Introduction to Identification and Classification of Soil and Rock

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An Introduction to Identification and Classification of Soil and Rock

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1. INTRODUCTION

This is an introduction to soil and rock identification and classification. It is not a design or engineering manual, or an exhaustive treatise. It is intended to give those engineers and construction professionals not familiar with the topic an introduction to the terminology, techniques and concepts involved, so that they can move forward in applying this information to engineering projects in their professional activities.

2. SOIL DEPOSITS

2.1 GEOLOGIC ORIGIN AND MODE OF OCCURRENCE.

2.1.1 Principal Soil Deposits. See Table 1 for principal soil deposits grouped in terms of origin (e.g., residual, colluvial, etc.) and mode of occurrence (e.g., fluvial, lacustrine, etc.).

2.1.2 Importance. A geologic description assists in correlating experiences between several sites, and in a general , indicates the pattern of strata to be expected prior to making a field investigation (test borings, etc.). Soils with similar origin and mode of occurrence are expected to have comparable if not similar engineering properties. For quantitative foundation analysis, a geological description is inadequate and more specific classification is required. A study of references on local geology should precede a major subsurface exploration program.

2.1.3 Soil Horizon. Soil horizons are present in all sedimentary soils and transported soils subject to weathering. The A horizon contains the maximum amount of organic matter; the underlying B horizon contains clays, sesquioxides, and small amounts of organic matter. The C horizon is partly weathered parent soil or rock and the D horizon is unaltered parent soil and rock.

Major Division	Principal Soil Deposits	Pertinent Engineering Characteristics
Sedimentary Soils		
Residual		
Material formed by disintegration of underlying parent rock	Residual sands and fragments of gravel size formed by solution and leaching of cementing material, leaving the more resistant particles, commonly quartz Residual clays formed by decomposition of silicate rocks, disintegration of shales, and solution of carbonates in limestone. With few exceptions becomes more compact, rockier, and less weathered with increasing depth.	Generally favorable foundation conditions Variable properties requiring detailed investigation. Deposits present favorable foundation conditions except in humid and tropical climates, where depth and rate of weathering are very great.
Organic		
Accumulation 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 vegetation matter having a dark color and odor of decay. Muck. Peat deposits which have advanced in stage of decomposition to such extent that the botanical character is no longer evident.	Very compressible. Entirely unsuitable for supporting building foundations.

Table 1

Principal Soil Deposits

Major Division	**Principal Soil Deposits**	**Pertinent Engineering Characteristics**
(continued) Materials transported and deposited by running water	Estuarine deposits. Mixed deposits of marine and alluvial origin laid down in widened channels at mouths of rivers and influenced by tide of body of water into which they are deposited	Generally fine-grained and compressible. Many local variations in soil conditions.
	Alluvial-Lacustrine deposits. Material deposited within lakes (other than those associated with glaciations) by waves, currents, and organo-chemical processes. Deposits consist of unstratified organic clay or clay in central portions of the stratified silts and sands in peripheral zones.	Usually very uniform in horizontal direction. Fine-grained soils generally compressible.
	Deltaic deposits. Deposits found in the mouths of rivers which result in extension of the shoreline.	Generally fine-grained and compressible. Many local variations in soil condition.
	Piedmont deposits. Alluvial deposits at foot of hills or mountains. Extensive plains or alluvial fans.	Generally favorable foundation conditions
Aeolian		
Materials transported and deposited by wind	Loess. A calcareous, unstratified deposit of silts or sandy or clayey silt transverse by a network of tubes 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 uniform grain sizes may exist in relatively loose condition.

Table 1 (continued)
Principal Soil Deposits

Major Division	Principal Soil Deposits	Pertinent Engineering Characteristics
Glacial		
Material transported and deposited by glaciers or by meltwater 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. Glacio-Fluvial deposits. Coarse and fine-grained material deposited by streams of meltwater from glaciers. Material deposited on ground surface beyond terminal of glacier is known as an outwash plain. Gravel ridges known as kames and eskers. Glacio-Lacustrine deposits. Material deposited within lakes by meltwater 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.	Consists of material of all sizes in various proportions from boulder and gravel to clay. Deposits are unstratified. Generally present favorable foundation conditions, but rapid changes in conditions are common. Many local variations. Generally present favorable foundation conditions. Very uniform in a horizontal direction
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. Marine clays. Organic and inorganic deposits of fine-grained material.	Relatively uniform and of moderate to high density. Generally very uniform in composition. Compressible and usually very sensitive to remolding.

Table 1 (continued)
Principal Soil Deposits

Major Division	**Principal Soil Deposits**	**Pertinent Engineering Characteristics**
Colluvial		
Material transported and deposited by gravity.	Talus. Deposits created by gradual accumulation of unsorted rock fragments and debris at base of cliffs. Hillwash. Fine colluviums consisting of clayey sand, sand silts, or clay. Landslide deposits. Considerable masses of soil or rock that have slipped down, more or less as units, from their former position on steep slopes.	Previous movement indicates possible future difficulties. Generally unstable foundation conditions.
Pyroclastic		
Material ejected from volcanoes and transported by gravity, wind and air.	Ejecta. Loose deposits of volcanic ash, lapilli, bombs, etc. Pumice. Frequently associated with lava flows and mud flows, or may be mixed with nonvolcanic sediments.	Typically shardlike particles of silt size with larger volcanic debris. Weathering and redeposition produce highly plastic compressible slay. Unusual and difficult foundation conditions.

Table 1 (continued)
Principal Soil Deposits

Definitions of Soil Components and Fractions		
Grain Size		
Material	**Fraction**	**Sieve Size**
Boulders		12”
Cobbles		3” – 12”
Gravel	coarse	¾” – 3”
	fine	No. 4 – ¾”
Sand	coarse	No. 10 – No. 4
	medium	No. 40 – No. 10
	fine	No. 200 – No. 40
Fines (Silt & Clay)	coarse	Passing No. 200
Coarse and Fine-Grained Soils		
Descriptive Adjective	**Percentage Requirement**	
trace	1 – 10%	
little	10 – 20%	
some	20 – 35%	
substantial	35 – 50%	
Fine-Grained Soils. Identify in accordance with plasticity characteristics, dry strength, and toughness as described in Table 3.		
Stratified soils	alternating	
	thick	
	thin	
	With	
	parting	0 to 1/16” thickness
	seam	1/16 to ½” thickness
	layer	½ to 12” thickness
	stratum	> 12” thickness
	pocket	small, erratic deposit, usually less than 1 foot
	lens	lenticular deposit
	occasional	one or less per foot of thickness
	frequent	more than one per foot of thickness

Table 2
Visual Identification of Samples

3. SOIL IDENTIFICATION

3.1 REQUIREMENTS. A complete engineering soil identification includes: (a) a classification of constituents, (b) the description of appearance and structural characteristics, and (c) the determination of compactness or consistency in situ.

3.1.1 Field Identification. Identify constituent materials visually according to their grain size, and/or type of plasticity characteristics per ASTM Standard D2488, Description of Soils (Visual-Manual Procedure).

3.1.1.1 Coarse-Grained Soils. Coarse-grained soils are those soils where more than half of particles finer than 3-inch size can be distinguished by the naked eye. The smallest particle that is large enough to be visible corresponds approximately to the size of the opening of No. 200 sieve used for laboratory identification. Complete identification includes grain size, color, and/or estimate of compactness.

(a) Color. Use color that best describes the sample. If there are two colors describe both colors. If there are more than two distinct colors, use multi-colored notation.

(b) Grain Size. Identify components and fractions in accordance with Table 2 - Coarse-Grained Soils.

(c) Grading. Identify both well graded and poorly graded sizes as explained in Table 3, under Supplementary Criteria for Visual Identification.

(d) Assigned Group Symbol. Use Table 3 for estimate of group symbols based on the Unified Classification System.

(e) Compactness. Estimate compactness in situ by measuring resistance to penetration of a selected penetrometer or sampling device. If the standard penetration test is performed, determine the number of blows of a 140 pound hammer falling 30 inches required to drive a 2-inch OD, 1-3/8 inch ID split barrel sampler 1 foot. The number of blows thus obtained is known as the standard penetration resistance, N. The split barrel is usually driven 18 inches. The penetration resistance is based on the last 12 inches.

1) Description Terms. See Figure 1 (Reference 1, Soils and Geology, Procedures for Foundation Design of Buildings and Other Structures (Except Hydraulic Structures), by the Departments of the Army and Air Force) for descriptive terms of compactness of sand. Figure 1 is applicable for normally consolidated sand.

2) Compactness Based on Static Cone Penetration Resistance, q+c. Reference 2, Cone Resistance as Measure of Sand Strength, by Mitchell and Lunne, provides guidance for estimating relative density with respect to the cone resistance. If q+c, and N values are measured during the field exploration, a q+c,-N correlation could be made, and Figure 1 is used to describe compactness. If N is not measured, but q+c, is measured, then use N = q+c,/4 for sand and fine to medium gravel and N = q+c,/5 for sand, and use Figure 1 for describing compactness.

(f) Describe, if possible, appearance and structure such as angularity, cementation, coatings, and hardness of particles.

(g) Examples of Sample Description: Medium dense, gray coarse to fine sand, trace silt, trace fine gravel (SW). Dry, dense, light brown coarse to fine sand, some silt (SM).

3.1.1.2 Fine-Grained Soils. Soils are identified as fine-grained when more than half of the particles are finer than No. 200 sieve (as a field guide, such particles cannot be seen by the naked eye). Fine-grained soils cannot be visually divided between silt and clay, but are distinguishable by plasticity characteristics and other field tests.

(a) Field Identification. Identify by estimating characteristics in Table 3.

(b) Color. Use color that best describes the sample. If two colors are used, describe both colors. If there are more than two distinct colors, use multi-colored notation.

(c) Stratification. Use notations in Table 2.

(d) Appearance and Structure. These are best evaluated at the time of sampling. Frequently, however, it is not possible to give a detailed description of undisturbed samples in the field. Secondary structure in particular may not be recognized until an undisturbed sample has been

Primary Divisions for Field and Laboratory Identification			Group Symbol	Typical Names	Laboratory Classification Criteria	Supplementary Criteria for Visual Identification
Coarse-grained soils. (More than half of material finer than 3” sieve is larger than No. 200 sieve.)	Gravel. (More than half of the coarse fraction is larger than No. 4 sieve.)	Clean gravels. (Less than 5% of material smaller than No. 200 sieve.)	GW	Well graded gravels, gravel-sand mixtures, little or no fines.	$C_U = D_{60}/D_{10}$ greater than 4. $C_Z = (D_{30})^2/(D_{10} \times D_{60})$ between 1 and 3.	Wide range in grain size and substantial amounts of all intermediate particle size.
			GP	Poorly graded gravels, gravle-sand mixtures, little or no fines.*	Not meeting both criteria for GW.	Predominately one size (uniformly graded) or a range of sizes with some intermediate sizes missing (gap graded).

* Materials with 5 to 12 percent smaller than No. 200 seive are borderline cases, designated: GW-GM, SW-SC, etc.

Table 3
Unified Soil Classification System

Primary Divisions for Field and Laboratory Identification			Group Symbol	Typical Names	Laboratory Classification Criteria		Supplemental Criteria for Visual Identification
Coarse-grained soils. (More than half of material finer than 3" sieve is larger than No. 200 sieve.)	Gravel. (More than half of the coarse fraction is larger than No. 4 sieve.)	Gravels with fines. (more than 12% of material smaller than No. 200 sieve size	GM	Silty gravels and gravel-sand-silt mixtures	Atterberg limits below "A" line, or PI less than 4	Atterberg limits above "A" limit with PI between 4 and 7 is borderline case GM-GC	Nonplastic fines or fines of low plasticity
			GC	Clayey gravels, and gravel-sand-clay mixtures	Atterberg limits above "A" line, and PI greater than 7		Plastic fines
	Sands. (More than half of the coarse fraction is smaller than No. 4 sieve size.)*	Clean sands. (Less than 5% of material smaller than No. 200 sieve size.)	SW	Well graded sands, gravelly sands, little or no fines.*	$C_U = D_{60}/D_{10}$ greater than 6. $C_Z = (D_{30})^2/(D_{10} \times D_{60})$ between 1 and 3.		Wide range in grain sizes and substantial amounts of all intermediate sizes.
			SP	Poorly graded sands and gravelly sands, little or no fines.*	Not meeting both criteria for SW.		Predominately one size (uniformly graded) or a range of sizes with some intermediate sizes missing.
		Sands with fines. (More than 12% of material smaller than No. 200 sieve ize.)*	SM	Silty sands, sand-silt mixtures.	Atterberg limits below "A" line, or PI less than 4	Atterberg limits above "A" limit with PI between 4 and 7 is borderline case SM-SC	Nonplastic fines or fines of low plasticity
			SC	Clayey sands, sand-clay mixtures	Atterberg limits above "A" line, and PI greater than 7		Plastic fines

* Materials with 5 to 12 percent smaller than No. 200 seive are borderline cases, designated: GW-GM, SW-SC, etc.

Table 3 (continued)
Unified Soil Classification System

Primary Divisions for Field and Laboratory Identification		**Group Symbol**	**Typical Names**	**Laboratory Classification Criteria**		**Supplementary Criteria for Visual Identification**		
						Dry Strength	**Reaction to Shaking**	**Toughness Near Plastic Limit**
Fine-grained soils. (More than half of material is smaller than No. 200 sieve size.) (Visual: more than half of particles are so fine that they cannot be seen by naked eye.)	Silts and clays. (Liquid limit less than 50)	ML	Inorganic silts, very fine sands, rock flour, silty or clayey fine sands.	Atterberg limits below "A" line, or PI less than 4	Atterberg limits above "A" limit with PI between 4 and 7 is borderline case ML-CL	None to slight	Quick to slow	None
		CL	Inorganic clays of low to medium plasticity; gravelly clays, silty clays, sandy clays, lean clays.	Atterberg limits above "A" line, and PI greater than 7		Medium to high	None to very slow	Medium
		OL	Organic silts and organic silt-clays of low plasticity.	Atterberg limits below "A" line.		Slight to medium	Slow	Slight

Table 3 (continued)
Unified Soil Classification System

Primary Divisions for Field and Laboratory Identification		**Group Symbol**	**Typical Names**	**Laboratory Classification Criteria**	**Supplementary Criteria for Visual Identification**		
Fine-grained soils. (More than half of material is smaller than No. 200 sieve size.) (Visual: more than half of particles are so fine that they cannot be seen by naked eye.)	Silts and clays. (Liquid limit greater than 50.)	MH	Inorganic silts, micaceous fine sands or silts, elastic silts	Atterberg limits below "A" line,	**Dry Strength**	**Reaction to Shaking**	**Toughness Near Plastic Limit**
					Slight to medium	Slow to none	Slight to medium
		CH	Inorganic clays of high plasticity, fat clays.	Atterberg limits above "A" line,	High to very high	None	High
		CM	Organic clays of medium to high plasticity.	Atterberg limits below "A" line,	Medium to high	None to very slow	Slight to medium
	Highly organic soils	Pt	Peat, muck and other highly organic soils.	High ignition loss, LL and PI decrease after drying.	Organic color and odor, spongy feel, frequently fibrous texture.		

Table 3 (continued)
Unified Soil Classification System

examined and tested in the laboratory. On visual inspection, note the following items:

1) Ordinary appearance, such as color; moisture conditions, whether dry, moist, or saturated; and visible presence of organic material.

2) Arrangement of constituent materials, whether stratified, varved, or heterogeneous; and typical dip and thickness of lenses or varves.

3) Secondary structure, such as fractures, fissures, slickensides, large voids, cementation, or precipitates in fissures or openings.

(e) General Field Behavior.

1) Clays. Clays exhibit a high degree of dry strength in a small cube allowed to dry, high toughness in a thread rolled out at plastic limit, and exude little or no water from a small pat shaken in the hand.

2) Silts. Silts have a low degree of dry strength and toughness, and dilate rapidly on shaking so that water appears on the sample surface.

3) Organic Soils. Organic soils are characterized by dark colors, odor of decomposition, spongy or fibrous texture, and visible particles of vegetal matter.

(f) Consistency. Describe consistency in accordance with Table 4 (Reference 3, Soil Mechanics in Engineering Practice, by Terzaghi and Peck). Use a pocket penetrometer or other shear device to check the consistency in the field.

(g) Assignment of Group Symbol. Assign group symbol in accordance with Table 3.

(h) Examples of Sample Description:

- Very stiff brown silty CLAY (CL), wet
- Stiff brown clayey SILT (ML), moist
- Soft dark brown organic CLAY (OH), wet.

SPT Penetration (blows/foot)	Estimated Consistency	Estimated Range of Unconfined Compressive Strength (tons/sq. ft.)
< 2	Very soft (extruded between fingers when squeezed)	< 0.25
2 – 4	Soft (molded by light finger pressure)	0.25 – 0.50
4 – 8	Medium (molded by strong finger pressure)	0.50 – 1.00
8 – 15	Stiff (readily indented by thumb but penetrated with great effort)	1.00 – 2.00
15 – 30	Very stiff (readily indented by thumbnail)	2.00 – 4.00
> 30	Hard (indented with difficulty by thumbnail)	> 4.00

Table 4
Guide for Consistency of Fine-Grained Soils

4. SOIL CLASSIFICATION AND PROPERTIES

1. REFERENCE. Soil designations described here conform to the Unified Soil Classification (see Table 3) per ASTM D2487, Classification of Soil for Engineering Purposes.

2. UTILIZATION. Classify soils in accordance with the Unified System and include appropriate group symbol in soil descriptions. (See Table 3 for elements of the Unified System.) A soil is placed in one of 15 categories or as a borderline material combining two of these categories. Laboratory tests may be required for positive identification. Use the system in Table 2 for field soil description and terminology.

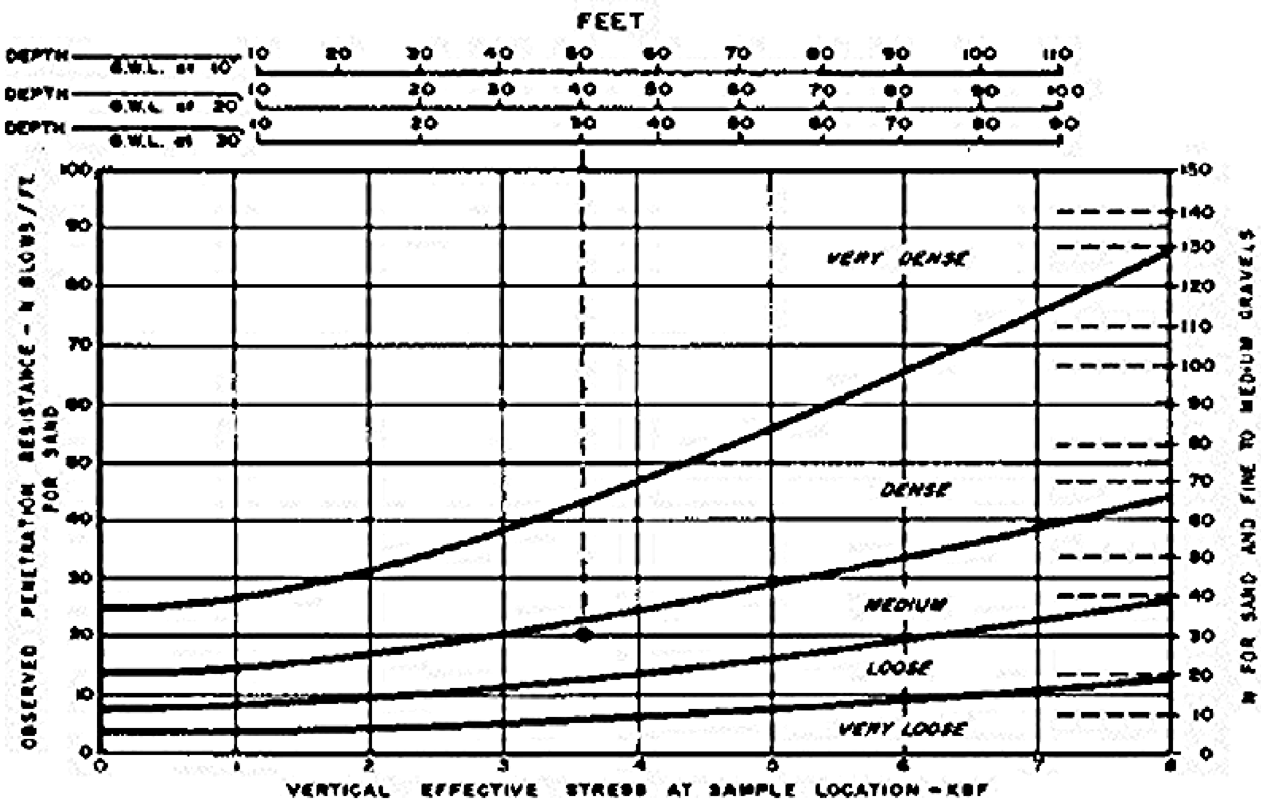
2.1 Sands and Gravels. Sands are divided from gravels on the No. 4 sieve size, and gravels from cobbles on the 3-inch size. The division between fine and medium sands is at the No. 40 sieve, and between medium and coarse sand at the No. 10 sieve.

2.2 Silts and Clays. Fine-grained soils are classified according to plasticity characteristics determined in Atterberg limit tests. Categories are illustrated on the plasticity chart in Figure 2.

2,3 Organic Soils. Materials containing vegetable matter are characterized by relatively low specific gravity, high water content, high ignition loss, and high gas content. Decrease in liquid limit after oven-drying to a value less than three-quarters of the original liquid limit is a definite indication of an organic soil. The Unified Soil Classification categorizes organic soils based on the plotted position on the A-line chart as shown in Figure 2. However, this does not describe organic soils completely. Therefore, Table 5 (Reference 4, unpublished work by Ayers and Plum) is provided for a more useful classification of organic soils.

3. TYPICAL PROPERTIES. Some typical properties of soils classified by the Unified System are provided in Table 6 (Reference 5, Basic Soils

Engineering, by Hough). More accurate estimates should be based on laboratory and/or field testing, and engineering evaluation.



Example:

Blow count in sand at a depth of 40 ft = 20
Depth of Groundwater Table = 20 ft
Compactness ~ medium

Figure 1
Estimated Compactness of Sand from Standard Penetration Test

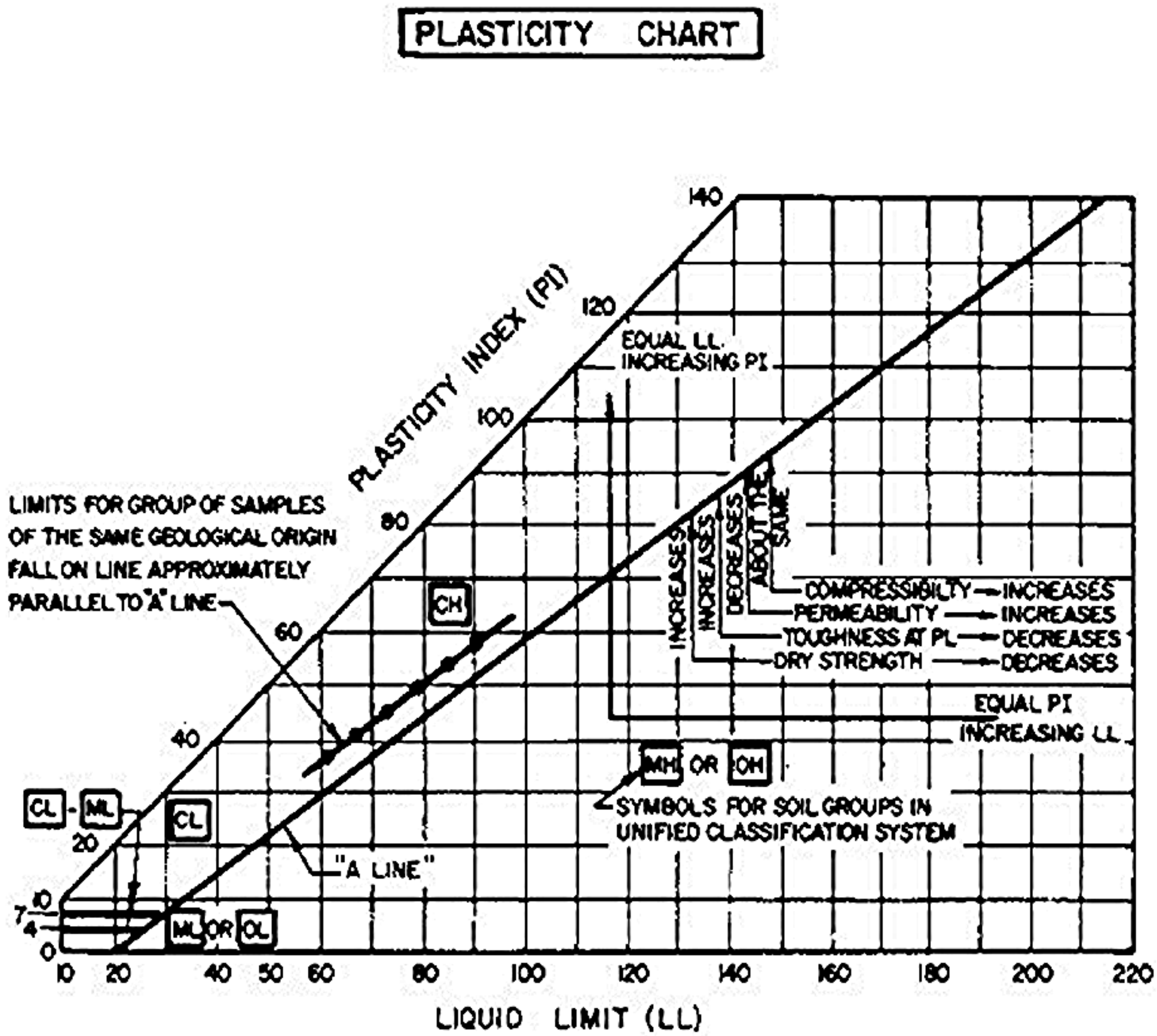


Figure 2
Utilization of Atterberg Plasticity Limits

Category	Name	Organic Content (% by weight)	Group Symbols	Distinguishing Characteristics for Visual Identification	Range of Laboratory Test Values
Organic matter	Fibrous peat	75 to 100% organics either visible or inferred	Pt	Light weight, spongy and often elastic at w_n --- shrinks considerably on air drying. Much water squeezes from sample.	w_n = 500 to 1200% γ = 60 to 70 pcf G = 1.2 to 1.8 $C_c/ (1+e_o)$ = .4+
	Fine grained peat			Light weight, spongy but not often elastic at w_n --- shrinks considerably on air drying. Much water squeezes from sample.	w_n = 400 to 800% LL = 400 to 900% PI = 200 to 500 γ = 60 to 70 pcf G = 1.2 to 1.8 $C_c/ (1+e_o)$ = .35 to .4+
Highly organic soils	Silty peat	30 to 75% organics either visible or inferred		Relatively light weight, spongy. Thread usually weak and spongy near PL. Shrinks on air drying; medium dry strength. Usually can squeeze water from sample readily. Slow dilatency.	w_n = 250 to 500% LL = 250 to 600% PI = 150 to 350 γ = 65 to 90 pcf G = 1.8 to 2.3 $C_c/ (1+e_o)$ = .3 to .4
	Sandy peat			Sand fraction visible. Thread weak and friable near PL; shrinks on air drying; low dry strength. Usually can squeeze water from sample readily. High dilatency. Gritty.	w_n = 100 to 400% LL = 150 to 300% (plot below A line) PI = 50 to 150 γ = 70 to 100 pcf G = 1.8 to 2.4 $C_c/ (1+e_o)$ = .2 to .3

Table 5
Soil Classification for Organic Soils

	Particle Size and Gradation				Voids(1)					Unit Weight(2) (lb./cu.ft.)						
	Approximate Size Range (mm)		Approx. D_{10} (mm)	Approx. Range Uniform Coefficient C_u	Void Ratio			Porosity (%)		Dry Weight			Wet Weight		Submerged Weight	
	D_{max}	D_{min}			e_{max} loose	e_{cr}	e_{min} dense	n_{max} loose	n_{min} dense	Min loose	100% Mod. AASHO	Max dense	Min loose	Max dense	Min loose	Max dense
GRANULAR MATERIALS																
Uniform Materials																
a. Equal spheres (theoretical values)	-	-	-	1.0	0.92	-	0.35	47.6	26	-	-	-	-	-	-	-
b. Standard Ottawa SAND	0.84	0.59	0.67	1.1	0.80	0.75	0.50	44	33	92	-	110	93	131	57	69
c. Clean, uniform SAND (fine or medium)	-	-	-	1.2 to 2.0	1.0	0.80	0.40	50	29	83	115	118	84	136	52	73
d. Uniform, inorganic SILT	0.05	0.005	0.012	1.2 to 2.0	1.1	-	0.40	52	29	80	-	118	81	136	51	73
Well-graded Materials																
a. Silty SAND	2.0	0.005	0.02	5 to 10	0.90	-	0.30	47	23	87	122	127	88	142	54	79
b. Clean, fine to coarse SAND	2.0	0.05	0.09	4 to 6	0.95	0.70	0.20	49	17	85	132	138	86	148	53	86
c. Micaceous SAND	-	-	-	-	1.2	-	0.40	55	29	76	-	120	77	138	48	76
d. Silty SAND & GRAVEL	100	0.005	0.02	15 to 300	0.85	-	0.14	46	12	89	-	146(3)	90	155(3)	56	92
MIXED SOILS																
Sandy or Silty CLAY	2.0	0.001	0.003	10 to 30	1.8	-	0.25	64	20	60	130	135	100	147	38	85
Skip-graded Silty CLAY with stones or rk fragments	250	0.001	-	-	1.0	-	0.20	50	17	84	-	140	115	151	53	89
Well-graded GRAVEL, SAND, SILT & CLAY mixture	250	0.001	0.002	25 to 1000	0.70	-	0.13	41	11	100	140	148(4)	125	156(4)	62	94
CLAY SOILS																
CLAY (30%-50% clay sizes)	0.05	0.5μ	0.001	-	2.4	-	0.50	71	33	50	105	112	94	133	31	71
Colloidal CLAY (-0.002 mm: 50%)	0.01	10Å	-	-	12	-	0.60	92	37	13	90	106	71	128	8	66
ORGANIC SOILS																
Organic SILT	-	-	-	-	3.0	-	0.55	75	35	40	-	110	87	131	25	69
Organic CLAY (30% - 50% clay sizes)	-	-	-	-	4.4	-	0.70	81	41	30		100	81	125	18	62

(1). Granular materials may reach e_{max} when dry or only slightly moist. Clays can reach e_{max} only when fully saturated.

(2). Granular materials reach minimum unit weight when at e_{max} and with hygroscopic moisture only. The unit submerged weight of any saturated soil is the unit weight minus the unit weight of water.

(3). Applicable for very compact glacial till. Unusually high unit weight values for tills are sometimes due to not only an extremely compact condition but to unusually high specific gravity values.

(4). Applicable for hardpan.

General Note: Tabulation is based on G = 2.65 for granular soil, G = 2.7 for clays, and G = 2.6 for organic soils.

Table 6
Typical Values of Soil Index Properties

5. ROCK CLASSIFICATION AND PROPERTIES

5.1 VISUAL CLASSIFICATION. Describe the rock sample in the following sequence:

5.1.1 Weathering Classification. Describe as fresh, slightly weathered, etc. in accordance with Table 7 (Reference 6, Suggested Methods of the Description of Rock Masses, Joints and Discontinuities, by ISRM Working Party).

5.1.2 Discontinuity Classification. Describe spacing of discontinuities as close, wide, etc., in accordance with Table 8. In describing structural features, describe rock mass as thickly bedded or thinly bedded, in accordance with Table 8. Depending on project requirements, identify the form of joint (stepped, smooth, undulating, planar, etc.), its dip (in degrees), its surface (rough, smooth, slickensided), its opening (giving width), and its filling (none, sand, clay, breccia, etc.).

5.1.3 Color and Grain Size. Describe with respect to basic colors on rock color chart (Reference 7, Rock Color Chart, by Geological Society of America). Use the following term to describe grain size:

5.1.3.1 For Igneous and Metamorphic Rocks:

- coarse-grained - grain diameter >5mm
- medium-grained - grain diameter 1 - 5mm
- fine-grained - grain diameter <1mm
- aphanitic - grain size is too small to be perceived by unaided eye
- glassy - no grain form can be distinguished.

5.1.3.2 For Sedimentary Rocks

- coarse-grained - grain diameter >2mm
- medium-grained - grain diameter = 0.06 - 2mm
- fine-grained - grain diameter = 0.002 - 0.06mm
- very fine-grained - grain diameter <0.002mm

5.1.3.3 Use lOX hand lens if necessary to examine rock sample.

5.1.4 Hardness Classification. Describe as very soft, soft, etc. in accordance with Table 9 (from Reference 5), which shows range of strength values of intact rock.

Grade	Symbol	Diagnostic Features
Fresh	F	No visible sign of decomposition or discoloration. Rings under hammer impact.
Slightly Weathered	WS	Slight discoloration inwards from open fractures. Otherwise similar to F.
Moderately Weathered	WM	Discolored throughout. Weaker minerals such as feldspar decomposed. Strength somewhat less than fresh rock but cores cannot be broken by hand or scraped by knife. Texture preserved.
Highly Weathered	WH	Most minerals somewhat decomposed. Specimens can be broken by hand with effort or shaved with knife. Core stones present in rock mass. Texture becoming indistinct but fabric preserved.
Completely Weathered	WC	Mineral decomposed to soil but fabric and structure preserved (Saprolite), Specimens easily crumbled or penetrated.
Residual Soil	RS	Advanced state of decomposition resulting in plastic soils. Rock fabric and structure completely destroyed. Large volume change.

Table 7
Weathering Classification

Description for Structural Features: Bedding, Foliation, or Flow Banding	Spacing	Description for Joints, Faults or Other Fractures
Very thickly (bedded, foliated or banded	> 6 feet	Very widely (fractured or jointed)
Thickly	2 – 6 feet	Widely
Medium	8 – 24 inches	Medium
Thinly	2 ½ - 8 inches	Closely
Very thinly	¾ - 2 ½ inches	Very closely
Description for Micro-Structural Features: Lamination, Foliation or Cleavage	**Spacing**	**Description for Joints, Faults or Other Fractures**
Intensely (laminated, foliated or cleaved)	¼ - ¾ inches	Extremely close
Very intensely	Less than ¼ inch	

Table 8
Discontinuity Spacing

Class	Hardness	Field Test	Approximate Range of Uniaxial Compression Strength (kg/cm^2)
I	Extremely hard	Many blows with geologic hammer required to break intact specimen	> 2000
II	Very hard	Hand held specimen breaks with hammer end of pick under more than one blow	2000 1000
III	Hard	Cannot be scraped or peeled with knife, hand held specimen can be broken with single moderate blow with pick	1000 – 500
IV	Soft	Can just be scraped or peeled with knife. Indentations 1 mm to 3 mm show in specimen with moderate blow with pick.	500 – 250
V	Very soft	Material crumbles under moderate blow with sharp end of pick and can be peeled with a knife, but is too hard to hand-trim for triaxial test specimen.	250 - 10

Table 9
Hardness Classification of Intact Rock

5.1.4 Hardness Classification. Describe as very soft, soft, etc. in accordance with Table 9 (from Reference 5), which shows range of strength values of intact rock associated with hardness classes.

5.1.5 Geological Classification. Identify the rock by geologic name and local name (if any). A simplified classification is given in Table 10. Identify subordinate constituents in rock sample such as seams or bands of other type of minerals, e.g., dolomitic limestone, calcareous sandstone, sandy limestone, mica schist. Example of typical description:

- Fresh gray coarse moderately close fractured Mica Schist.

5.2 CLASSIFICATION BY FIELD MEASUREMENTS AND STRENGTH TESTS.

5.2.1 Classification by Rock Quality Designation and Velocity Index.

5.2.1.1 The Rock Quality Designation (RQD) is only for NX size core samples and is computed by summing the lengths of all pieces of core equal to or longer than 4 inches and dividing by the total length of the coring run. The resultant is multiplied by 100 to get RQD in percent. It is necessary to distinguish between natural fractures and those caused by the drilling or recovery operations. The fresh, irregular breaks should be Ignored and the pieces counted as intact. Depending on the engineering requirements of the project, breaks induced along highly anisotropic planes, such as foliation or bedding, may be counted as natural fractures. A qualitative relationship between RQD, velocity index and rock mass quality is presented in Table 11 (Reference 8, Predicting Insitu Modulus of Deformation Using Rock Quality Indexes, by Coon and Merritt).

5.2.1.2 The velocity index is defined as the square of the ratio of the field compressional wave velocity to the laboratory compressional wave velocity. The velocity index is typically used to determine rock quality using geophysical surveys. For further guidance see Reference 9, Design of Surface and Near Surface Construction in Rock, by Deere, et al.

5.2.2 Classification by Strength.

5.2.2.1 Uniaxial Compressive Strength and Modulus Ratio. Determine the uniaxial compressive strength in accordance with ASTM Standard D2938, Unconfined Compressive Strength of Intact Rock Core Specimens. Describe the strength of intact sample tested as weak, strong, etc., in accordance with Figure 3 (Reference 10, The Point Load Strength Test, by Broch and Franklin).

5.2.2.2 Point Load Strength. Describe the point load strength of specimen tested as low, medium, etc. in accordance with Figure 3. Point load strength tests are sometimes performed in the field for larger projects where rippability and rock strength are critical design factors. This simple field test can be performed on core samples and irregular rock specimens. The point load strength index is defined as the ratio of the applied force at failure to the squared distance between loaded points. This index is related to the direct tensile strength of the rock by a proportionality constant of 0.7 to 1.0 depending on the size of sample. Useful relationships of point load tensile strength index to other parameters such as specific gravity, seismic velocity, elastic modulus, and compressive strength are given in Reference 11, Prediction of Compressive Strength from Other Rock Properties, by DiAndrea, et al. The technique for performing the test is described in Reference 9.

5.2.2.3 Classification by Durability. Short-term weathering of rocks, particularly shales and mudstones, can have a considerable effect on their engineering performance. The weatherability of these materials is extremely variable, and rocks that are likely to degrade on exposure should be further characterized by use of tests for durability under standard drying and wetting cycle (see Reference 12, Logging Mechanical Character of Rock, by Franklin, et al.). If, for example, wetting and drying cycles reduce shale to grain size, then rapid slaking and erosion in the field is probable when rock is exposed (see Reference 13, Classification and Identification of Shales, by Underwood).

5.3 ENGINEERING AND PHYSICAL PROPERTIES OF ROCK. A preliminary estimate of the physical and engineering properties can be made based on the classification criteria given together with published charts, tables and correlations interpreted by experienced engineering geologists. (See Reference 8; Reference 13; Reference 14, Slope Stability in Residual Soils, by Deere and Patton; Reference 15, Geological Considerations, by Deere; Reference 16, Engineering Properties of Rocks, by Farmer.) Guidance is provided in Reference 14 for description of weathered igneous and metamorphic rock (residual soil, transition from residual to saprolite, etc.) in terms of RQD, percent core recovery, relative permeability and strength. Typical strength parameters for weathered igneous and metamorphic rocks are also given in Reference 14. Guidance on physical properties of some shales is given in Reference 13.

COMMON IGNEOUS ROCKS					
Color	Light		Intermediate	Dark	
Principal Mineral	Quartz & Feldspar, other minerals minor	Feldspar	Feldspar & Hornblende	Augite and Feldspar	Augite Hornblende Olivine
Texture					
Coarse, Irregular, Crystalline	Pegmatite	Syenite pegmatite	Diorite pegmatite	Gabbro pegmatite	
Coarse and Medium Crystalline	Granite	Syenite	Diorite	Gabbro	Peridotite
Fine Crystalline	Aplite			Diabase	
Aphanitic	Felsite			Basalt	
Glassy	Volcanic glass			Obsidian	
Porous (gas openings)	Pumice		Scoria or vesicular basalt		
Fragmental	Tuff (fine), breccias (coarse), cinders (variable)				

Table 10
Simplified Rock Classification

COMMON SEDIMENTARY ROCKS				
Group	**Grain Size**	**Composition**		**Name**
Clastic	Mostly coarse grains	Rounded pebbles in medium-grained matrix		Conglomerate
		Angular coarse rock fragments, often quite variable		Breccia
	More than 50% of medium grains	Medium quartz grains	Less than 10% of other minerals	Siliceous sandstone
			Appreciable quantity of clay minerals	Argillaceous sandstone
			Appreciable quantity of calcite	Calcareous sandstone
			Over 25% feldspar	Arkose
			25-50% feldspar and darker minerals	Graywacke
	More than 50% fine grain size	Fine to very fine quartz grains with clay minerals		Siltstone (if laminated, shale)
		Microscopic clay minerals	10% other minerals	Shale
			Appreciable calcite	Calcareous shale
			Appreciable carbon/carbonaceous material	Carbonaceous shale
			Appreciable iron oxide cement	Ferruginous shale

Table 10 (continued)
Simplified Rock Classification

COMMON SEDIMENTARY ROCKS			
Group	**Grain Size**	**Composition**	**Name**
Organic	Variable	Calcite and fossils	Fossiliferous limestone
	Medium to microscopic	Calcite and appreciable dolomite	Dolomite limestone or dolomite
	Variable	Carbonaceous material	Bituminous coal
Chemical	Microscopic	Calcite	Limestone
		Dolomite	Dolomite
		Quartz	Chert, flint, etc.
		Iron compounds with quartz	Iron formation
		Halite	Rock salt
		Gypsum	Rock gypsum

COMMON METAMORPHIC ROCKS		
Texture	**Structure**	
Coarse crystalline	**Foliated**	**Massive**
	Gneiss	Metaquartzite
Medium crystalline	Schist (Sericite) (Mica) (Talc) (Chlorite) (etc.)	Marble Quartzite Serpentine Soapstone
Fine to microscopic	Phyllite Slate	Hornfels Anthracite coal

Table 10 (continued)
Simplified Rock Classification

ROD %	Velocity Index	Rock Mass Quality
90 – 100	0.80 – 1.00	Excellent
75 - 90	0.60 – 0.80	Good
50 – 75	0.40 – 0.60	Fair
25 – 50	0.20 – 0.40	Poor
0 – 25	0 – 0.20	Very poor

Table 11
Engineering Classification for In Situ Rock Quality

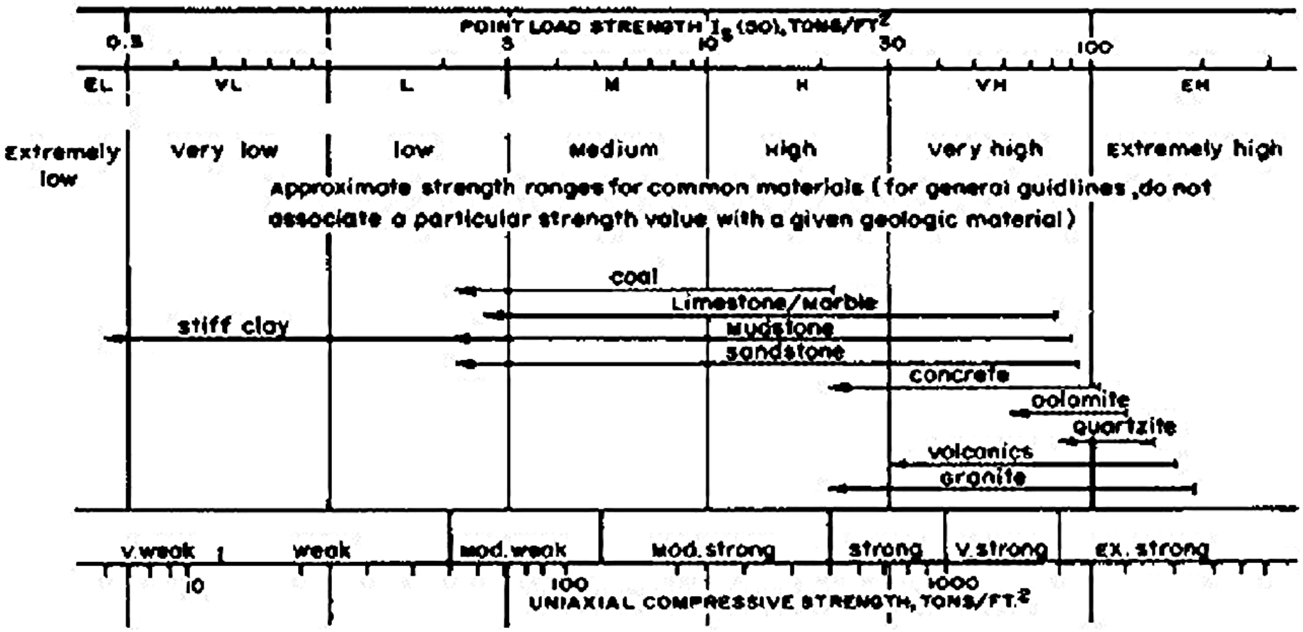


Figure 3
Strength Classification

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