberg limits or limits of consistency are determined on soil materials passing the 40-mesh sieve. 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.

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 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.

Table 3–3 Consistency chart for cohesive soils (silt and clay)

Consistency rating	Standard penetration test (N = blows/ft)	Pocket penetrometer	Unconfined compressive strength (UCS) (MPa)	Material strength number (M_s)	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 0.21	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	0.21 to 0.47	Indented only by thumbnail. Slight indentation by pushing point of geologic pick. Requires hand pick for excavation.
Hard	> 30	> 4.0			Indented by thumbnail with difficulty.

Notes

1. Cohesive soil is material with a plasticity index (PI) greater than 10. Use NEH 628, chapter 52, table 52–2 for cohesionless soils.
2. 1 kPa equals 1 kN/m^2.
3. Vane shear strength (ASTM D2573, field; ASTM D4648, lab) also may be used for unconfined compressive strength (ASTM D2166).
4. Cohesive soils in which blow counts are greater than 30 or strengths greater than 0.625 MPa are to be taken as rock, for which the hardness can be obtained from NEH 628, chapter 52, table 52–4.
5. Cohesive soils must be evaluated for hardness in the saturated condition.
6. M_s of a cohesive soil also can be determined as the product of unconfined compressive strength (in MPa) times its coefficient of relative density. 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
7. Correlation between 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 or field assessment tests. Vane shear strength values also are applicable in the lower strength ranges.

(4) Density

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. 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, and very dense. Table 3–4 summarizes density.

Table 3–4 Density chart for cohesionless soils[1/] (sands and gravels)

Relative density rating	Standard penetration test [2/, 5/] (N = blows/ft) [4/, 5/]	In situ deformation modulus (IDM) (MPa) [5/]	Material strength number (M_s) [3/]	Field test
Very loose	< 5	< 0.005	< 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	0.005–0.01	0.02–0.04	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	0.01–0.03	0.04–0.09	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	0.03–0.08	0.09–0.21	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	0.08–0.2	0.21–0.45	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

1/ Cohesionless soil is a material with a PI less than or equal to 10. Use NEH 628, chapter 52, table 52–3 for cohesive soils.

2/ Standard penetration test, SPT (ASTM D1586) used for most sandy-type cohesionless soils. In situ deformation modulus (IDM) used for most gravel-type soils and coarse detritus.

3/ M_s of a cohesionless soil is approximately determined from results of IDM testing by the following relationship:
M_s = 1.7 (IDM) 0.832 for IDM in MPa

4/ Cohesionless soils in which blow counts are greater than 50 or IDM is greater than 0.20 MPa to be taken as rock, for which the hardness may be obtained from NEH 628, chapter 52, table 52–4.

5/ Correlation between SPT and IDM should be used as a guide only as results may vary in different geologic areas. Lab strength tests are recommended on soil materials to support SPT or field assessment tests.

(5) Moisture content

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. Table 3–5 summarizes moisture descriptions.

(6) Permeability

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. 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.

Coefficient of permeability—The coefficient of permeability of a 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:

- Lugeon value or unit = 1 Lugeon = 1 L/min/meter of borehole @ 10 kg/cm^2
  (1 MN/m^2)(150 lb/in^2)
- Meinzers units = gal/ft^2/d under unit hydraulic gradient
- Feet/day = ft^3/ft^2/d under unit hydraulic gradient
- Centimeters/second = cm^3/cm^2/s under unit hydraulic gradient
- Feet/year = ft^3/ft^2/yr under unit hydraulic gradient
- Inches/hour = in^3/in^2/h 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 table 3–6.

Table 3–5 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

Table 3–6 Conversion factors for permeability units

From \ To	Meinzers units	Feet per day	Centimeters per second	Feet per year	Inches per hour
Meinzers units	1	0.13368	4.7159×10^{-5}	48.8256	0.06684
ft/d	7.4806	1	3.5278×10^{-4}	365.2422	0.5
cm/s	2.12049×10^{4}	2.83464×10^{3}	1	1.03530×10^{7}	1.41731×10^{3}
ft/yr	0.02048	2.7379 × 10–3	9.6590×10^{-7}	1	1.3689×10^{-3}
in/h	14.9611	2.0	7.0556×10^{-4}	730.4844	1

(7) Consolidation

Consolidation refers to the volume change 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. Density, plasticity, porosity, permeability, and organic content are important factors in determining the degree of compressibility.

(8) Shearing strength

Shearing strength is the resistance of soil particles to sliding on one another.

(9) 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 on the basis of plasticity rather than on grain-size diameter. This system is not entirely adequate to define all physical characteristics needed for identification and correlation purposes.

631.0302 Rock characteristics related to engineering properties

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

(a) Permeability

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.

Relative permeability ratings for various rock materials are shown in NEH 631.0406, Rock Material Field Classification System.

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

(b) Consolidation

The bearing strength of rock is normally adequate to support dams designed by the 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. 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.

Mineral extraction, including oil and gas, adjacent to or beneath embankments or reservoirs should be identified and potential impacts assessed according to existing policies.

(c) Shearing resistance

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

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. For further details on classification of rock for excavation, see NEH Part 642, NRCS Standard Specifications, Construction and Construction Materials.

631.0303 Geologic properties of materials

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.

(a) Origin

(1) Type of deposit

Type of deposit describes the mode, agent, and processes of formation of the deposit. It furnishes information on the continuity of strata and the uniformity of physical characteristics which 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.

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 definition is 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

The age of a stratum establishes its vertical position in the geologic column and its relationship to other strata. Age should always be indicated using accepted geologic eras, periods, epochs, and ages when identifiable.

(b) Orientation

(1) Stratigraphy

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.

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, gravity), and the processes of deposition and consolidation are elements of stratigraphy. 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

The depth and thickness of materials at specific points at a site are determined from exposure and subsurface borings or test holes. Continuity must be interpreted on the basis of 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 which may have an effect on the design and construction of a dam.

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–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 which pinch out between bore holes.

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

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. 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.

See NEH, Part 631, Chapter 4, Engineering Classification of Rock Materials for further description of structure of rock materials.

(c) Fossils and artifacts

(1) Paleontology

Evidences of life in the past are 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. 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

Direct or indirect evidence of prehistoric and historic artifacts and features may be encountered during investigations. Sampling may reveal implements, cuttings, fire pits, or structures used by prehistoric people.

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. If uncertain about what has been encountered, call the NRCS State or area cultural resources specialist (CRS) or coordinator (CRC), report your findings and ask for guidance on how to proceed. The 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 actually meets the criteria for protection. The NRCS CRS or CRC can help make this determination. If bone that may be human remains is encountered, immediately notify the CRS or CRC. They will help identify the bone and, if necessary, help notify the proper authorities.

(d) Field tests

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 section on the USCS. In addition to these standard tests, additional tests may be used to classify materials and identify special properties. Some of these tests are described in table 3–7.

Using some of the field tests provided can help determine the USCS classification by looking at table 3–8.

The field procedure does not require specialized equipment. Small bottles of clear water and dilute hydrochloric acid are used. Acetone and other reagents may also be needed to perform any tests shown in table 3–4. Experience in classifying materials in USCS can be learned initially through the use of numbers 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.

Table 3–7 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 dilute hydrochloric acid (1/10 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</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. Put 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 2 feet (gravel sizes are not included in the ball).
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 (nonplastic)</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>Stickness</td><td>A high degree of stickness in the natural state is indicative of higher plasticity.</td></tr>
<tr><td>Grittiness test</td><td>This test should not be performed when hazardous waste contamination is suspected or known to be present. Place a small amount of soil between 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 1-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 a half ounce of the clear solution into a glass container without disturbing the settled soil in the bottom of the bottle.
5. Add a half 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 cubic centimeters 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 cubic centimeters of nitrobenzene and 0.1 gram malachite green. Montmorillonite and illite clays usually show a greenish yellow or pale yellow color.</td></tr>
</table>

Table 3–8 USCS classification by field tests

USCS	Description	Dilatency 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

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

The classification consists of 15 soil groups, each having distinctive engineering properties. Boundary classifications are provided for soils which have characteristics of two groups. Letter symbols have been derived from terms which are descriptive of the soil components, gradation, and liquid limit. These are combined to identify each of the 15 soil groups. Table 3–9 lists these letter symbols.

(a) Soil components

The term "soil components" applies to the solid mineral grains comprising earth materials. These components range in size from more than 12 inches to colloidal size. 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. Table 3–10 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 table 3–1.

A quarter-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 3–4, USCS plasticity chart, classifies the finer grained soil relative to liquid limit and plasticity index.

Table 3–9 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
M	Silt	L or H	Low/high liquid limit
C	Clay	L or H	Low/high liquid limit
O	Organic	L or H	Low/high liquid limit
Pt	Peat	—	—

(b) Gradation

Coarse-grained soil gradation descriptors are shown in table 3–11. In the soil mechanics laboratory, the amounts of the various sized grains are determined by sieving and mechanical analysis and the results plotted on Form SCS–353 or equivalent. The type of gradation is readily apparent from the shape of the grain-size curve. Figure 3–5 illustrates the grain-size distribution graphs of some typical soils.

Poorly graded soils have steeply sloping curves, very flat curves, or abrupt changes in the slope of the curves, when plotted on semi-log graph paper. 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.

The coefficient of uniformity (C_u), 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:

Table 3–10 Soil components and significant properties (Wagner 1957)

Soil component	Symbol	Grain size range and description	Significant properties
Boulder	None	Rounded to angular, bulky, hard, rock particle, average diameter greater than 12 inches	Boulders and cobbles are very stable components, used for fills, 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 less than 12 inches and greater than 3 inches	
Gravel Coarse Fine	G	Rounded to angular, bulky, hard, rock particle, passing 3-inch sieve (76.2 mm), retained on No. 4 sieve (4.76 mm). 3¾ inches ¾ inch to 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 sands and gravels. 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.
Sand Coarse Medium Fine	S	Rounded to angular, bulky, hard, rock particle, passing No. 4 sieve (4.76 mm), retained on No. 200 sieve (0.074 mm) No. 4 to 10 sieves (4.76–2.0 mm) No. 10 to 40 sieves (2.0–0.42 mm) No. 40 to 200 sieves (0.42–0.074 mm)	
Silt	M	Particles less than No. 200 sieve (0.074 mm) identified by behavior; i.e., slightly or nonplastic 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 less than 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 also 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.

Figure 3–4 Unified Soil Classification System plasticity chart

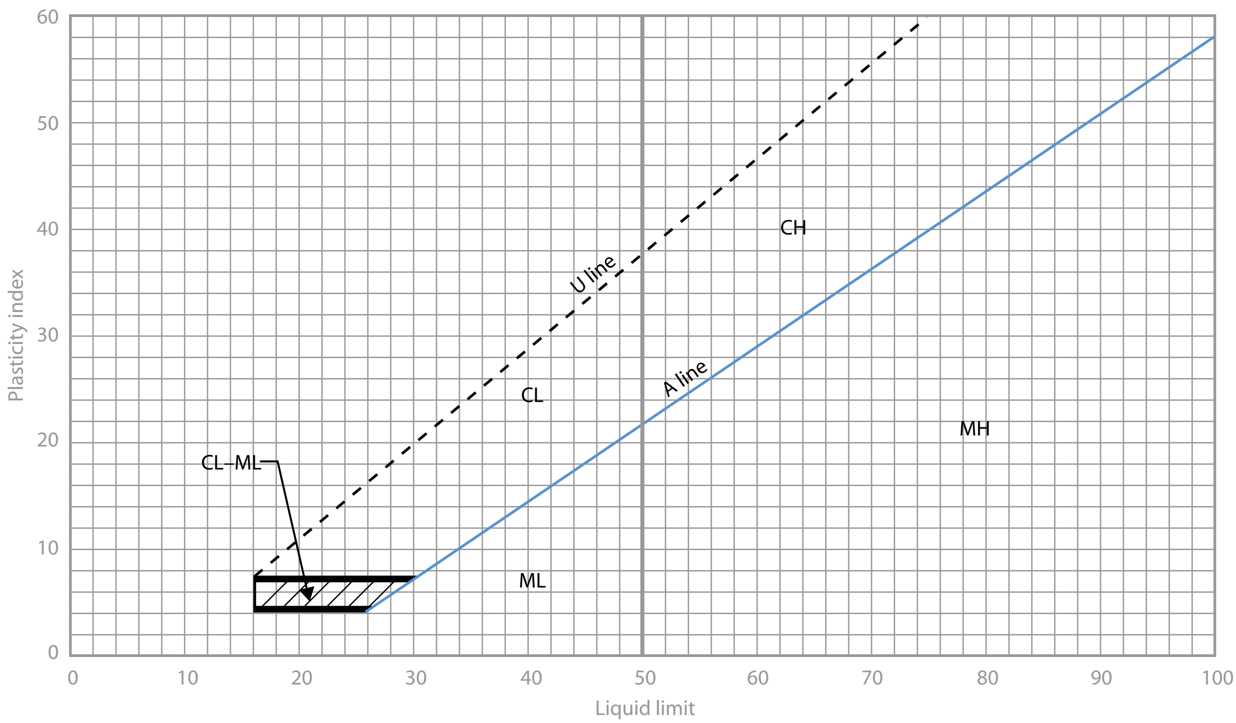


Figure 3–5 Grain size distribution graph

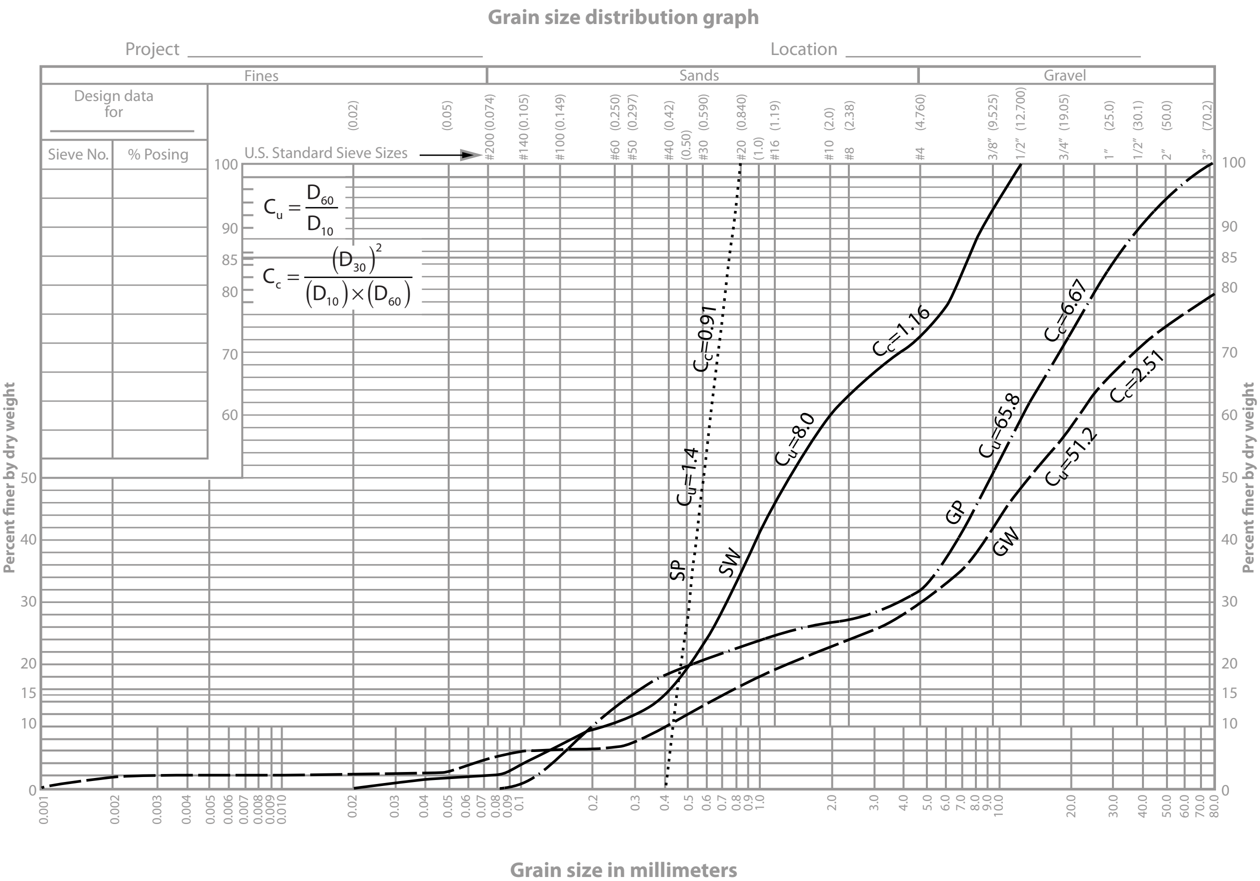


Table 3–11 Gradation descriptors for coarse-grained soils

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. C_u>4 and 1<C_c<3, where $C_u = D_{60}/D_{10}$ and $C_c=(D_{30})^2/D_{60}D_{10}$
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. C_u<4 and/or 1>C_c>3

Coefficient of Uniformity $C_u = \frac{D_{60}}{D_{10}}$

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

See figure 3–6 for an explanation of the use of these coefficients and other criteria (Atterburg limits) for laboratory identification procedures.

(c) Consistency

The most conspicuous physical property of fine-grained soils is their consistency, which is a function of their degree of plasticity. The various stages of consistency were described under mass characteristics. Atterberg limit tests are used to determine the liquid and plastic limits of soils in the laboratory. Field tests for dilatancy (reaction to shaking), dry strength (crushing characteristics), and toughness (consistency near the plastic limit) have been devised for field determinations. Figures 3–7 and 3–8 contain the procedures for making these field determinations and the methods of field classifications. The manual field tests are illustrated in figure 3–9.

(d) Field classification procedures

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:

- appoximate 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 where known or applicable

Figure 3–8, Field identification criteria, lists 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.

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 oversized material may be of importance 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.

Step-by-step procedures for classifying soils in the field are shown in table 3–12.

Figures 3–10, 3–11, and 3–12, 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 3–6 The Unified Soil Classification, laboratory criteria

Coarse-grained soils	**Grains** < 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 P.I. < 4	Plasticity limits above "A" line with P.I. > 4 < 7 are boundary cases and require use of dual symbols	**GM**
				Plasticity limits of material passing No. 40 sieve size plots below "A" line or P.I. > 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 P.I. < 4	Plasticity limits above "A" line with P.I. > 4 < 7 are boundary cases and require use of dual symbols	**SM**
				Plasticity limits of material passing No. 40 sieve size plots below "A" line or P.I. > 7		**SC**
Fine-grained soils	**Silts and clays** Liquid limit < 50	Below "A" line and P.I. < 4		Above "A" line and P.I., > 4 < 7 are borderline cases requiring use of dual symbols		**ML**
		Above "A" line and P.I. > 7				**CL**
		Below "A" line and P.I. < 4 and $\frac{\text{L.L. (oven dry soil)}}{\text{L.L. (air dry soil)}} < 0.7$		Plasticity chart (see below)		**OL**
	Silts and clays Liquid limit < 50	Below "A" line				**MH**
		Above "A" line				**CH**
		Below "A" line and P.I. < 4 and $\frac{\text{L.L. (oven dry soil)}}{\text{L.L. (air dry soil)}} < 0.7$				**OH**
Highly organic soils				$\frac{\text{L.L. (oven dry soil)}}{\text{L.L. (air dry soil)}} < 0.7$		**PT**

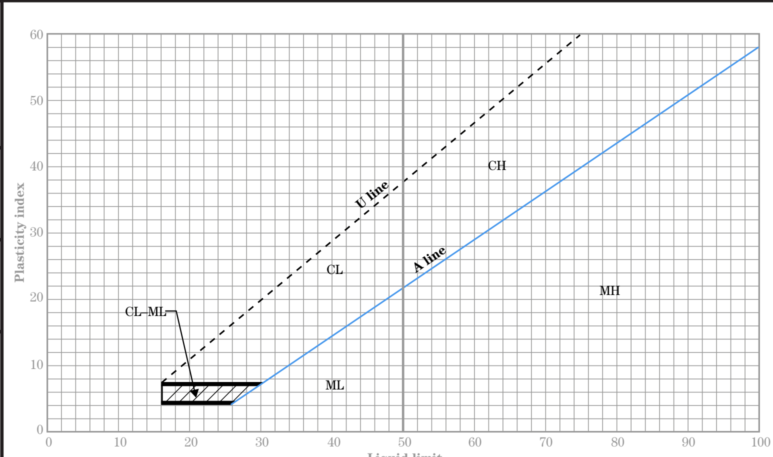


Figure 3–7 Unified Soil Classification, field identification criteria

No. 200 sieve size is about the smallest particle visible to the naked eye

Major division	Group			Subgroup	Description	Symbol
Coarse-grained soils > 50% of material (by weight) is of individual grains visible to the naked eye	**Gravel and gravely soils** < 50% of coarse fraction passes the No. 4 sieve size	Borderline cases require the use of dual,symbols	For visual classification, the 3/4 inch size may be used as equivalent to the No. 4 sieve size	**Clean gravels** Will not leave dirt stain on a wet palm	Wide range in grain sizes and substantial amounts of all intermediate particle sizes	**GW**
					Predominately 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	Nonplastic 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% half 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**
					Predominately 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	Nonplastic 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**	**Dilatancy (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	**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**

Figure 3–8 Unified Soil Classification, 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>GW</th></tr>
<tr><td rowspan="15">These procedures are to be performed on the minus No. 40 sieve size particles, or < 1/64 inch. 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.

Toughness (Consistency near plastic limit)
After removing particles > No. 40 sieve size, a specimen of soil about 0.5 in^3 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 inch 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. Nonplastic soils cannot be rolled into a thread at any moisture content. The toughness increases with the P.I.</td>
<td rowspan="7">Coarse-grained soil</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 and other pertinent descriptive information; and symbol in parentheses.

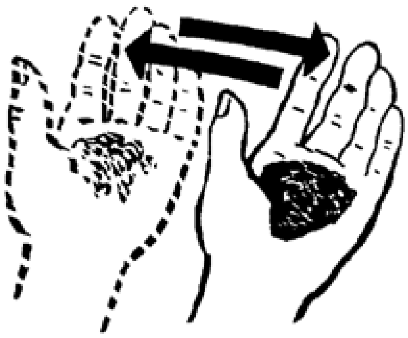
Example:
Silty sand, gravelly; about 20% hard, angular gravel particles 1/2-inch maximum size; rounded and subangular sand grains coarse to fine; about 15% nonplastic fines with low dry strength; well compacted and moist in place; alluvial sand, (SM).</td>
<td>GP</td></tr>
<tr><td>GM</td></tr>
<tr><td>GC</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="6">Fine-grained soils</td>
<td rowspan="8">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 and other pertinent descriptive information; and symbol in parentheses.

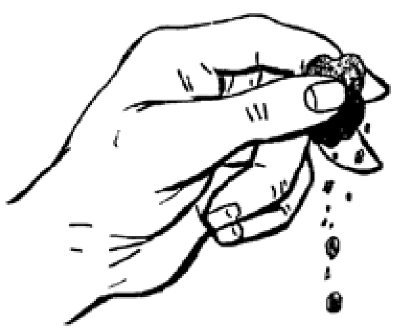
Example:
Clayey silt, brown, slightly plastic, small percentage of fine sand, numerous vertical root holes, firm and dry in place, loess, (ML).</td>
<td>ML</td></tr>
<tr><td>CL</td></tr>
<tr><td>OL</td></tr>
<tr><td>MH</td></tr>
<tr><td>CH</td></tr>
<tr><td>OH</td></tr>
<tr><td rowspan="2">Organic soils</td><td>PT</td></tr>
<tr><td></td></tr>
</table>

Figure 3–9 Manual field tests for soils

(a)



Dilatancy test: Shaking wet soil



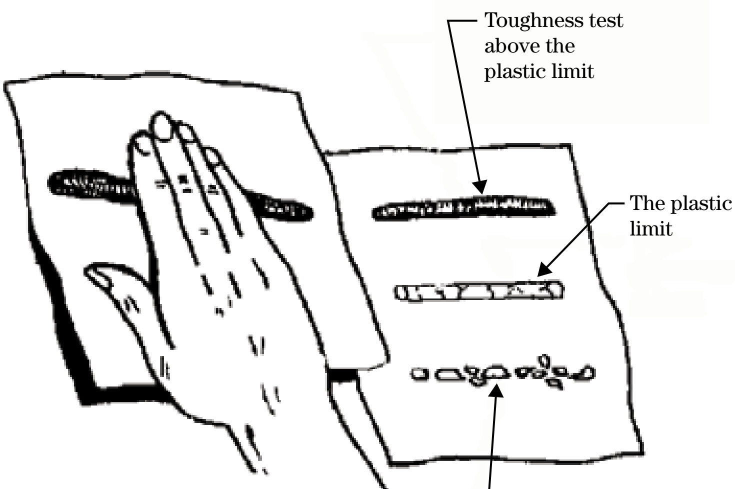
Dry strength test: Crumbling dry sample between fingers

Shine test

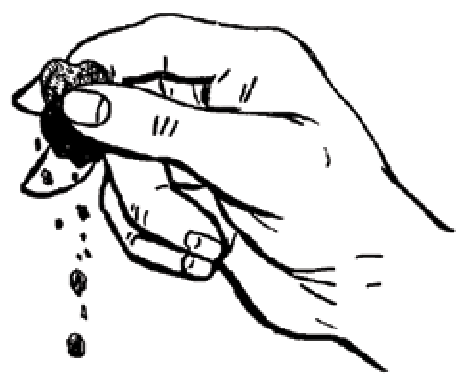
Ribbon test

Figure 3–9 Manual field tests for soils—continued

(b)



Rolling soil into threads



Remolding tough thread at plastic limit into lump and deforming

Table 3–12 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 greater than 50 percent of coarse fraction greater than No. 4 sieve (about 1/4 in). Classify as sand if greater than 50 percent of coarse fraction is less than No. 4 sieve.
3	If gravel or sand, determine whether it is “clean” having less than 5 percent fines; borderline, 5 to 12 percent fines; or “dirty” having greater than 12 percent fines. Fines are defined as the fraction less than the 200 mesh sieve size. Less than 5 percent fines will not stain the hands when wet.
4	If the gravel or sand is clean, decide if it is well graded (W) or poorly graded (P) and assign an appropriate group name and symbol: GW, GP, SW, or SP. Well-graded materials have a good representation of all particle sizes. Poorly graded materials have excess or absence of intermediate particle sizes.
5	If the gravel or sand contains greater than 12 percent 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 percent, are classified in the laboratory with dual symbols; i.e., GP–GC, SP–SC. Classification of borderline cases, well as boundary cases between various groups, require 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 in accordance with the instructions given on the left-hand side of figure 3–8. 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 3–8.
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.

Figure 3–10 Engineering properties of Unified Soil Classes

Typical names	Requirements for seepage control						Unified soil classes
	Shear strength	Compress-iblity	Workability as construction material	Permeability			
				When compacted	K cm/s	K ft/d	
Well-graded gravels, gravel-sand mixtures, little or no fines	Excellent	Negligible	Excellent	Pervious	K > 10^{-2}	K > 30	**GW**
Well-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 = 3×10^{-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, sands 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-silt mixtures	Good to fair	Low	Good	Impervious	K = 10^{-6} to 10^{-8}	K = 3×10^{-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 = 3×10^{-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 = 3×10^{-1} to 3×10^{-3}	**OL**
Inorganic silts, micaceous or diatomaceous fine sandy or silty soil, elastic silts	Fair to poor	High	Poor	Semi-pervious to impervious	K = 10^{-4} to 10^{-6}	K = 3×10^{-1} to 3×10^{-3}	**MH**
Inorganic clays of high plasticity, fat clays	Poor	High very high	Poor	Impervious	K = 10^{-6} to 10^{-8}	K = 3×10^{-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 = 3×10^{-3} to 3×10^{-5}	**OH**
Peat and other highly organic soils	Not suitable for construction						**PT**

Figure 3–11 Engineering properties of Unified Soil Classes for embankments

Embankments								
Compaction character-istics	Standard procter unit density lb/ft^3	Type of roller desirable	Relative characteristics		Resistance to piping	Ability to take plastic deformation under load without shearing	General description and use	Unified soil classes
			Perme-ability	Compress-ibility				
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	**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 sued 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**
Poor to very poor	70–95	Sheepsfoot	Medium to low	Very high	Good to poor	Good	Poor stability, core of hyd-raulic fill dam, not desirable in rolled-filled construction	**MH**
Fair to good	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 3–12 Engineering properties of Unified Soil Classes for foundations and channels

Channels: long duration to constant flow — Relative desirability: Erosion resistance	Channels: Relative desirability: Compacted earth lining	Foundation: Bearing value	Foundation: Relative desirability: Seepage important	Foundation: Relative desirability: Seepage not important	Requirements for seepage control: Permanent reservoir	Requirements for seepage control: Floodwater retarding	Unified Soil Classes
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 vol. change critical	Fair to poor	9	13	None	None	**CH**
—	—	Very poor	10	14	None	None	**OH**
—	—	Remove from foundation					**PT**

Foundation soils, being undisturbed, are influenced to a great degree by their geologic origin. Judgment and testing must be used in addition to the generalizations below.

Note: No. 1 is the best numerical rating.

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