CHAPTER 2

IDENTIFICATION AND CLASSIFICATION OF SOIL AND ROCK

2-1. Natural soil deposits.

a. The character of natural soil deposits is influenced primarily by parent material and climate. The parent material is generally rock but may include partially indurated materials intermediate between soil and rock. Soils are the results of weathering, mechanical disintegration, and chemical decomposition of the parent material. The products of weathering may have the same composition as the parent material, or they may be new minerals that have resulted from the action of water, carbon dioxide, and organic acids with minerals comprising the parent material.

b. The products of weathering that remain in place are termed residual soils. In relatively flat regions, large and deep deposits of residual soils may accumulate; however, in most cases gravity and erosion by ice, wind, and water move these soils to form new deposits, termed transported soils. During transportation, weathered material may be mixed with others of different origin. They may be ground up or decomposed still further and are usually sorted according to grain size before finally being deposited. The newly formed soil deposit may be again subject to weathering, especially when the soil particles find themselves in a completely different environment from that in which they were formed. In humid and tropical climates, weathering may significantly affect the character of the soil to great depths, while in temperate climates it produces a soil profile that primarily affects the character of surface soils.

c. The character of natural soil deposits usually is complex. A simplified classification of natural soil deposits based on methods of deposition is given in table 2-1, together with pertinent engineering characteristics of each type. More complete descriptions of natural soil deposits are given in geology textbooks. The highly generalized map in figure 2-1 shows the distribution of the more important natural soil deposits in the United States.

2-2. Identification of soils.

a. It is essential to identify accurately materials comprising foundation strata. Soils are identified by visual examination and by means of their index properties (grain-size distribution, Atterberg limits, water content, specific gravity, and void ratio). A description based on visual examination should include color, odor when present, size and shape of grains, gradation, and density and consistency characteristics.- Coarsegrained soils have more than 50 percent by weight retained on the No. 200 sieve and are described primarily on the basis of grain size and density. With regard to grain-size distribution, these soils should be described as uniform, or well-graded; and, if in their natural state, as loose, medium, or dense. The *shape* of the grains and the presence of foreign materials, such as mica or organic matter, should be noted.

b. Fine-grained soils have more than 50 percent by weight finer than the No. 200 sieve. Descriptions of these soils should state the color, texture, stratification, and odor, and whether the soils are soft, firm, or stiff, intact or fissured. The visual examination should be accompanied by estimated or laboratory-determined index properties. A summary of *expedient tests* for identifying fine-grained soils is given in table 2-2. The important index properties are summarized in the following paragraphs. Laboratory tests for determining index properties should be made in accordance with standard procedures.

2-3. Index properties.

a. Grain-size distribution. The grain-size distribution of soils is determined by means of sieves and/or a hydrometer analysis, and the results are expressed in the form of a cumulative semilog plot of percentage finer versus grain diameter. Typical grain-size distribution curves are shown in figure 2-2. The knowledge of particle-size distribution is of particular importance when coarse-grained soils are involved. Useful values are the effective size, which is defined as the grain diameter corresponding to the 10 percent finer ordinate on the grain-size curve; the coefficient of uniformity, which is defined as the ratio of the $_{D60}$ size to the D, , size (fig 2-2); the coefficient of curvature, which is defined as the ratio of the square of the $_{Do3}$ size to the product of the $_{D1o}$ and $_{D60}$ sizes (table 2-3); and the 15 and 85 percent sizes, which are used in filter design.

b. Atterberg limits. The Atterberg limits indicate the range of water content over which a cohesive soil behaves plastically. The upper limit of this range is known as the liquid limit (LL); the lower, as the plastic limit (PL). The LL is the water content at which a soil will just begin to flow when slightly jarred in a pre

Table 2-1. A Simplified Classification of Natural Soil Deposits

Major Divisions			Principal Soil Type	Pertinent Engineering Characteristics
Residual Soils	Mineral	Material formed by distintegration of underlying parent rock or partially indurated materials	Residual sands and rock fragments of various sizes formed by solution and leaching of cementing material, leaving the more resistant particles; commonly quartz	Generally favorable foundation conditions.
			Residual clay, extremely finely divided clay material formed in place by the weathering of rock, derived either by the chemical decay of feldspar and other rock minerals or by the removal of nonclay-mineral constituents by solution from a clay-bearing rock.	Variable properties requiring investigation to determine depth and conditon of weathering.
	Organic	Accumulations of highly organic material formed in place by the growth and subsequent decay of plant life	Peat. A somewhat fibrous aggregate of decayed and decaying vegetable matter having a dark color and odor of decay	Very compressible. Entirely unsuitable for supporting building foundations
			Muck. Finely divided, well-decomposed organic material intermixed with a high percentage (20-50%) of mineral matter	
Transported Soils	Alluvial	Material transported and deposited by running water	Floodplain deposits. Unconsolidated soils deposited by a stream within that portion of its valley subject to in-. undation by floodwater	
			Natural levees. Long, broad, low ridges of sand, silt, or silty clay deposited by a stream on its floodplain and along both banks of its channel during overbank flow.	Generally favorable foundation conditions.
			Point bar. Alternating deposits of arcuate ridges and swales (lows) formed on the inside or convex bank of migrating river bends. Ridge deposits consist primarily of silt and sand, swales are clay-filled	Generally favorable foundation conditions; however, detailed investigations are necessary to locate discontinuities. Flow slides may be a problem along riverbanks.
			Channel fill. Deposits laid down in abandoned meander loops isolated when rivers shorten their courses. Composed primarily of clay; however, silty and sandy soils are found at the upstream and downstream ends	Fine-grained soils are usually compressible. Portions may be very heterogeneous. Silty soils generally present favorable foundation conditions
			Backswamp. The prolonged accumulation of floodwater sediments in flood basins behind the natural levees of a river. Materials are generally clays but tend to become more silty near riverbank	Relatively uniform in a horizontal direction. Clays are usually subjected to seasonal volume changes
			Terrace deposits. Unconsolidated alluvium (including gravel) produced by renewed downcutting of the valley flood by a rejuvenated stream	Generally favorable conditions. Usually not subject to flooding.
			Fan Deposits. Alluvial deposits at foot of hills or mountains. Extensive plains or alluvial fans	Generally favorable foundation conditions
			Deltaic deposits. Deposits formed at the mouths of rivers which result in extension of the shoreline	Generally fine-grained and compressible. Many local variations in soil condition
	Lacustrine	Material deposited in a lake	Lacustrine deposits. Material deposited within lakes (other than those associated with glaciation) by waves, currents, and and organo-chemical processes. Deposits consist of unstratified organic clay or clay in central portions of the lake and typically grade to stratified silts and sands in peripheral zones	Usually very uniform in horizontal direction. Fine-grained soils generally compressible
	Estuarine	Material deposited in an estuary	Estuarine deposits. Fine-grained sediment (usually silt and clay) of marine and fluvial origin mixed with decomposed organic matter laid down in brackish water of an estuary	Generally compressible. Many local varations
	Aeolian	Material transported and deposited by wind	Loess. An unstratified calcarous deposit consisting predominantly of silt with subordinate grain sizes ranging from sand to clay. Often contains fossils and is tranversed by a network of small, narrow, vertical tubes frequently filled with calcium carbonate conceptions formed by root fibers now decayed.	Relatively uniform deposits characterized by ability to stand in vertical cuts. Collapsible structure. Deep weathering or saturation can modify characteristics
			Dune sands. Mounds, ridges, and hills of uniform fine sand characteristically exhibiting rounded grains	Very iniform grain-size; may exist in relatively loose condition
	Glacial	Material transported and deposited by glaciers, or by melt water from the glacier	Glacial till. An accumulation of debris, deposited beneath, at the side (lateral moraines), or at the lower limit of a glacier (terminal moraine). Material lowered to ground surface in an irregular sheet by a melting glacier is known as a ground moraine	Consists of material of all sizes in various proportions from boulders and gravel to clay. Deposits are unstratified. Generally present favorable foundation conditions; but, rapid changws in conditions are common
			Glacio-Fluvial deposits. Coarse and fine-grained material deposited by streams of melt water from glaciers. Material deposited on ground surface beyond terminal of glacier is known as an outwash plain. Gravel ridges known as kames and eskers	Many local variations. Generally present favorable foundation conditions
			Glacio-Lacustrine deposits. Material deposited within lakes by melt water from glaciers. Consisting of clay in central portions of lake and alternate layers of silty clay or silt and clay (varved clay) in peripheral zones	Very uniform in a horizontal direction

(Continued)

Table 2-1. A Simplified Classification of Natural Soil Deposits-Continued

Major Divisions			Principal Soil Type	Pertinent Engineering Characteristics
Transported Soils	Marine	Material transported and deposited by ocean waves and currents in shore and offshore areas	Shore deposits. Deposits of sands and/or gravels formed by the transporting, destructive, and sorting action of waves on the shoreline	Relatively uniform and of moderate to high density
			Marine clays. Organic and inorganic deposits of fin-grained material	Generally very uniform in composition. Compressible and unually very sensitive to remolding
	Colluvial	Material transported and deposited by gravity	Talus. Deposits created by gradual accumulation of unsorted rock fragments and debris at base of cliffs	
			Colluvial deposits. Fine colluvium consisting of clayey sand, sandy silt, or clay	Previous movements indicate possible future difficulties. Generally unstable foundation conditions
			Landside deposits. Considerable masses of soil or rock that have slipped down, more or less as units, from their former position on steep slopes	
	Pyroclastic	Material ejected from volcanoes and transported by gravity wind, and air	Ejecta. Loose deposits of volcanic ash, lapilli, bombs, cinders, etc	Typically shardlike particles of silt size with larger volcanic debris. Weathering and redeposition produce highly plastic compressible clay. Unusual and difficult foundation conditions

scribed manner. The PL is the water content at which the soil will just begin to crumble when rolled into threads 1/8 inch in diameter. Fat clays that have a high content of colloidal particles have a high LL, while lean clays having a low content of colloidal parti- cles have a correspondingly low LL. A decrease in LL and PL after either oven- or air-drying usually indicates presence of organic matter. The plasticity index (PI) is defined as the difference between the LL and PL. The liquidity index (LI) is defined as the natural water content w_n, minus the PL, divided by the PI; i. e. , LI = (w_n - PL)/PI. The LI is a measure of the consistency of the soils. Soft clays have an LI approaching 100 percent; whereas, stiff clays have an LI approaching zero.

c. Activity. The activity, A, of a soil is defined as A = PI/(% < 0.002 mm). The activity is a useful parameter for correlating engineering properties of soil.

d. Natural water content. The natural water content of a soil is defined as the weight of water in the soil expressed as a percentage of dry weight of solid matter present in the soil. The water content is based on the loss of water at an arbitrary drying temperature of 1050 to 1100C.

e. Density. The mass density of a soil material is its weight per unit volume. The dry density of a soil is defined as the weight of solids contained in the unit volume of the soil and is usually expressed in pounds per cubic foot. Various weight-volume relationships are presented in figure 2-3.

f. Specific gravity. The specific gravity of the solid constituents of a soil is the ratio of the unit weight of the solid constituents to the unit weight of water. For routine analyses, the specific gravity of sands and clayey soils may be taken as 2. 65 and 2. 70, respectively.

g. Relative density. Relative density is defined by the following equation:

$$DR(\%) = \frac{e_{max} - e}{e_{max} - e_{min}} \times 100 \qquad (2\text{-}1)$$

where
emax = void ratio of soil in its loosest state
e = void ratio in its natural state
emin = void ratio in its densest possible state

Alternatively,

$$D_R(\%) = \frac{yd - yd_{min}}{yd_{max} - yd_{min}} \times \frac{yd_{max}}{yd} \times 100 \qquad (2\text{-}2)$$

where
yd = dry unit weight of soil in its natural state
ydmin = dry unit weight of soil in its loosest state
ydmax = dry unit weight of soil in its densest state

Thus, DR = 100 for a very dense soil, and DR = 0 for a very loose soil. Methods for determining e_{max} or corresponding densities have been standardized. Relative density is significant only in the case of coarse-grained soils.

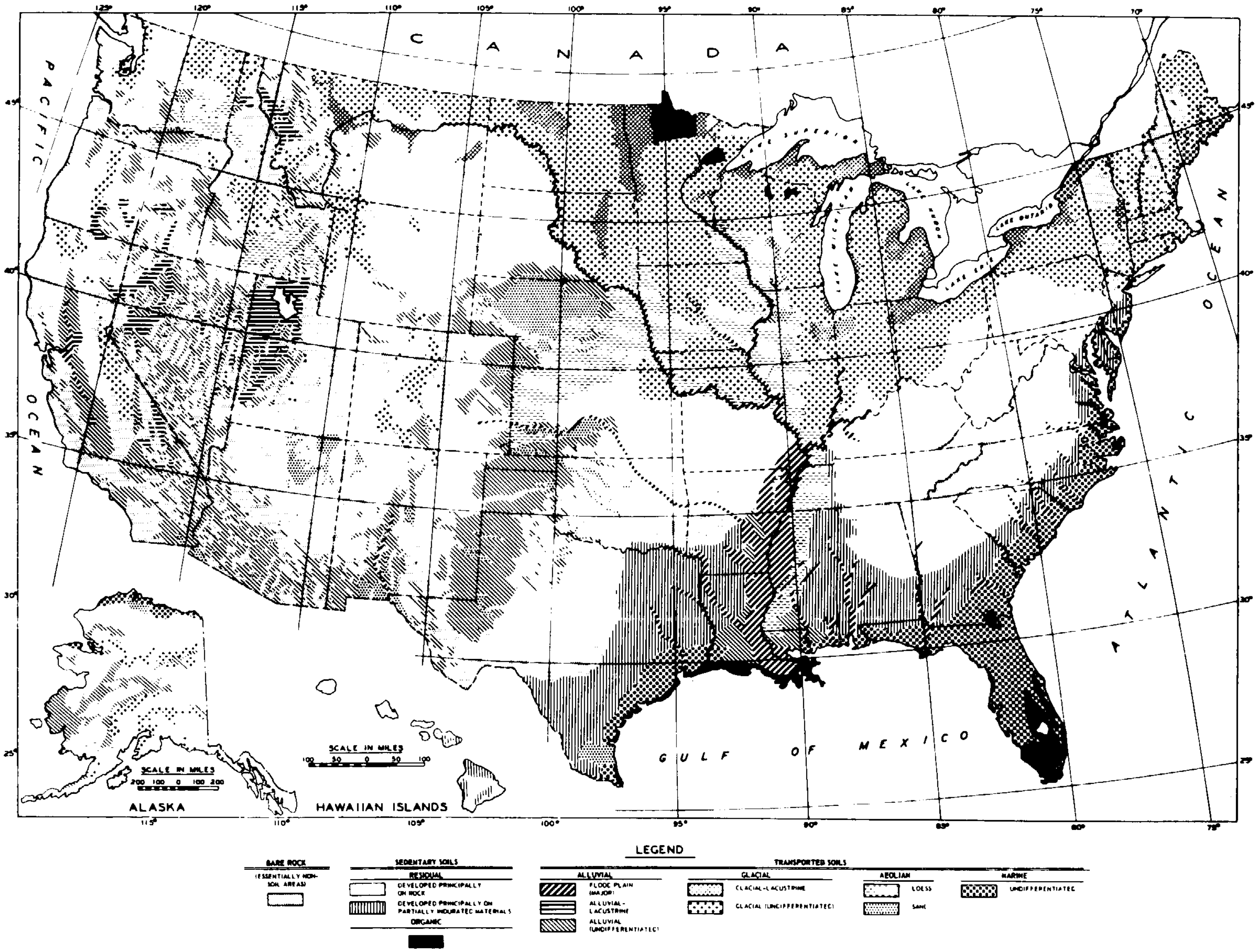

Figure 2-1. Distribution of natural soil deposits In the United States.

Table 2-2. Determination of the Consistency of Clays

Unconfined Compressive Strength, q_u tsf	Field Identification	Consistency
Less than 0.25	Easily penetrated several inches by fist	Very soft
0.25 - 0.5	Easily penetrated several inches by thumb	Soft
0.5 - 1.0	Can be penetrated several inches by thumb with moderate effort	Medium
1.0 - 2.0	Readily indented by thumb but penetrated only with great effort	Stiff
2.0 - 4.0	Readily indented by thumbnail	Very stiff
Over 4.0	Indented with difficulty by thumbnail	Hard

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h. Consistency. The consistency of an undisturbed cohesive soil may be expressed quantitatively by the unconfined compressive strength **qu.** Qualitative expressions for the consistency of clays in terms of q_μ are given in table 2-2. If equipment for making unconfined compression tests is not available, a rough estimate can be based on the simple field identification suggested in the table; various small penetration or vane devices are also helpful.

2-4. Soil classification. The Unified Soil Classification System, based on identification of soils according to their grain-size distribution, their plasticity characteristics, and their grouping with respect to behavior, should be used to classify soils in connection with foundation design. Table 2-3 summarizes the Unified Soil Classification System and also presents field identification procedures for fine-grained soils or soil fractions. It is generally advantageous to include with the soil classification anv regional or locally accepted terminology as well as the soil name (table 2-4).

2-5. Rock classification.

a. Geological classification. The geological classification of rock is complex, and for most engineering applications a simplified system of classification, as shown in table 2-5, will be adequate. For any in-depth geology study, proper stratigraphic classification by a qualified geologist should be made to ensure that proper interpretation of profiles is being made. All the rock types in table 2-5 may exist in a sound condition or may be fissured, jointed, or altered by weathering to an extent that will affect their engineering behavior. Descriptive criteria for the field classification of rock is contained in table 2-6.

b. Classification of intact rock. An engineering classification of intact rock is contained in table 2-7. The classification is based on the uniaxial compressive strength and the tangent modulus.

2-6. Rock properties for foundation design.

a. The principal rock properties of concern for foundation design are the structural features and shear strength. Strength properties of rock are discussed in chapter 3. Structural features include-

(1) Types and patterns for rock defects (table 2-6)-cracks, joints, fissures, etc.

(2) Bedding planes-stratification and slope (strike and dip).

(3) Foliation-a general term for a planar arrange-

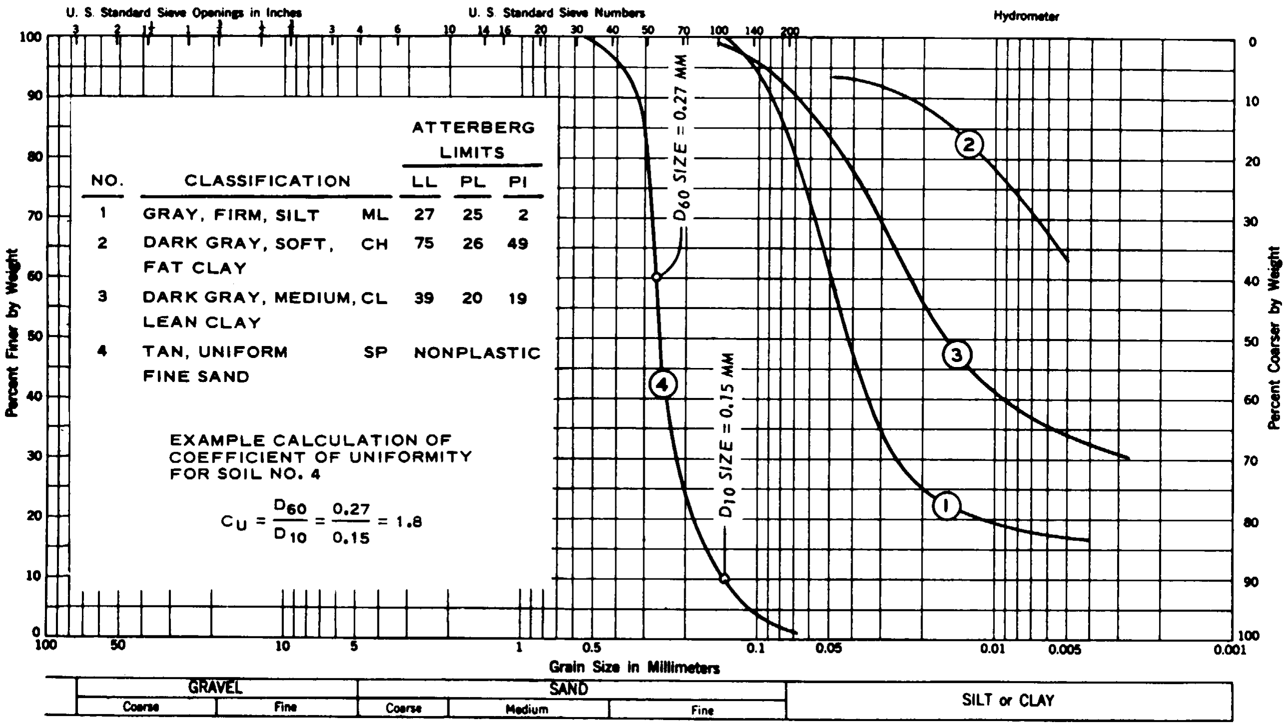

Figure 2-2. Typicalgrain-size distribution curves.

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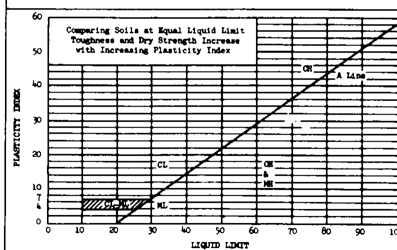
Major Divisions			Group Symbols	Typical Names	Field Identification Procedures (Excluding particles larger than 3 in. and basing fractions on estimated weights)			Information Required for Describing Soils	Laboratory Classification Criteria		
1	2		3	4	5			6	7		
Coarse-grained Soils More than half of material is larger than No. 200 sieve size.	Gravels More than half of coarse fraction is larger than No. 4 sieve size.	Clean Gravels (Little or no fines)	GW	Well-graded gravels, gravel-sand mixtures, little or no fines.	Wide range in grain sizes and substantial amounts of all intermediate particle sizes.			For undisturbed soils add information on stratification, degree of compactness, cementation, moisture conditions, and drainage characteristics.	Use grain-size curve in identifying the fractions as given under field identification. Determine percentages of gravel and sand from grain-size curve. Depending on percentage of fines (fraction smaller than No. 200 sieve size) coarse-grained soils are classified as follows: Less than 5% = GW, GP, SW, SP, More than 12% = GM, GC, SM, SC. 5% to 12% = Borderline cases requiring use of dual symbols.	$C_u = \frac{D_{60}}{D_{10}}$ Greater than 4; $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ Between 1 and 3	
			GP	Poorly graded gravels or gravel-sand mixtures, little or no fines.	Predominantly one size or a range of sizes with some intermediate sizes missing.					Not meeting all gradation requirements for GW	
		Gravels with Fines (Appreciable amount of fines)	GM	Silty gravels, gravel-sand-silt mixture.	Nonplastic fines or fines with low plasticity (for identification procedures see ML below).			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.		Atterberg limits below "A" line or PI less than 4	Above "A" line with PI between 4 and 7 are borderline cases requiring use of dual symbols.
			GC	Clayey gravels, gravel-sand-clay mixtures.	Plastic fines (for identification procedures see CL below).					Atterberg limits above "A" line with PI greater than 7	
The No. 200 sieve size is about the smallest particle visible to the naked eye.	Sands More than half of coarse fraction is smaller than No. 4 sieve size.	Clean Sands (Little or no fines)	SW	Well-graded sands, gravelly sands, little or no fines.	Wide range in grain size and substantial amounts of all intermediate particle sizes.					$C_u = \frac{D_{60}}{D_{10}}$ Greater than 6; $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ Between 1 and 3	
	(For visual classification, the 1/4-in. size may be used as equivalent to the No. 4 sieve size)		SP	Poorly graded sands or gravelly sands, little or no fines.	Predominantly one size or a range of sizes with some intermediate sizes missing.			Example: Silty sand, gravelly; about 20% hard, angular gravel particles 1/2-in. 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).		Not meeting all gradation requirements for SW	
		Sands with Fines (Appreciable amount of fines)	SM	Silty sands, sand-silt mixtures.	Nonplastic fines or fines with low plasticity (for identification procedures see ML below).					Atterberg limits below "A" line or PI less than 4	Above "A" line with PI between 4 and 7 are borderline cases requiring use of dual symbols.
			SC	Clayey sands, sand-clay mixtures.	Plastic fines (for identification procedures see CL below).					Atterberg limits above "A" line with PI greater than 7	
Fine-grained Soils More than half of material is smaller than No. 200 sieve size.					Identification Procedures on Fraction Smaller than No. 40 Sieve Size						
					Dry Strength (Crushing characteristics)	Dilatancy (Reaction to shaking)	Toughness (Consistency near PL)				
	Silts and Clays Liquid limit is less than 50		ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands or clayey silts with slight plasticity.	None to slight	Quick to slow	None	For undisturbed soils add information on structure, stratification, consistency in undisturbed and remolded states, moisture and drainage conditions.			
			CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays.	Medium to high	None to very slow	Medium				
			OL	Organic silts and organic silty clays of low plasticity.	Slight to medium	Slow	Slight	Give typical name; indicate degree and character of plasticity; amount and maximum size of coarse grains; color in wet condition; odor, if any; local or geologic name and other pertinent descriptive information; and symbol in parentheses.			
	Silts and Clays Liquid limit is greater than 50		MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts.	Slight to medium	Slow to none	Slight to medium				
			CH	Inorganic clays of high plasticity, fat clays.	High to very high	None	High				
			OH	Organic clays of medium to high plasticity, organic silts.	Medium to high	None to very slow	Slight to medium	Example: Clayey silt, brown; slightly plastic; small percentage of fine sand; numerous vertical root holes; firm and dry in place; loess; (ML).			
Highly Organic Soils			Pt	Peat and other highly organic soils.	Readily identified by color, odor, spongy feel and frequently by fibrous texture.						



PLASTICITY CHART

For laboratory classification of fine-grained soils

(1) Boundary classifications: Soils possessing characteristics of two groups are designated by combinations of group symbols. For example GW-GC, well-graded gravel-sand mixture with clay binder. (2) All sieve sizes on this chart are U. S. standard.

Table 2-3. Unified Soil Classification System

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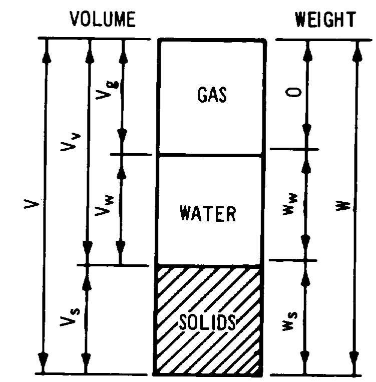

WATER CONTENT	$w = \frac{W_w}{W_s}$
SPECIFIC GRAVITY	$G_s = \frac{W_s}{V_s \gamma_w}$
VOLUME OF SOLIDS	$V_s = \frac{W_s}{G_s \gamma_w}$
VOLUME OF VOIDS	$V_v = V - V_s$
VOID RATIO	$e = \frac{V_v}{V_s} = \frac{n}{1-n}$
POROSITY	$n = \frac{V_v}{V} = \frac{e}{1+e}$
DEGREE OF SATURATION	$S = \frac{V_w}{V_v} = \frac{w G_s}{e}$
UNIT WEIGHT OF WATER (FRESH WATER)	$\gamma_w = \frac{W_w}{V_w} = 62.4$ PCF
DRY UNIT WEIGHT	$\gamma_d = \frac{W_s}{V} = \frac{\gamma_m}{1+w}$
WET UNIT WEIGHT	$\gamma_m = \frac{W}{V}$
SUBMERGED (BOUYANT) UNIT WEIGHT	$\gamma' = \gamma_m - \gamma_w = \frac{G_s - 1}{1+e} \gamma_w$

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Figure 2-3. Weight-volume relationships.

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Table 2-4. Descriptive Soil Names Used in Local Areas (L)and Names Widely Used

Adobe	Calcareous silts and sandy-silty clays which are usually high in colloidal clay content, found in the semiarid regions of the southwestern United States and North Africa.
Alluvium	Deposits of mud, silt, and other material commonly found on the flat lands along the lower courses of streams.
Argillaceous	Soils which are predominantly clay or abounding in clays or clay-like materials.
Bentonite	A clay of high plasticity formed by the decomposition of volcanic ash; it has high swelling characteristics.
(L) Boulder clay	Another name, used widely in Canada and England, for glacial till.
(L) Buckshot	Clays of the southern and southwestern United States which, upon drying, crack into small, hard lumps of more or less uniform size.
(L) Bull's liver	This is a name used in some sections of the United States to describe an inorganic silt of slight plasticity. When saturated, it quakes like jelly from vibration or shock.
Calcareous	Soils which contain an appreciable amount of calcium carbonate, usually from limestone.
Caliche	This term is widely used in construction to describe deposits which contain various amounts of silt, clay, and sand cemented by calcium carbonate deposited by evaporation of groundwater, as found in France, North Africa, Texas, and other southwestern states.
(L) Coquina	Consists essentially of marine shells which are held together by a small amount of calcium carbonate to form a fairly hard rock. Coquina shells (and oyster shells) are widely used for granular stabilization of soils along the Gulf Coast of the United States.
Coral	Calcareous, rock-like material formed by secretions of corals and coralline algae.
Diatomaceous earth	Composed essentially of the siliceous skeletons of diatoms (extremely small unicelled organisms). It is composed principally of silica, is white or light gray in color, and extremely porous.
(L) Dirty sand	A slightly silty or clayey sand.
Disintegrated granite	Granular soil derived from advanced weathering and disintegration of granite rock.
(L) Fat clay	Fine, colloidal clay of high plasticity.
Fuller's earth	Unusually highly plastic clays of sedimentary origin, white to brown in color. Used commercially to absorb fats and dyes.
(L) Gumbo	Peculiar, fine-grained, highly plastic silt-clay soils which become impervious and soapy, or waxy and sticky, when saturated.
Hardpan	A general term used to describe a hard, cemented soil layer which does not soften when wet. Use of this term should be avoided since it implies a condition rather than a type of soil.
Lateritic soils	Residual soils which are found in tropic regions. Many different soils are included in this category and they occur in many sections of the world. They are frequently red in color, and in their natural state have a granular structure with low plasticity and good drainability. When they are remolded in the presence of water, they often become plastic and clayey to the depth disturbed.
Lean clay	Silty clays and clayey silts, generally of low to medium plasticity.
(L) Limerock	A soft, friable, compact, cream-white, high-calcium limestone found in the southeastern United States which consists of coral and other marine remains which have been disintegrated by weathering.
Loam	A general agricultural term which is applied most frequently to sandy-silty topsoils which contain a trace of clay, are easily worked, and are productive of plant life.
Loess	Silty soil of aeolian origin characterized by a loose, porous structure, and a natural vertical slope. It covers extensive areas in North America (especially in the Mississippi Basin), Europe, and Asia (especially North Central Europe, Russia, and China).
Marl	A soft, calcareous deposit mixed with clays, silts, and sands, often containing shells or organic remains. It is common in the Gulf Coast area of the United States.
Micaceous soils	Soil which contains a sufficient amount of mica to give it distinctive appearance and characteristics.
Muck (mud)	The very soft, slimy silt or organic silt which is frequently found on lake or river bottoms.
Peat	A term which is frequently applied to fibrous, partially decayed organic matter or a soil which contains a large proportion of such materials. Large and small deposits of peat occur in many areas and present many construction difficulties. Peat is extremely loose and compressible.
Muskeg	Peat deposits found in northwestern Canada and Alaska.
(L) Red dog	The residue from burned coal dumps.
Rock flour	A fine-grained soil, usually sedimentary, of low plasticity and cohesion. Particles are usually in the lower range of silt sizes. At high moisture contents, it may become "quick" under the action of traffic.
Shale	A thinly laminated rock-like material resulting from consolidation of clay under extreme pressure. Some shales revert to clay on exposure to air and moisture.
Talus	A fan-shaped accumulation of mixed fragments of rock that have fallen, because of weathering, at or near the base of a cliff or steep mountainside.
Topsoil	A general term applied to the top few inches of soil deposits. Topsoils usually contain considerable organic matter and are productive of plant life.
Tufa	A loose, porous deposit of calcium carbonate which usually contains organic remains.
Tuff	A term applied to compacted deposits of the fine materials ejected from volcanoes, such as more or less cemented dust and cinders. Tuffs are more or less stratified and in various states of consolidation. They are prevalent in the Mediterranean area.
Varved clay	A sedimentary deposit which consists of alternate thin (1/8 in. to 1/2 in.) layers of silt and clay.
Volcanic ash	Uncemented volcanic debris, usually made up of particles less than 4 mm in diameter. Upon weathering, a volcanic clay of high compressibility is frequently formed. Some volcanic clays present unusually difficult construction problems, as do those in the area of Mexico City and along the eastern shores of the island of Hawaii.

Table 2-5. A Simplified Classification for Rocks

Igneous Rocks	Color	Principal Minerals	Texture: Very Coarse, Irregular Crystalline	Texture: Coarse and Medium Crystalline	Texture: Fine Crystalline	Texture: Micro-crystalline	Texture: Glassy	Texture: Porous (Gas Openings)	Texture: Fragmental
	Light	Quartz and Feldspar	Pegmatite	Granite	Aplite	Felsite: Rhyolite	Pitchstone	Pumice	Ash (fine, loose), tuff (fine-cemented), breccia (coarse), cinders (variable)
		Feldspar, Little or no Quartz	Syenite Pegmatite	Syenite		Felsite: Trachyte			
	Intermediate	Feldspar and Hornblende	Diorite Pegmatite	Diorite; Dolerite	Diabase	Andesite		Scoria or vesicular basalt	
	Dark	Augite and Feldspar	Gabbro Pegmatite	Gabbro; Dolerite		Basalt			
		Augite, Hornblende Olivine		Peridotite					

Sedimentary Rocks	Group	Grain Size	Composition		Name
	Clastic	Appreciable quantity of grains more than 2-mm diameter	Rounded pebbles in medium-grained matrix		Conglomerate
			Angular coarse rock fragments, often quite variable		Breccia
		More than 50% of grains are 0.06-to 2.00-mm diameter	Medium quartz grains	Less than 10% of other minerals	Siliceous sandstone
				Appreciable quantity of clay minerals	Argillaceous sandstone
				Appreciable quantity of calcite	Calcareous sandstone
				Appreciable quantity of iron oxide cement	Ferruginous sandstone
				Over 25% feldspar; less than 75% quartz	Arkose
				10-50% feldspar and darker minerals; 30 to 40% quartz	Graywacke
		More than 50% of grains are 0.002-to 0.06-mm diameter	Fine to very fine quartz grains with clay minerals		Siltstone (if laminated, shale)
		Predominantly grains less than 0.002-mm diameter	Microscopic clay minerals	Less than 10% other minerals	Shale (if not laminated, claystone)
				Appreciable calcite	Calcareous shale
				Appreciable carbonaceous material	Carbonaceous shale
				Appreciable iron oxide cement	Ferruginous shale
	Organic	Variable	Calcite and fossils		Fossiliferous limestone
			Carbonaceous material		Bituminous coal
	Chemical	Microcopic	Calcite		Limestone
			Dolomite		Dolomite
			Quartz		Chert, flint, etc.
			Iron compounds with quartz		Iron
			Halite		Rock salt
			Gypsum		Rock gypsum

Metamorphic Rocks	Foliation	Texture: Coarse Crystalline & Banded	Texture: Coarse Crystalline	Texture: Medium Crystalline	Texture: Fine to Microscopic Crystalline
	Foliated	Gneiss	Schist { Sericite, Mica, Talc, Chlorite, Hematite, etc. }	Phyllite	Slate
	Non-Foliated		Marble, Quartzite, Serpentine, Soapstone [a]	Marble, Quartzite, Serpentine, Soapstone [a]	Hornfels, Anthractive Coal, Marble, Quartzite, Serpentine, Soapstone [a]

[a] Variable grain size.

Table 2-6. Descriptive Criter for Rock

1. Rock type
   a. Rock name (Generic)
   b. Hardness
   (1) Very soft: can be deformed by hand
   (2) Soft: can be scratched with a fingernail
   (3) Moderately hard: can be scratched easily with a knife
   (4) Hard: can be scratched with difficulty with a knife
   (5) Very hard: cannot be scratched with a knife
   c. Degree of weathering
   (1) Unweathered: no evidence of any mechanical or chemical alteration.
   (2) Slightly weathered: slight discoloration on surface, slight alteration along discontinuities, less than 10 percent of the rock volume altered, and strength substantially unaffected.
   (3) Moderately weathered: discoloring evident, surface pitted and altered with alteration penetrating well below rock surfaces, weathering "halos" evident, 10 to 50 percent of the rock altered, and strength noticeably less than fresh rock.
   (4) Highly weathered: entire mass discolored, alteration in nearly all of the rock with some pockets of slightly weathered rock noticeable, some minerals leached away, and only a fraction of original strength (with wet strength usually lower than dry strength) retained.
   (5) Decomposed: rock reduced to a soil with relect rock texture (saprolite) and generally molded and crumbled by hand.
   d. Lithology (macro description of mineral components). Use standard adjectives, such as shaly, sandy, silty, and calcareous. Note inclusions, concretions, nodules, etc.
   e. Texture and grain size
   (1) Sedimentary rocks

Texture	Grain Diameter, mm	Particle Name	Rock Name
*	< - 80	Cobble	Conglomerate
*	5 -. 80	Gravel	
Coarse grained	2 - 5		
Medium grained	0.4 - 2	Sand	Sandstone
Fine grained	0.1 - 0.4		

* Use clay-sand texture to describe conglomerate matrix.

(Continued) (Sheet 1 of 3)

Table 2-6. Descriptive Criteria for Rock-Continued

Texture	Grain Diameter, mm	Particle Name	Rock Name
Very fine grained	> - 0.1	Clay, Silt	Shale, Claystone, Siltstone, Limestone

(2) Igneous and metamorphic rocks

Texture	Grain Diameter, mm
Coarse grained	> - 5
Medium grained	1 - 5
Fine grained	0.1 - 1
Aphanite	< 0.1

(3) Textural adjectives. Use simple standard textural adjectives such as porphyritic, vesicular, pegmatitic, granular, and grains well developed. Do not use sophisticated terms such as holohyaline, hypidiomorphic granular, crystaloblastic, and cataclastic.

2. <u>Rock structure</u>

a. Bedding

(1) Massive: >3 ft thick

(2) Thick bedded: beds from 1 to 3 ft thick

(3) Medium bedded: beds from 4 in. to 1 ft thick

(4) Thin bedded: beds less than 4 in. thick

b. Degree of fracturing (jointing)

(1) Unfractured: fracture spacing greater than 6 ft

(2) Slightly fractured: fracture spacing from 3 to 6 ft

(3) Moderately fractured: fracture spacing from 1 to 3 ft

(4) Highly fractured: fracture spacing from 4 in. to 1 ft

(5) Intensely fractured: fracture spacing less than 4 in.

c. Shape of rock blocks

(1) Blocky: nearly equidimensional

(2) Elongated: rod-like

(3) Tabular: flat or bladed

(Continued)

(Sheet 2 of 3)

Table 2-6. Descriptive Criteria for Rock-Continued

3. Discontinuities
   - a. Joints
     - (1) Type: bedding, cleavage, foliation, schistosity, extension
     - (2) Separations: open or closed, how far open
     - (3) Character of surface: smooth or rough; if rough, how much relief, average asperity angle
     - (4) Weathering of clay products between surfaces
   - b. Faults and shear zones
     - (1) Single plane or zone: how thick
     - (2) Character of sheared materials in zone
     - (3) Direction of movement, slickensides
     - (4) Clay fillings
   - c. Solution, cavities, and voids
     - (1) Size
     - (2) Shape: planar, irregular, etc.
     - (3) Orientation (if applicable): developed along joints, bedding planes, at intersections of joints and bedding planes, etc.
     - (4) Filling: percentage of void volume and type of filling material (e.g. sand, silt, clay, etc.).

(Sheet 3 of 3)

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ment of texture or structural features in any type of rock; e.g., cleavage in slate or schistosity in a metamorphic rock. The term is most commonly applied to metamorphic rock.

b. Samples that are tested in the laboratory (termed "intact" samples) represent the upper limit of strength and stress-strain characteristics of the rock and may not be representative of the mass behavior of the rock. Coring causes cracks, fissures, and weak planes to open, often resulting in a recovery of many rock fragments of varying length for any core barrel advance. Only samples (intact pieces) surviving coring and having a length/diameter ratio of 2 to 2.5 are tested. Rock Quality Designation (RQD) is an index or measure of the quality of the rock mass. RQD is defined as:

$$RQD = \frac{\sum \text{Lengths of intact pieces} \geq 4 \text{ in. long}}{\text{Length of core advance}}$$

Referring to figure 2-4, with a core advance of 60 inches and a sum of intact pieces, 4 inches or larger, of 34 inches, the RQD is computed as:

$$RQD = \frac{34}{60} = 0.57$$

Also shown in figure 2-4 is a qualitative rating of the rock mass in terms of RQD. RQD depends on the drilling technique, which may induce fracture as well as rock discontinuities. Fresh drilling-induced fractures may be identified by careful inspection of the recovered sample.

2-7. Shales.

a. Depending on climatic, geologic, and exposure conditions, shale may behave as either a rock or soil but must always be handled and stored as though it is soil. For these reasons, shale is considered separately from either soil or rock. Shale is a fine-grained sedimentary rock composed essentially of compressed

Table 2- 7. Engineering Classification of Intact Rock

I. On basis of strengh, σ_{ult} :[a]

Class	Description	Uniaxial Compressive
A	Very high strength	Over 32,000
B	High strength	16,000 - 32,000
C	Medium strength	8,000 - 16,000
D	Low strength	4,000 - 8,000
E	Very low strength	Less than 4,000

II. On basis of modulus ratio, E_t / σ_{ult} :[a]

Class	Description	Uniaxial Compressive
H	High modulus ratio	Over 500
M	Average (medium) ratio	200-500
L	Low modulus ratio	Less than 200

[a] Rocks are classified by both strength and modulus ratio, such as AM, BL, BH, and CM.
[b] Modulus ratio = E_t/σ_{ult}, where E_t = tangent modulus at 50 percent ultimate strength and σ_{ult} = uniaxial compressive strength.

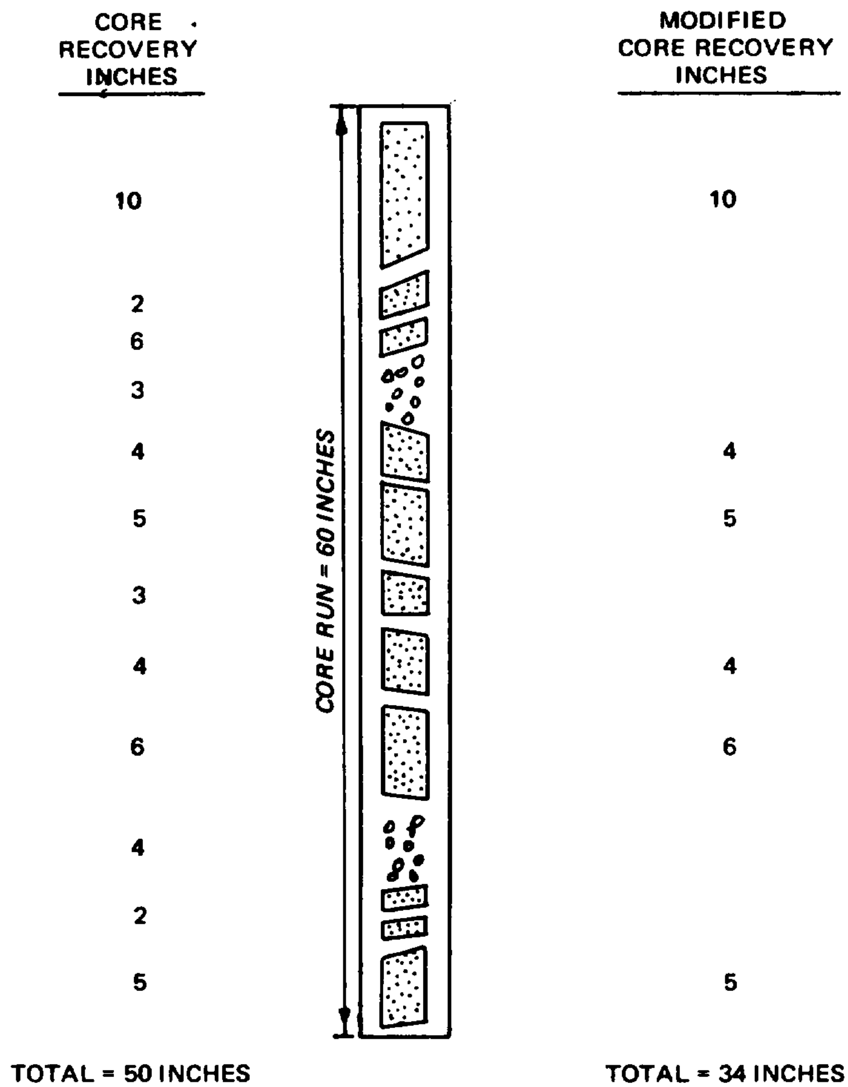
(Courtesy of K. G. Stagg and O. C. Zienkiewiez, Rock Mechanics in Engineering Practice, 1968, pp 4-5. Reprinted by permission of John Wiley & Sons, Inc, New York.)

and/or cemented clay particles. It is usually laminated from the general parallel orientation of the clay particles as distinct from *claystone, siltstone,* or *mudstone,* which are indurated deposits of random particle orientation. The terms "argillaceous rock" and "mudrock" are also used to describe this type of rock. Shale is the predominate sedimentary rock in the earth's crust.

b. Shale may be grouped as compaction shale, and cemented (rock) shale. Compaction shale is a transition material from soil to rock and can be excavated with usual large excavation equipment. Cemented shale generally requires blasting. Compaction shales have been formed by consolidation pressure and very little cementing action. Cemented shales are formed by a combination of cementing and consolidation pressure. They tend to ring when struck by a hammer, do not slake in water, and have the general characteristics of good rock. Compaction shales, being of an interme- diate quality, will generally soften and expand upon exposure to weathering when excavations are opened.

c. Dry unit weight of shale may range from about 80 pounds per cubic foot for poor-quality compaction shale to 160 pounds per cubic foot for high-quality cemented shale. Shale may have the appearance of sound rock on excavation but will often deteriorate, during or after placement in a fill, into weak clay or silt, of low shear strength. Figure 2-5 may be used as a guide in classifying shale for foundation use.

d. Compaction shales may swell for years after a structure is completed and require special studies whenever found in subgrade or excavated slopes. The predicted behavior of shales cannot be based sofely upon laboratory tests and must recognize local experiences.



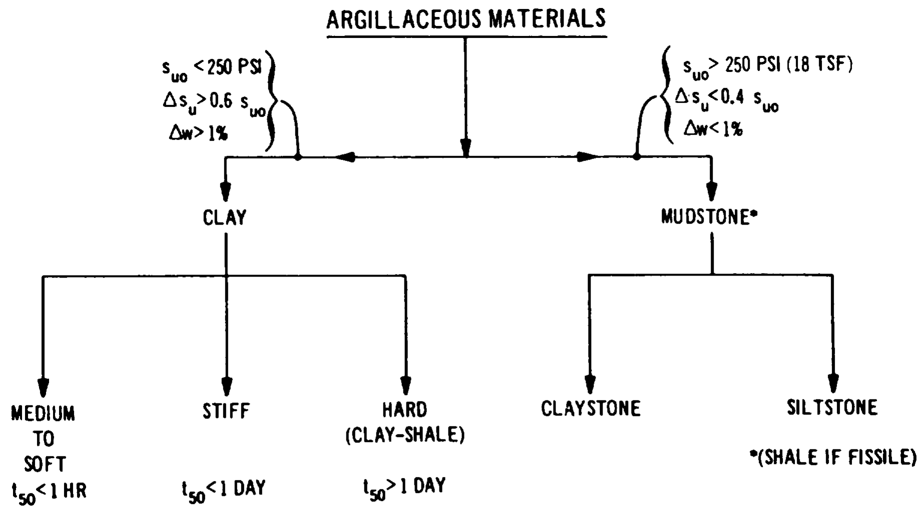
ROCK QUALITY RATING

RQD	DESCRIPTION
0-25	VERY POOR
25-50	POOR
50-75	FAIR
75-90	GOOD
90-100	EXCELLENT

CORE RECOVERY = 50/60 = 83%
RQD = 34/60 = 57%

(Courtesy of K. G. Stagg and O. C. Zienkiewiez, Rock Mechanics in Engineering Practice, 1968, p 15. Reprinted by permission of John Wiley & Sons, Inc. New York.)

Figure 2-4. Modified core recovery as in index of rock quality.



s_{uo} = UNDRAINED SHEAR STRENGTH AT NATURAL WATER CONTENT (Q TEST USING 50 PSI CHAMBER PRESSURE)

Δs_u = STRENGTH LOSS AFTER SOFTENING TO EQUILIBRIUM WATER CONTENT

Δw = CHANGE IN WATER CONTENT AFTER SOFTENING

t_{50} = TIME OF SOFTENING FOR LOSS OF 50% OF s_{uo}

a. ENGINEERING CLASSIFICATION OF ARGILLACEOUS MATERIALS

LL = LIQUID LIMIT

w_s = MAX. WATER CONTENT DUE TO SLAKING

LI = LIQUIDITY INDEX

ΔLI = CHANGE IN LIQUIDITY INDEX

RATE OF SLAKING: $\Delta LI = I_{L1} - I_{L0}$ (2 HR WATER IMMERSION)	AMOUNT OF SLAKING [a]: VERY LOW VL LL < 20	LOW L LL BETWEEN 20 & 50	MEDIUM M LL BETWEEN 50 & 90	HIGH H LL BETWEEN 90 & 140	VERY HIGH VH LL > 140
SLOW, S $\Delta LI < 0.75$	VL S	L S	M S	H S	VH S
FAST, F $0.75 < \Delta LI < 1.25$	VL F	L F	M F	H F	VH F
VERY FAST, VF $\Delta LI > 1.25$	VL VF	L VF	M VF	H VF	VH VF

[a] WATER CONTENT AFTER SLAKING EQUALS LL.

b. CLASSIFICATION IN TERMS OF SLAKING CHARACTERISTICS

(Courtesy of N. R. Morgenstern and K. D. Eigenbrod, "Classification of Argillaceous Soils and Rock," Journal, Geotechnical Division, Vol 100, No. GT10, 1974, pp 1137-1155. Reprinted by permission of American Society of Civil Engineers, New York.)

Figure 2-5. Classification of shales.